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FACULTY OF PHYSICS
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Moscow
July 11–16, 2022

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Edited by K. A. Stopani and N. S. Zelenskaya

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Foreword

This year the Lomonosov Moscow State University hosts the LXXII International conference “NUCLEUS-2022.” The first Conference in this series (known to physicists as Meeting at the time) also took place in Moscow in the convention hall of the Moscow University in 1951. It was opened by the President of the Academy of Sciences of the Soviet Union M. V. Keldysh. Academician D. V. Skobeltsyn was the chair of the organizing committee, and corresponding member of the Academy of Sciences B. S. Dzhelepov, representing the Leningrad school of nuclear physicists, was the vice-chair. The proceedings of the Meeting, published in Izvestiya Akademii Nauk SSSR, Seriya Fizicheskaya vol. 16, No. 3 (1952), numbered only five articles, all of them from Leningrad.

The next Meeting, also held in the Moscow University in 1952, became more representative due to a larger number of participants from scientific and educational institutions of Moscow, but the list of organizers was kept unchanged. For 44 years, since 1953 the organizing committee of the Meeting was headed by B. S. Dzhelepov, who had established its familiar traditions: publication of the Program and the Book of Abstracts, publication of the proceedings in leading nuclear physics journals, the tradition to call the Meeting annually, and to hold it in Leningrad each five years. These traditions are still kept by our scientific brotherhood.

Starting from the 2nd Meeting the number of participants and their geography began to rapidly enlarge. In addition to Moscow and Leningrad, the Meetings began to be held by scientific centers of soviet republics (now – neighbouring countries), contributing to development of nuclear science across the Soviet Union. The Samarkand Meeting of 1981 became a champion, having attracted about five and a half hundred participants with over six hundred talks.

The range of the topics of the Meeting was expanding. As a result All-Soviet Meetings on Nuclear Spectroscopy and Structure of Atomic Nucleus turned into International Conferences on Nuclear Physics. A number of major discoveries were reported and discussed for the first time there.

The present Book of Abstracts brings to the reader results of modern studies in the field of nuclear physics and their applications, including medical physics.

Plenary sessions

NUCLEAR PHYSICS FOR THE WORLD ECONOMY

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This paper reviews the achievements of nuclear physics for various fields of knowledge and unique technologies in the sectors of the world economy. It is difficult to imagine modern society without the achievements of nuclear physics. It is also one of the driving forces for the development of our civilization.

Counting back to the first nuclear reaction carried out, which is more than a hundred years old, we can conditionally distinguish three stages in the development of nuclear physics. The first one ranges (1919 – ~1954) from the first nuclear reaction to the creation of nuclear weapons and energy; the second part goes from the emergence of elementary particle physics to its intensive application in practical technologies (~1950 – ~2000); the third stage is the dominant development of applied nuclear physics research and technologies (since ~2000).

The impressive achievements of nuclear physics include the creation of nuclear energy, nuclear medicine and radiation therapy, nuclear beam diagnostics, the widest use of nuclear physics facilities – accelerators in industry and agriculture, the construction of the first all-European TOKAMAK, unique experiments on neutrino coupling, and many others.

The nuclear physics development leaves a firm confidence that the rate of nuclear technologies and methods invasion into our life will only increase.

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2. A. V. Belousov *et al.*, Yadernaya fizika **82**, 425-439 (2019).

NICA MEGASCIENCE PROJECT AT JINR: STATUS AND PLANS

A. Butenko[1], H. Khodzhibagiyan[1], S. Kostromin[1], V. Lebedev[1], I. Meshkov[*1, 2], A. Sidorin[1, 3], E. Syresin[1, 3], G. Trubnikov[1, 2]
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The Nuclotron-based Ion Collider fAcility (NICA) is the flagship project at the Joint Institute Nuclear Research (Dubna, Russia). Two goals of the project — experimental studies of dense nuclear (baryonic) matter and particle spin physics — are combined in the project on the basis of a common experimental method: the investigation of collisions of nuclei at relativistic energies. The project is under active stage-by-stage realization. The report describes in detail the NICA scheme, the technical solutions being used and status of the project development.

An achievement of design luminosity requires overcoming many technological and beam physics problems which solutions are described in this report.

FOURTH GENERATION LIGHT SOURCE SKIF IN NOVOSIBIRSK: STATUS AND PERSPECTIVES

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SKIF is the Russian acronym for Siberian Circular Light Source – a new fourth generation synchrotron light facility that is now under development in Novosibirsk (Russia). SKIF consists of 200 MeV linear accelerator-preinjector, 3 GeV booster synchrotron (154 m in circumference), 3 GeV electron storage ring (476 m) with extremely low natural horizontal emittance of 73 pm·rad and number of scientific and engineering infrastructures [1]. Fig.1 shows the SKIF buildings and premises with the main ring-shape building in the middle.

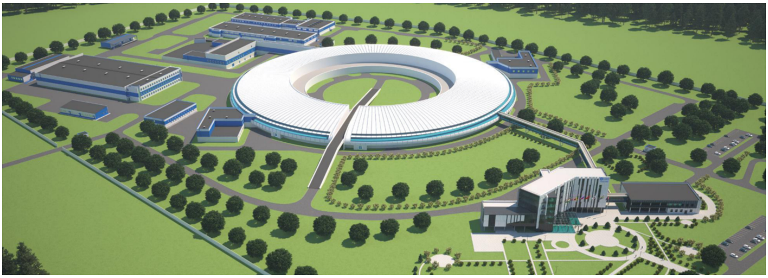

Fig. 1. General view of the SKIF light source facility.

SKIF storage ring has 16-fold symmetry magnetic lattice with 16 6-m-long straight sections; two sections are for RF system and injection others 14 will accommodate different insertion devices (including superconducting ones) delivering high brightness X-rays to up to 30 experimental stations. First six stations are under development now.

Here we report status of the SKIF design and manufacture including accelerator systems, experimental stations, engineering infrastructure and civil engineering.

1. Baranov G. *et al.*, Phys. Rev. Accel. and Beams **24**, 120704 (2021).

SOME HIGHLIGHTS OF RESEARCH ON HEAVY ION COLLISIONS BY ALICE AT LHC

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In this overview, we present several recent experimental observations by ALICE collaboration in studies of strongly interacting matter formed in *pp*, *p*-Pb and Pb-Pb collisions at the LHC. The talk will include results of medium induced effects on strange and charm particles yields, shape of jets, production of light (anti)(hyper)nuclei, studies of residual strong interaction between strange, charm and light hadrons. We will also discuss enhanced production of multi-strange hadrons in high-multiplicity *pp* and *p*-Pb collisions and particle flows observed for small systems. And we will also present the status of ALICE upgrade for RUN 3 and future prospects.

HEAVY-ION PHYSICS WITH CMS DETECTOR

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We present a selection of very recent results by the CMS collaboration on heavy-ion physics at the LHC (CERN).

STRUCTURE OF HEAVY NUCLEI AND NUCLEON-NUCLEON INTERACTION

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The report considers:

- phenomenological approaches to finding effective nucleon-nucleon forces for calculations of nuclear structure;
- shell model calculations in large configuration spaces;
- calculations of nuclei structure based on free nucleon-nucleon potential;
- Energy Density Functional approach;
- effective field theory for nucleon-nucleon interactions in the cores.

NUCLEAR STRUCTURE ACROSS ENERGY SCALES

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The microscopic theory of atomic nuclei now spans energy scales from kilo-electron-volts to giga-electron-volts. The leading degrees of freedom for prominent experimental phenomena range from clusters or collective modes of nucleons to quarks and gluons. Many profound questions can be raised. Is there harmony across scales? Are there emergent phenomena at one scale that trace their origins to a higher energy scale? Are there theoretical tools that are useful at more than one scale? Can one establish that theory retains predictive power?

At the highest energy scales accessible to current and planned laboratory experiments, there is widespread agreement that atomic nuclei should be well-described by the Standard Model of Elementary Particles. How can we achieve this? I will present Basis Light Front Quantization [1] as a relativistic Hamiltonian approach for quarks and gluons that is complementary to Lattice QCD and capable of describing nuclear phenomena using supercomputer simulations. The first goal of successfully describing mesons and nucleons is progressing rapidly and phenomena such as chiral symmetry breaking are becoming better understood [2]. Near-term goals include the properties of exotic baryonic systems and properties of the pion-nucleon and nucleon-nucleon interactions.

At the lower energy scales, Chiral Effective Field Theory (χEFT) [3,4] has emerged as the systematic and controllable embodiment of QCD below the chiral symmetry breaking scale. Can we discover collective nuclear phenomena emerging from treating all nucleons on an equal footing? I will present recent results from the *ab initio* No-Core Shell Model (NCSM) [5] with χEFT interactions showing promising agreement between theory and experiment [6] within well-quantified theoretical uncertainties. Exotic phenomena such as alpha clustering [7] and predictions of a tetraneutron resonance [8] serve as example highlights.

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ANALYTIC CONTINUATION OF EXPERIMENTAL DATA ON SCATTERING AND REACTION PROCESSES AS A WAY TO OBTAIN INFORMATION ON CHARACTERISTICS OF BOUND NUCLEAR STATES

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Asymptotic normalization coefficients (ANC) determine the asymptotic behavior of nuclear wave functions in binary channels at distances between fragments exceeding the radius of nuclear interaction (see the recent review paper [1] and references therein). ANCs are of particular importance for nuclear astrophysics. They determine the overall normalization of cross sections of radiative capture reactions at astrophysical energies [2]. In terms of ANCs, the cross sections of peripheral nuclear transfer reactions are parameterized. ANCs should be included in the number of important nuclear characteristics along with such quantities as binding energies, probabilities of electromagnetic transitions, etc.

Unlike binding energies, ANCs cannot be directly measured. In the present work, we discuss two ways to obtain information about ANCs by analytic continuation of experimental data. The first method is based on the analytic continuation of the experimental differential cross sections (DCS) of nuclear transfer reactions in the variable $z = \cos\theta$, where θ is the scattering angle in the center-of-mass system. The idea of the method goes back to the work of G. F. Chew [3], in which it was stated that the extrapolation in cos θ of the DCS of the elastic *NN* scattering to the pole corresponding to the exchanged virtual pion can be used to determine the pion-nucleon coupling constant. When applying this method, it is very important to take into account the Coulomb interaction in the initial, final and intermediate states [4].

The second approach uses the analytic continuation in energy of the partial-wave amplitudes of elastic scattering, determined from the phase-shift analysis of experimental data, to the pole point located in the nonphysical region of negative energies. In this way, ANCs were determined for a number of light nuclei. As an example, we present the recently obtained by us average values of the ANCs $C(J^\pi)$ for the virtual decay of the excited bound states of the ^{16}O nucleus, which are important for nuclear astrophysics: $^{16}\mathrm{O}^*(J^\pi)\to\alpha+{}^{12}\mathrm{C}$(g.s.). We got: $C(0^+) = 1.01\cdot10^3$ fm$^{-1/2}$; $C(3^-) = 3.53\cdot10^2$ fm$^{-1/2}$; $C(2^+) = 1.57\cdot10^5$ fm$^{-1/2}$; $C(1^-) = 2.55\cdot10^{14}$ fm$^{-1/2}$.

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PECULIARITIES OF STRUCTURE OF WEAKLY BOUND LITHIUM NUCLEI (*A* = 6–11) AND NUCLEAR REACTION MECHANISMS AT LOW ENERGIES

K. A. Kuterbekov[1], A. K. Azhibekov[2,3], A. M. Kabyshev[1]
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Review talk considers present-day status of experimental and theoretical results on angular distributions and total cross sections of reactions with light weakly bound lithium nuclei ($^{6-11}$Li). Peculiarities of stucture of light weakly bound lithium nuclei ($^{6-11}$Li), their effect on mechanisms of nuclear reactions are discussed. The works from recent (2017–2022) years [1–5] are also analyzed in the review.

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NUCLEON RESONANCE STRUCTURE AND EMERGENCE OF HADRON MASS FROM CLAS/CLAS12 DATA

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Studies of genuinely nonperturbative nucleon resonances (N*) structure in exclusive electroproduction off protons shed light on emergence of the dominant part >98% of hadron mass which is one of the most important and still open problem in the Standard Model. [1]. The current status of the N* electroexcitation studies in connection with the insight into strong interaction dynamics in the regime of comparable with unity OCD running coupling, so called strong QCD regime, as well as future extension of these efforts from the data of ongoing experiments with the new CLAS12 detector in Hall B at Jefferson Lab, will be presented in the talk. CLAS experimental data on the exclusive $\pi^0 p$, π^+n and $\pi^+\pi^- p$ electroproduction channels provided the first and only available in the world results on helicity N→N* transition amplitudes for most nucleon resonances in the mass range <1.8 GeV and at photon virtuality Q^2 up to 5.0 GeV^2 [2]. Consistent results on dressed quark mass function obtained from independent studies of pion, nucleon elastic electromagnetic form-factors and electroexcitation amplitudes of Δ(1232)3/2+, N(1440)1/2+, and Δ(1600)3/2+ resonances conclusively demonstrated the capability to map out momentum dependence of dressed quark mass getting insight into emergence of hadron mass (EHM) from QCD.

The CLAS12 detector [3] is the only facility in the world capable to explore N* electroexcitation amplitudes at Q^2 >5.0 GeV^2 where the transition from the strong to the perturbative QCD regimes is expected and where the dominant part of hadron mass is generated. These studies will address key open problems of the Standard Model on the nature of hadron mass, quark-gluon confinement, and their emergence from QCD in connection with dynamical chiral symmetry breaking [4].

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SUPERNOVA NEUTRINO SPECTRA & OBSERVATIONS BY LARGE VOLUME TELESCOPES

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The neutrino dynamics in hot and dense matter corresponding to supernova explosions is considered. The kinetic equation for a neutrino phase-space distribution function is obtained, taking into account inelastic scattering by nuclear particles [1]. The transfer and diffusion components in an energy space are argued to dominate in the transport properties. It is shown that the energy transfer coefficient changes from positive to negative values when the neutrino energy exceeds four times the temperature. Effects in the neutrino dynamics and energy spectra are discussed.

Strongly variable transient supernova neutrino fluxes can be detected using Large-Volume Neutrino Telescopes: KM3NeT, Baikal-GVD, etc. Sensitivity to neutrinos on a scale of 10 MeV can be achieved by observing a collective increase in the rate r of counting coincidences using multiple detectors [2]. For multiple k coincidences the ratio signal/background is given by $(1+ r_{\rm SN} / r_{\rm B})^k \approx (1+ k\, r_{\rm SN} / r_{\rm B})$ with supernova and background detection rates $r_{\rm SN}$ and $r_{\rm B}$. Evidently, the k–fold coincidence enhances the detector sensitivity by a factor k. The strengthening of neutrino hard energies is also favorable for supernova neutrino observations by Large Volume Telescopes.

1. V. N. Kondratyev, *et al.*, Phys. Rev. **C 100**, 045802 (2019).
2. V. N. Kondratyev, *et al.*, Particles **5**, 128 (2022).

THE JUNO EXPERIMENT: STATUS AND PROSPECTS

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Jiangmen Underground Neutrino Observatory is an experiment under construction in China. A spherical detector of 35 m in diameter filled with 20 kt of liquid scintillator and equipped with more than 17 612 (25 600) large (small) photomultipliers will provide immense statistics, high energy resolution ($\sigma = 3\%$ at 1 MeV) and low energy threshold (0.2 MeV) making the physics program broad.

The primary goal is determination of the neutrino mass ordering and precision measurement of the neutrino oscillation parameters via observation of more than 100'000 reactor electron antineutrinos from Yangjiang and Taishan nuclear power plants. The experiment will also observe high statistics of the solar neutrinos from pp, ^{7}Be and ^{8}B. The geo- neutrinos will be measured with uncertainty of 5%. JUNO will also be able to observe atmospheric neutrinos in sub-GeV and GeV region, diffuse supernovae neutrino background with significance of 3σ in 10 years and will be able to see the neutrinos from the core collapse supernova.

The experiment will have competitive sensitivity to the nucleon decay and the cold dark matter annihilation in the Sun.

In addition to the JUNO detector the JUNO experiment will be equipped with two satellite detectors: TAO and OSIRIS. The TAO will measure the antineutrino spectrum from the Taishan nuclear power plant with energy resolution of $\sigma = 2\%$ at 1 MeV and statistical uncertainty of 1%. It will be able to test short baseline neutrino oscillation up to the masses of 8 eV^2. A new project Serappis aims to use the modified OSIRIS detector to measure the solar pp neutrinos with energy resolution of $\sigma = 2.5\%$ and precision of few percents.

The talk will cover the status of the experiment and will provide the latest estimation of its sensitivity.

COMPTON DESINTEGRATION OF POSITRONIUM

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The recent experiments on Compton scattering using a new experimental technique [1] gave rise to a new wave of interest in this old effect discovered 100 years ago. To describe the process of Compton decay of positronium we use the nonrelativistic A^2 approximation.

We study the Compton single ionization of positronium in comparison with the same of hydrogen [2]. The initial photon energy of a few keV allows one to apply the non-relativistic approach. Interesting differences in the behavior of various differential cross sections of the process are observed. In particular, the conditions were found, under which the electron and positron move parallel to each other with equal velocities, which leads to a series of resonances (see Fig. 1). This suggests that the probability of annihilation is suppressed in this continuum state, and it is likely to be a long-lived one, especially in the presence of external electric and magnetic fields.

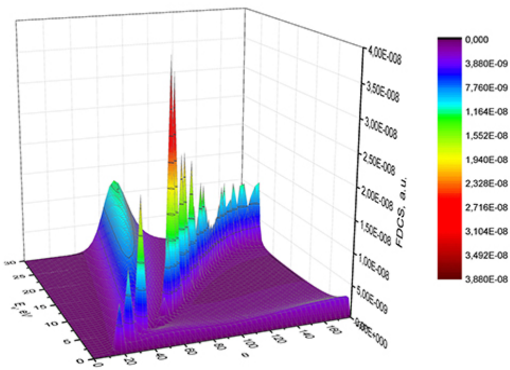

Fig. 1. FDCS (atomic units) of Compton positronium decay versus the energy E_e(eV) of the emitted electron and the photon scattering angle θ. The photon energy is ω = 5 keV

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2. S. Houamer *et al.* EPJD **74**, 81 (2020).

LOW-ENERGY M1 STATES IN DEFORMED NUCLEI: SPIN SCISSORS OR SPIN-FLIP?

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A low-energy magnetic dipole (*M*1) spin-scissors resonance (SSR) located just below the orbital scissors resonance (OSR) was predicted in deformed nuclei within the Wigner function moments (WFM) approach, see [1,2] and references therein. We analyze this prediction for ^{160,162,164}Dy and ^{232}Th using fully self-consistent Skyrme quasiparticle random phase approximation (QRPA) method [3]. Accuracy of our calculations is confirmed by a good description of *M*1 spin-flip giant resonance in these nuclei. It is shown that Dy isotopes indeed have at 1.5–2.4 MeV 1^+ states with a large *M*1 spin strength. These states are almost fully exhausted by a few 2qp low-orbital ($l = 2, 3$) spin-flip configurations. In contrast to WFM deformation-induced spin-scissors picture, our calculations show that deformation is not the origin of the low-energy spin *M*1 states but only a factor affecting their features. This conclusion is illustrated by simple arguments in terms of mean-field spectra and nuclear current distributions.

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PARTICLE-HOLE DISPERSIVE OPTICAL MODEL: PAST AND FUTURE

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Particle-Hole Dispersive Optical Model (PHDOM) has been originally proposed [1] and then implemented to describing main properties of various isoscalar and isovector giant resonances (GRs) in medium-heavy closed-shell nuclei (see, e.g., Ref. [2] and references therein). Main properties include the energy-averaged strength distribution, transition density, and probabilities of direct one-nucleon decay. In fact, PHDOM is an extension of standard and non-standard continuum-RPA versions to taking into account (phenomenologically and in average over the energy) the spreading effect. For this reason, PHDOM might be related to semi-microscopic models.

In this review talk, a description of the model, its ingredients, and recent results [2, 3] are planned to be briefly presented. Extension of PHDOM to taking into account nucleon pairing in open-shell spherical nuclei, and consideration, within the model, of tensor correlations in GR formation (the first attempt has been undertaken in Ref. [4]) will be discussed.

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CROSSING ROTATIONAL BANDS IN SUPERHEAVY EVEN-EVEN NUCLEI

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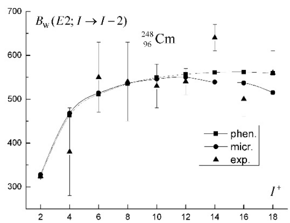
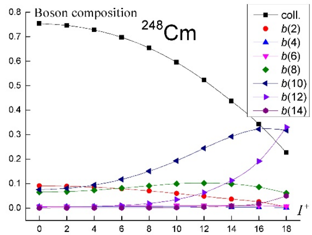
For $Z > 92$ even-even nuclei, with the exception of the $^{244}\mathrm{Pu}$ only, in yrast bands there is no manifestation of the reverse bending of the moment of inertia from the square of rotation frequency (back-bending). This leads to the possibility of reproducing the level energies of yrast bands up to spins values $I^{\pi} = 32^{+}$ in the framework of the IBM1 phenomenology [1]. In present report the structure of the yrast band states was calculated within the framework of the microscopic version of IBM1 [2,3], where bosons with large spins up to $J^{\pi} = 14^{+}$ were used. The calculation was carried out for $^{248}\mathrm{Cm}$, since only for it the values of $B(E2)$ were measured up to high spins. The mapping of phonons to bosons is carried out by the traditional way. The wave functions in the boson representation have the form $\Psi(I)=|\psi_c(I)>+\Sigma\alpha_{i1,c1}|(b_{i1}^{+}\psi_{c1})^{(I)}>$, where $|\psi_c>$ are wave functions containing a superposition of d-bosons only. Moreover, the collectivization is so strong that the number of quadrupole bosons $<n_d>=19$ in $|\psi_c>$ for the ground state. The Hamiltonian is taken in the form $H=H_{\mathrm{IBM}}+\Sigma\omega_i b_i^{+}b_i+V^{(1)}+V^{(2)}+V^{(3)}$, where H_{IBM} is the IBM1 Hamiltonian with parameters obtained from D-phonons and taking into account renormalizations due to B_{i}, non-collective phonons, $\omega_{\mathrm{i}}-$ energies of b_{i}-bosons. $V^{(1)}$: $d^{+}ds^{+}b$, $d^{+}dds^{+}s^{+}b$, $d^{+}d^{+}sb, d^{+}d^{+}db$, $V^{(2)}$: $d^{+}d^{+}d^{+}bss, V^{(3)}$: $b^{+}bd^{+}s$, $b^{+}bd^{+}d^{+}ss, b^{+}bd^{+}d$. The parameters that determine the boson operators are calculated based on the microscopic procedure. This leads to precise reproduction of energies up to spin 14^{+} with an error not exceeding a few keV. As can be seen from the presented figure, the reproduction of the $B(E2)$ values by using the IBM1 phenomenology [1] corresponds to the experiment. The composition of the wave functions is presented in the following figure and it shows a smooth replacement of the collective component, built only from d-bosons, by components that include high-spin pairs or $b(J)$-bosons with momentums $J^{(\pi)}=10^{+}$, 12^{+}. Such smooth replacement explains the absence of the back-bending and the smooth dependence of $B(E2)$ on spin.





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EFFECTIVE INTERACTIONS AND EFFECTIVE OPERATORS FROM THE NO-CORE SHELL MODEL

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The nuclear shell model is one of the oldest microscopic approaches to nuclear structure at low energies [1,2]. The basic idea of the method is to solve the many-body Schrodinger equation by diagonalizing the Hamiltonian, containing nucleon kinetic energies and internucleon interactions, in the many-body harmonic-oscillator basis. Because of the rapid increase of the model space with the number of nucleons, only for very light nuclei this problem can be solved exactly, starting from realistic nucleon-nucleon interactions. Such an approach is called the No-Core Shell Model (NCSM) [3]. For heavier nuclei, truncations have to be made and the eigenproblem is typically solved for valence nucleons moving in a model space comprised of one oscillator shell beyond a closed-shell core. Thus, effective interactions and effective operators must be exploited.

With well-adjusted phenomenological effective interactions, the shell model represents a powerful approach in nuclear structure [4], capable of providing very detailed information on nuclear spectra, static properties and transition rates. Derivation of microscopic effective valence-space interactions and effective electroweak operators is still a challenge.

In the present contribution we present new microscopic effective interactions for the traditional shell model derived from the NCSM [5,6]. This is done by application of Okubo-Lee-Suzuki transformation to the NCSM results. We will explain the formalism and demonstrate theoretical spectra for the *sd* shell nuclei in comparison with the phenomenological description and with experiment. Finally, we will present newly constructed electric quadrupole and magnetic dipole operators and show the agreement of valence-space calculations with the NCSM results.

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GAMOW-TELLER AND ANALOG RESONANCES IN NEUTRON-RICH Sn ISOTOPES

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Charge-exchange resonances: the giant Gamow–Teller (GTR [1]), analog (AR) resonances and the so-called "pigmy" resonance (PR), which are lying below GTR [2], have been studied in the microscopic theory of finite Fermi systems and in the semiclassical approach. Calculations are presented for tin isotopes with the mass numbers A = 112–140 and compared with experimental data [3, 4].

The calculations were performed with the refined constants of local spin-isospin ($\vec{\sigma}\vec{\tau}$) and isospin-isospin ($\vec{\tau}\vec{\tau}$) interaction of quasiparticles – g_0' and f_0' accordingly. These interaction constants are phenomenological parameters and they were determined from comparison with experimental data [5]. The calculated energy difference $\Delta E_{G-A} = E_G - E_A$ tends to zero with increasing A number and $N - Z$ indicating the restoration of Wigner SU(4)-symmetry [6].

The energies and matrix elements of the excited resonant states that determine the structure of the charge-exchange strength function $S(E)$ were calculated. A comparison of the calculated and experimental strength functions $S(E)$ also shows their similarity both in energies and in matrix elements. The influence of charge-exchange resonances on the process of neutrino capture by nuclei was also investigated [7] and it is shown that taking these resonances into account is of fundamental importance.

This work was supported in part by the Russian Science Foundation (grant RSF 21-12-00061) and by the Kurchatov Institute grant (order 2767 dated 28.10.2021).

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THE MODEL FOR DESCRIBING THE WIDTH OF DOUBLE GAMMA DECAY OF THE QUADRUPOLE STATE OF SPHERICAL NUCLEI

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To describe the γγ-decay, a formalism relates the electromagnetic interaction up to second order in the electromagnetic operators and two-quantum processes in atomic nuclei. In Ref. [1], the γγ-decay of a nuclear transition in competition with an allowed γ-decay has been discovered. This is the observation of the γγ-decay of the first excited $J^{\pi} = 11/2^{-}$ state of ^{137}Ba directly competing with an allowed γ-decay to the $J^{\pi} = 3/2^{+}$ ground state. The branching ratio of the competitive γγ-decay of the $11/2^{-}$ isomer of the odd-even nucleus ^{137}Ba to the ground state relative to its single γ-decay was determined to be $(2.05 \pm 0.37) \times 10^{-6}$. This discovery has very recently been confirmed and the data were made more precise, in particular with respect to the contributing multipolarities [2].

This paper reports on the situation, in which the γγ-decay of the low-energy quadrupole state of the even-even nucleus occurs in a nuclear transition which could proceed by a single γ-decay in competition. The coupling between one-, two- and three- phonon terms in the wave functions of excited nuclear states is taken into account within the microscopic model based on the Skyrme energy density functional.

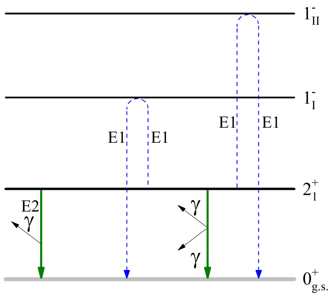

Fig. 1. Scheme for estimating the width of nuclear double γ-decay. The dashed lines correspond to the virtual transitions.

It is shown that the γγ-decay width is sensitive to the interaction between one- and two-phonon configurations in the giant dipole resonance region [3]. The maximal branching ratio of the competitive γγ-decay relative to its single γ-decay is predicted for ^{48}Ca as 3×10^{-8}. This prediction can be tested experimentally.

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THE ROLE OF PLASMA SCREENING FOR THE LOCATION OF THE QCD CRITICAL END POINT

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I show that in a strongly interacting plasma, the fluctuations responsible for deviations from those of a description based on a simple Hadron Resonance Gas Model naturally arise from the proper inclusion of the plasma screening properties. These are encoded in the contribution of the so called "ring diagrams" and thus in the introduction of a key feature of plasmas near phase transitions, namely, long-range correlations. I illustrate this property using the Linear Sigma Model with quarks which in the high temperature and chiral symmetry approximations renders analytical results. After fixing the model parameters using input from LQCD for the crossover transition at vanishing baryon chemical potential, I study the location of the Critical End Point (CEP) in the effective QCD phase diagram. I use the model to study baryon number fluctuations and show that in heavy-ion collisions, the CEP can be located for collision energies of order of 2 GeV per nucleon, namely, in the lowest NICA or within the HADES energy domain.

PROBING OF EXOTIC MULTIQUARK STATES IN HADRON AND HEAVY ION COLLISIONS

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The spectroscopy of exotic mesons with masses above the $2m_D$ open charm threshold has been full of surprises and remains poorly understood [1]. The currently most compelling theoretical descriptions of the mysterious *XYZ* mesons attribute them to hybrid structure with a tightly bound $c\bar{c}$ diquark [2] or $cq\bar{c}\bar{q}'$ tetraquark core [3–5] that strongly couples to S-wave $D^{(*)}\bar{D}^{(*)}$ molecular like structures. In this picture, the production of a *XYZ* states in high energy hadron collisions and its decays into light hadron plus charmonum final states proceed via the core component of the meson, while decays to pairs of open-charmed mesons proceed via the $D^{(*)}\bar{D}^{(*)}$ component.

These ideas have been applied with some success to the *XYZ* states [2], where a detailed calculation finds a $c\bar{c}$ core component that is only above 5% of the time with the $D\bar{D}^{(*)}$ component (mostly $D^{(0)}\bar{D}^{(*0)}$) accounting for the rest. In this picture these states are compose of three rather disparate components: a small charmonium-like $c\bar{c}$ core with $r_{rms} < 1$ fm, a larger $D^{(+)}D^{(*-)}$ component with $r_{rms} \approx 1.5$ fm and a dominant component $D^{(0)}\bar{D}^{(*0)}$ with a huge, $r_{rms} \approx 9$ fm spatial extent.

In the hybrid scheme, *XYZ* mesons are produced in high energy proton-nuclei collisions via its compact ($r_{rms} < 1$ fm) charmonium-like structure and this rapidity mixes in a time (t ~ $\hbar/\delta M$) into a huge and fragile, mostly $D^{(0)}\bar{D}^{(*0)}$, molecular-like structure. δM is the difference between the *XYZ* mass and that of the nearest $c\bar{c}$ mass pole core state, which we take to be that of the $\chi_{c1}(2P)$ pure charmonium state which is expected to lie about 20 ~ 30 MeV above $M_{X(3872)}$ [6, 7]. In this case, the mixing time, $c\tau_{mix}$ 5 ~ 10 fm, is much shorter than the lifetime of *X(3872)* which is $c\tau_{X(3872)} > 150$ fm [8].

The near threshold production experiments in √s_pN~8GeV energy range with proton-proton and proton-nuclei collisions with √s_pN up to 26GeV and luminosity up to 10^{32} cm^{-2} s^{-1} planned at NICA may be well suited to test this picture for the X(3872) and other exotic XYZ mesons [9]. Their current experimental status together with hidden charm tetraquark candidates and present simulations what we might expect from A-dependence of XYZ mesons in proton-proton and proton-nuclei collisions are summarized.

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POSSIBLE PHYSICS STUDIES AT THE FIRST STAGE OF THE SPD NICA PROGRAMME

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In the talk will be done a review of suggestions for experiments with usage of the Spin Physics Detector (SPD) at the first stage of the NICA SPD Programme developing in JINR [1]. Double polarized *pp*, *dd* and *pd* collisions at c.m.s. *NN* energies of 3-10 GeV, which will be accessible at the initial stage of the planned experiments, allow one to study spin dependence of the *NN* interaction, search for multiquark states at double strangeness, charm and beauty thresholds, study the short range structure of the deuteron and color transparency phenomenon. Furthermore, double polarized *pd* scattering offers a possibility to test the Standard Model through the search for *T*-invariance violation.

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ISOTOPIC DEPENDENCE OF CHARGE AND MATTER RADII

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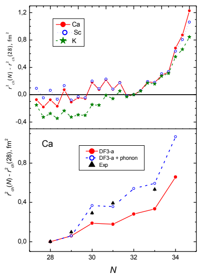
Fully self-consistent study of the charge and matter radii in the chains of the Ar - Ti, Ni, Cu isotopes is presented. The nuclei with pairing in both neutron and proton sectors are treated within the Energy Density Functional (EDF) approach with the Fayans functional DF3-a [1]. Recently the new option of this functional named Fy(Δr,HFB) has become popular [2]. We compare their performance in describing both isotopic trend of the radii and odd-even staggering (OES) found in the CERN-ISOLDE experiments for $^{36\text{-}52}$Ca [2] and $^{36\text{-}52}$K [3] isotopes (Figs.1,2). For K, Ca, Sc isotopes, the calculated differential charge radii $\delta\langle r^2\rangle$ relative to N = 28 show universal increase independent on the mass number A in agreement with the data [2-3]. Strong increase of the radii at $N >$ 28 in K, Ca, Sc isotopes (Fig.1b) is explained by A-dependent contribution of the quasiparticle-phonon coupling [4,5]. The corresponding 3-point filters Δ(3) for the binding energies and radii are consistent with magicity of the N = 20, 28, 32 shells in K isotopes [5] (Fig.2). Supported by the grant of Russian Scientific Foundation (RSF 21-12-00061).



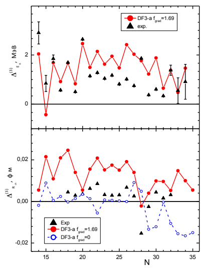


Fig. 1. a) The differential charge radii of K, Ca, Sc isotopes calculated within the DF3-a functional compared to the data [2,3]. b) An impact of the quasiparticle-phonon coupling on the differential charge radii of Ca, isotopes[4].
Fig. 2. The 3-point filters Δ(3) for binding energies and charge radii of K isotopes calculated from the DF3-a functional with (red) and without (blue) gradient paring vs the data [3].

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NUCLEON TRANSFER PROCESSES IN LOW-ENERGY REACTIONS WITH HELIUM ISOTOPES

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Experimental cross sections for formation of isotopes ^{44,46}Sc and ^{45}Ti in reactions ^{3,4,6}He + ^{45}Sc, ^{196,198}Au in reactions ^{3,4,6,8}He + ^{197}Au, and ^{194}Au in reaction ^{3}He + ^{194}Pt have been analyzed. To calculate nucleon transfer probabilities and cross sections, the time-dependent Schrödinger equation for nucleons of ^{3,4,6}He, ^{45}Sc, ^{197}Au, and ^{194}Pt has been solved numerically with a special choice of the shell model mean field for ^{3,4,6,8}He nuclei [1] (Fig. 1). Fusion-evaporation channels were taken into account using the code of the NRV web knowledge base [2]. It was shown that the contribution of fusion-evaporation to the experimental data is significant for reactions ^{3,4,6}He + ^{45}Sc, whereas in the case of reactions ^{3,4,6,8}He + ^{197}Au and ^{3}He + ^{194}Pt, it is negligible. The results of calculation (Fig. 2) are in good agreement with experimental data [3, 4].

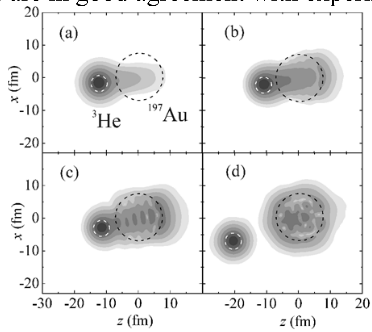

Fig. 1. Examples of time evolution of the probability density for the neutron of ^{3}He in the collision ^{3}He + ^{197}Au at $E_{c.m.}$ = 20 MeV and impact parameter b = 1 fm. The course of time corresponds to panel locations (a), (b), (c), (d).

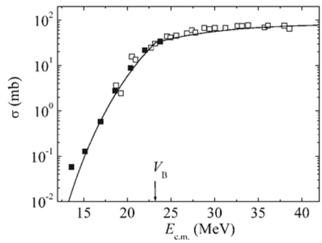

Fig. 2. Cross sections for formation of the isotope ^{198}Au in the reaction ^{3}He + ^{197}Au: experimental data [2] (filled squares) and [3] (empty squares) along with the results of calculations. The arrow indicates the position of the Coulomb barrier.

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INTERPRETATION OF THE INCOMPLETE FUSION OF NUCLEUS AS A QUASIFISSION OF DINUCLEAR SYSTEM

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The strong dependence of the correlation between energy and angular distributions of the observed alpha-particles in heavy ion collisions on the beam energy shows the importance of the impact parameter in the incomplete fusion [1,2]. The complete fusion of the interacting nuclei is transfer of all nucleons in light projectile to the target nucleus. This process may be hindered by the intrinsic fusion barrier $B^*_{\rm fus}$ [3], which increases sharply for small mass numbers A in collisions with large impact parameter: the fusion probability strongly decreases when the excitation energy $E^*_{\rm DNS}$ of the dinuclear system (DNS) is smaller then $B^*_{\rm fus}$. As a result, the DNS may emit the alpha-particle or heavier clusters during rotation around the axis at its the center-of-mass of DNS which is perpendicular to the $\boldsymbol{R}$ vector connecting fragments centres. This process is observed as the yield of the clusters in the incomplete fusion. The probability of the cluster formation emission is calculated by solution of the transport master equation [3] and the probability of its emission is calculated as a tunneling through the quasifission barrier $B^*_{\rm qf}$ [3], which is determined by the height of the potential well of the interaction between DNS fragments. The partial cross section of the incomplete fusion accompanying by the alpha-particle emission shows that its maximum has the shape of the Gaussian function with the maximum at the values of the orbital angular momentum L=35−50 $\hbar$ as a function of the beam energy $E_{\rm lab}$.

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THEORETICAL APPROACHES ALLOWING SIMULTANEOUS DESCRIPTION OF P-EVEN T-ODD ASYMMETRIES IN REACTIONS OF NUCLEAR FISSION BY POLARIZED NEUTRONS WITH THE EMISSION OF DIFFERENT LIGHT PARTICLES

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The cross section for a reaction of nuclear fission induced by polarized neutrons can be represented [1] as the sum of the cross section $d\sigma^{\{0\}}_{nf,p}(\theta)/d\Omega = \sigma^{\{0\}}_{nf,p}P^{\{0\}}_p(\theta)$ for the reaction with unpolarized neutrons, where $P^{\{0\}}_p(\theta)$ is the angular distribution of such light particles p as prescission α-particles and evaporative neutrons and γ-quanta, and the cross section $\left(d\sigma^{\{1\}}_{nf,p}(\theta)/d\Omega\right)$, which depends linearly on the polarization vector and is expressed in terms of the sum of the components $\left(d\sigma^{\{1\}}_{nf,p}(\theta)/d\Omega\right)_{ev(odd)}$, which are even and odd with respect to the transformation $\theta \to \pi - \theta$. These components can be associated with quantities $\left(\beta_{nf,p}(\theta)\right)_{ev(odd)} = \left(d\sigma^{\{1\}}_{nf,p}(\theta)/d\Omega\right)_{ev(odd)} / \sigma^{\{0\}}_{nf,p}$. The experimental values of these quantities are found [1] by expression $\left(\beta^{\exp}_{nf,p}(\theta)\right)_{ev(odd)} = \left(D^{\exp}_{nf,p}(\theta)P^{\{0\}}_p(\theta)\right)_{ev(odd)}$ through the experimental values of the asymmetry coefficients

$$D_{nf,p}(\theta) = \left(d\sigma^{\{1\}}_{nf,p}(\theta)/d\Omega\right) / \left(d\sigma^{\{0\}}_{nf,p}(\theta)/d\Omega\right), \tag{1}$$

expressed through the experimental particle count $N^{\pm}_p(\theta)$ rates p in coincidence with light fission fragments and found in [2, 3]. To find the theoretical values $\left(\beta^{th}_{nf,p}(\theta)\right)_{ev(odd)}$ of the quantities, expression

$$\left(\beta^{th}_{nf,p}(\theta)\right)_{ev(odd)} = \Delta_{p,ev(odd)}\, d\left(P^{\{0\}}_p(\theta)\right)_{odd(ev)} / d\theta \tag{2}$$

can be used, which takes into account the rotation of the direction of emission of the particle p with respect to the direction of the emission of a light fission fragment by an angle $\Delta_{p,ev(odd)}$ under the action of the Coriolis interaction associated with the rotation of the fissile system (FS) around the axis, perpendicular to its axis of symmetry. Due to the parity of the angular distributions $P^{\{0\}}_p(\theta)$ in the case of evaporation neutrons and γ-quanta, the value is $P^{\{0\}}_{n'(\gamma)}(\theta) = \left(P^{\{0\}}_{n'(\gamma)}(\theta)\right)_{ev}$, and the value is $\left(\beta_{nf,n'(\gamma)}(\theta)\right)_{ev} = 0$. In the semi-classical approach [2] the angles of rotation $\Delta_p = \Delta_{p,ev(odd)}$ are calculated using the method of trajectory calculations and can only take positive values. The experimental and theoretical values $\left(\beta_{nf,p}(\theta)\right)_{ev(odd)}$ of the quantities turn out to be in reasonable agreement in the case of any p particles for the ^{235}U, ^{239}Pu, and ^{241}Pu nuclei. At the same time, for the ^{233}U nucleus, it is possible to agree [2] the experimental and theoretical values of the coefficients $\left(\beta_{nf,\alpha}(\theta)\right)_{ev(odd)}$ in the case of α-particles by adding to the coefficient $D_{nf,\alpha}(\theta)$ the constant D_{TRI} associated [2] with the violation of the axial symmetry of the FS due to its transverse vibrations, while there is a complete mismatch in the signs of quantities $\left(\beta_{nf,n'(\gamma)}(\theta)\right)_{odd}$ for evaporation neutrons and γ-quanta. In the quantum mechanical approach [1], in contrast to the semiclassical approach, the angle of rotation $\Delta_{p,ev(odd)}$ can have any sign due to interference effects. Due to the complexity of calculating such angles in the quantum approach, they will be the maximum likelihood method. Then, in this approach, it is possible to agree on the experimental and theoretical values $\left(\beta_{nf,p}(\theta)\right)_{ev(odd)}$ both for prescission α-particles and evaporation neutrons and γ-quanta for all target nuclei, taking into account the fact that the angle $\Delta_{p,odd}$ has negative values in the case of the ^{233}U nucleus. In the case of α-particles for the ^{233}U nucleus, the specified agreement for the value $\left(\beta_{nf,\alpha}(\theta)\right)_{ev}$ is achieved by adding a constant $\tilde{\beta}_{nf,\alpha}$ to (2), the appearance of which can be associated [2] with the violation of the axial symmetry of the FS, when its transverse oscillations are taken into account.

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LIMITS OF NUCLEAR MASSES AND ELEMENTS

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A range of topics regarding the masses and binding energies of heaviest nuclei is considered. Synthesis of superheavy nuclei (SHN), their decay properties, and methods of their identification are discussed. A review of recent achievements and prospects for production of SHNs is presented.

STATUS OF THE MPD@NICA PROJECT

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The Multi-Purpose Detector (MPD) is the heavy-ion experiment, which is now under construction at Nuclotron-based Ion Collider fAcility (NICA) in Dubna. The MPD is designed to study the phase diagram of QCD matter at maximum baryonic densities reached in heavy-ion collisions in the energy range $\sqrt{s_{NN}}$ = 4–11 GeV, to determine the onset and the nature of the phase transition between the deconfined and hadronic matter and to search for the conjectured critical end point. In the first physics runs planned for 2023–2024, the MPD will study Bi+Bi collisions at $\sqrt{s_{NN}}$ = 9.2 GeV.

In this talk, we present current status of the NICA accelerator complex and the MPD detector, describe physics performance and physical program of the MPD detector with emphasis on the measurements foreseen for the first beam collisions.

STUDIES OF DENSE BARYONIC MATTER WITH THE BM@N EXPERIMENT AT THE NUCLOTRON

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In the near future, the BM@N experiment at the Nuclotron at JINR in Dubna will start a physics program with heavy ions including Au-beams at energies up to 3.8 A GeV and intensities up to $2 \cdot 10^6$ ions/s. The experiment is devoted to measure observables sensitive to the equation of state of dense baryonic matter, and to search for indications of a phase transition at high densities. To meet these goals, the existing BM@N set-up will be upgraded with fast hybrid tracking system, which includes beam tracking detectors, a large aperture silicon tracking system, GEM stations and cathode strip chambers. The measurement of the event plane and centrality will be achieved with a forward hadron calorimeter and granular hodoscopes. The physics program, the configuration of the upgraded BM@N set-up, results of physics performances studies will be presented.

DEEP-UNDERWATER NEUTRINO TELESCOPE BAIKAL-GVD

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The Baikal-GVD neutrino telescope is a water Cherenkov detector with a volume of 1 cubic kilometer constructed in Lake Baikal for the study of natural fluxes of high-energy neutrinos. Since April 2022, the telescope has been operating in a configuration with 10 clusters consisting of 8 strings of deep-sea optical modules (OM) each. The total number of OM, based on the photomultipliers R7081-100 with a photocathode with a diameter of 10 inches, is 2916. Each cluster is an autonomous independent neutrino telescope, which makes it possible to conduct physical research at all stages of the construction of the Baikal-GVD telescope. Currently Baikal-GVD is the largest neutrino telescope in the Northern Hemisphere. When analyzing the data obtained during the operation of the detector in the configurations of 2019, 2020 and 2021, the first candidates for events initiated by high-energy neutrinos of astrophysical nature, were identified. The Baikal-GVD detector is included in the international multichannel notification systems, in order to search for and further study transient astrophysical sources by methods of multi-wavelenght and multi-messenger astronomy.

MODERN TECHNOLOGIES FOR THE PRODUCTION OF NUCLEAR MEDICINE ISOTOPES

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In modern nuclear medicine the main clinical information is obtained from observing the radiopharmaceuticals (by incorporating a radionuclide into the pharmaceutical) distribution in the patient body. These pharmaceuticals are a mixture of a biochemical agent and a radionuclide that emits gamma quanta or positrons [1]. Diagnostic imaging with single-photon-emitting radionuclides produces both planar images and single-photon emission computed tomography

(SPECT) using a gamma camera. Radiopharmaceuticals labeled with positron-emitting radionuclides are used for positron emission tomography (PET). Nuclear medicine images depict anatomic, functional, and metabolic processes in human body [2].

Another important task in nuclear medicine methods is the targeted delivery of radiopharmaceuticals to cancer cells for the subsequent non-surgical treatment of the tumors. The combination of radionuclide imaging with radionuclide therapy in theranostics (therapy + diagnostics) can give an excellent result for effective early diagnosis and treatment of various localized oncological tumors and oncological diseases with minimal side effects [3]. Therefore, one can produce the radiopharmaceuticals with the following properties: half-life should be similar to the length of the medical procedure, the radionuclide should emit gamma rays (the energy of the gamma rays should be between 100 and 300 keV) together with emission of short-range charged particles (discrete spectrum for particles, no recoil nuclei are produced when these particles are emitted, and they have a high linear energy of transfer), the radionuclide should be chemically suitable for incorporating into a pharmaceutical without changing its biological behavior, the pharmaceutical should localize only in the area of interest, the radiopharmaceuticals should be simple to prepare and have the low production price [1, 3].

In present overview, the technologies for the production of nuclear medicine isotopes (main components of novel radiopharmaceuticals) together with new nuclear materials and specific nuclear reactions are discussed. Also the experimental and theoretical studies of the (p, xn) reactions excitation functions in the energy range 6–40 MeV for the light and medium mass nuclear systems with production of the scandium, technetium and antimony radionuclides were carried out. Such radionuclides should be prospective for the Theranostics methods.

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PIK REACTOR COMPLEX

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A review of the parameters and the state of affairs in the construction of the one of the most powerful neutron sources the PIK research reactor (National Research Center "Kurchatov Institute" - PNPI, Gatchina, Russia) will be presented.

The PIK reactor is a neutron source with record parameters, designed to become the flagship of neutron research in Russia. It is a pressurized vessel reactor, where light water (H_2O) is used as a coolant, and heavy water (D_2O) as a neutron reflector and moderator. The main design characteristics of the reactor are as follows [1]:

Thermal power – 100 MW;

The volume of the reactor core – 50 liters;

Thermal neutron flux in the moderator – 1.2 10^{15}n/cm^{2}s;

To extract neutron from the moderator, as well as to irradiate samples, the PIK reactor is equipped with a significant number of experimental channels.

The central experimental channel (CEC) is located in the water cavity of the reactor core. The thermal neutron flux density in the cavity is 5 10^{15}n/cm^{2}s;

Horizontal experimental channels (HEC) – 9 items;

Thermal neutron fluxes at the channel bottoms (0.1−1.2) 10^{15} n/cm^{2}s

Thermal neutron fluxes at the exit of channels (0.2−3) 10^{11} n/cm^{2}s

Channel diameters – 100−250 mm

Inclined experimental channels (NEC) – 6 items;

Thermal neutron fluxes at the bottoms – (0.2−1) 10^{15} n/cm^{2}s

Currently, the PIK reactor is under commissioning with the scheduled step-by-step increasing the power, and the 5 "first-day" neutron scattering instruments have been put into operation, and the first experiments are being carried out.

This facility will determine the development strategy for neutron research in the Russian Federation for several decades and will become the basis of the International Center for Neutron Research [2].

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NUCLEAR REACTIONS CONTRIBUTION IN SPACECRAFT ON-BOARD ELECTRONICS FAILURES

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In a wide range of characteristics of the corpuscular radiation of the near-Earth outer space (SE), protons dominate (more than 90%), which have a high penetrating power and cause radiation damage and upset the onboard electronics (OBE) of the spacecraft. The nature of failures can be either degradation of the initial characteristics of OBE elements with increasing radiation dose, or a failure as a result of the generation of a sufficiently high number of electron-hole pairs during ionization of OBE atoms by passing primary radiation (protons), or products of nuclear reactions between primary radiation and OBE atomic nuclei. In the report we shall give a brief analysis of the probability of failures of electronics under the influence of primary radiation and fragments-products of nuclear reactions, which have a significantly higher ionizing capacity.

Section 1. Nuclear structure: theory and experiment

FIRST EXPERIMENT AT THE SUPER HEAVY ELEMENT FACTORY. NEW DATA IN THE ^{243}Am + ^{48}Ca REACTION

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We present results of the first experiments aimed at the synthesis of Mc isotopes in the ^{243}Am+^{48}Ca reaction performed at the new gas-filled separator DGFRS-2 on-line to the new cyclotron DC280 at the SHE Factory at JINR. One hundred-ten new decay chains of ^{288}Mc, four new decay chains of ^{287}Mc and ten chains assigned to ^{289}Mc were detected. The α-decay of ^{268}Db with an energy of 7.6-8.0 MeV, half-life of 16^{+6}_{-4} h, and a branch of 55^{+20}_{-15}% was registered for the first time, and a new spontaneously fissioning isotope ^{264}Lr with a half-life of $4.9^{+2.1}_{-1.3}$ h was identified. Decay chain of the new superheavy isotope ^{286}Mc has been registered. We firstly observed spontaneous fission of ^{279}Rg. The cross section for the ^{243}Am(^{48}Ca,3n)^{288}Mc reaction was measured to be $17.1^{+6.3}_{-4.7}$ pb, which is the largest value for a superheavy nucleus at the Island of Stability. The cross section of ^{243}Am(^{48}Ca,5n)^{286}Mc was measured for first time.

DETAILED STUDY OF RADIOACTIVE DECAY PROPERTIES OF NOBELIUM ISOTOPES WITH α, β, γ-SPECTROSCOPY METHOD

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At FLNR JINR, experiments are aimed to investigate the radioactive decay properties (α, β, γ spectroscopy) and the cross sections measurements of trans-fermium elements, synthesized in complete fusion reaction of accelerated heavy ion beam with target nuclei, with subsequent evaporation of several light particles at the kinematic separator SHELS [1,2]. A number of experiments were devoted to the study of the radioactive decay properties of Nobelium isotopes are produced as an evaporation result of two or three neutrons by a compound nucleus in the reaction of ^{48}Ca beam with ^{204,206,208}Pb targets. These Nobelium isotopes have sufficiently high production cross-sections, which allow us collect good statistics for studying decay properties by methods of alpha, beta, gamma spectroscopy. Nobelium isotopes are interesting in how the radioactive decay properties change passing through the closed subshell $N = 152$, thereby could be obtain data are necessary to understanding how the heavy elements properties behave passing through the subshell $N = 162$.

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NEUTRON MULTIPLICITY DISTRIBUTIONS FOR ^{250}No SPONTANEOUS FISSION FROM GROUND STATE OR AT THE DECAY OF THE ISOMERIC STATE

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The spontaneous fission is one of the decay channel on a par with α- and β^+-decays for heavy and super-heavy isotopes ($Z > 100$). There are no established models that could describe all details of spontaneous process well yet. Therefore, experimental studies of such processes are high-interesting and important.

The combination of relatively high formation cross-section in complete fusion reactions and discovered K-isomer state living longer than its ground state [1] makes ^{250}No isotope attractive to experimental study. The SHELS separator [2] and SFiNx detection system [3] at FLNR JINR, Dubna, Russia allows us carrying out experiments to study prompt neutron yields from 250No spontaneous fission.

The previous experiment [4] hinted at possibility of spontaneous fission directly from an isometric state ^{250m}No. The difference between average numbers of neutrons per fission with corresponding lifetimes (for ground and isometric states) was quite large but statistically insignificant (≈2σ). Thus, conclusion about spontaneous fission from isomeric state possibility couldn't be drawn.

In the beginning of the 2022 the new experiment was carried out using modern analysis techniques and the detectors array with higher efficiency than in the previous one [4]. Approximately 1350 spontaneous fissions of ^{250}No were registered (vs ≈700 in [4]). Two activities with different lifetimes associated with ^{250}No and ^{250m}No were observed. The difference between average numbers of emitted spontaneous fission prompt neutrons for both activities are statistically insignificant (<1σ). Prompt neutrons multiplicity emission probability distributions for both activities separately and combined were restored using statistical regularization method [5].

The prompt neutron multiplicities distributions restoring technique will be discussed in the report. Furthermore, the structure of such distributions will be shown in conjunction with theoretical interpretation of processes.

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THE MULTIPLICITY OF NEUTRONS OF SPONTANEOUS FISSION OF ^{250}No OBTAINED IN COMPLETE FUSION REACTIONS WITH HEAVY IONS AT THE SHELS SEPARATOR

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For more than 20 years, experiments on the synthesis and study of the properties of radioactive decay of short-lived isotopes of transuranic elements have been conducted at the Flerov Nuclear Reactions Laboratory of JINR. The reactions of complete fusion of accelerated multicharged ions with target nuclei heavier than lead were mainly used. In these experiments, experimental installations with kinematic separation of recoil nuclei from background products are most often used. In these installations (separators), the separation in space of recoil nuclei, incoming ions and products of multi-nucleon transfer reactions occurs in electric and magnetic fields due to the difference in their trajectories caused by the difference in their ionic charge and energy (velocity) distributions.

This work describes the kinematic separator SHELS [1], which is used for the synthesis and study of the properties of heavy nuclei. A separator detection system consisting of a time-of-flight system, a focal semiconductor detector and a SFiNx detection system is described [2]. The new detection system consists of an assembly of multi-strip two-sided Si detectors, around which 116 proportional neutron counters filled with ^{3}He are placed. The detector system was used in the experiment to study the characteristics of spontaneous fission of the isotope ^{250}No, in which data on the yields of neutrons of spontaneous fission were compared with previously published results.

Preliminary data were obtained during processing. The neutron detection efficiency was (54.7 ± 0.1)%. The measured average number of neutrons in the ^{250}No fission act was (2.32 ± 0.07), which, taking into account the efficiency of the neutron detector, gives the value of the average number of neutrons ν = (4.24 ± 0.13).

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STUDY OF THE ^{242}Pu + ^{48}Ca AND ^{238}U + ^{48}Ca REACTIONS AT DGFRS-II

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This work presents the results of the experiments performed at the FLNR, JINR Superheavy Element Factory (SHE Factory). The experiments were carried out on the basis of the new cyclotron DC-280 with an intensity of accelerated particles of up to 10 pμA [1] and gas filled separator DGFRS-2 [2] and were aimed at study of the ^{242}Pu+^{48}Ca and ^{238}U+^{48}Ca reactions. The main goal of this experiments consisted in determining the capabilities of the SHE Factory for the production and study of new isotopes of known superheavy elements up to Og ($Z = 118$), as well as the synthesis of new ones with $Z > 118$.

The decay properties of ^{286}Fl and ^{287}Fl, as well as their α-decay products, have been updated from 25 and 69 new decay chains, respectively. Additionally, 16 decay chains of ^{283}Cn were observed in the ^{238}U+^{48}Ca reaction. During the experiment, the maximum intensity of the ^{48}Ca ion beam was 6.5 pμA. The stability of the target was measured at such high intensities. Possibility of existing of isomeric states in the ^{287}Fl consecutive α decays is discussed. A new α line with energy of 100-200 keV lower than the main one at 10.19 MeV was observed for the first time for even-even ^{286}Fl. The maximum cross section of $10.4^{+3.5}_{-2.1}$ pb was measured for the ^{242}Pu(^{48}Ca,3n)^{287}Fl reaction.

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POSSIBLE ROTATIONAL STRUCTURE OF ^{13}C LOW-LYING EXCITED STATES

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^{13}C is a good example of a “normal” nucleus that is well described in the framework of the shell model. Its level scheme is reliably determined up to excitation energies ~ 10 MeV.

However, some open questions remain regarding the structure of low-lying ^{13}C states. This leads to increased attention to ^{13}C so far.

In [1] a hypothesis was put forward about a new type of symmetry in the ^{13}C structure - D'_{3h} symmetry. Based on this symmetry within the framework of the algebraic cluster model [1] a rotational nature was predicted for low-lying excited states of ^{13}C and almost all low-lying ^{13}C states were distributed among 6 rotational bands. Thus, a critical analysis of the available data is required to answer the question about the nature of low-lying excited states of ^{13}C.

We propose to check the possibility of the existence of these rotational bands based on Modified diffraction model (MDM) analysis. The g.s.-based rotational band proposed in the framework of the algebraic cluster model may exist, since MDM analysis showed that all states of this band have normal, nonincreased root mean square radii. The second rotational band predicted in the framework of the algebraic cluster model, the band based on the 3.09 MeV state, is very interesting and promising, since its first state of this band is the state with a halo. And the question arises about the nature of other states of this band? It is quite natural that the states of one band should have similar features. Is the halo structure preserved for the other members of this band? It should also be noted that all other members of this band are unbound, while 3.09 MeV is bound. Indeed, a preliminary MDM analysis of the existing experimental data on the scattering of light particles showed that the elder members of this band have increased root mean square radius. This result speaks in favor of the possibility of the existence of this rotational band and, possibly, of the halo–like structure of its elder members. The band predicted in the framework of the algebraic cluster model, which contains the 9.90 MeV state, most likely does not exist, since we showed within MDM that the members of this assumed band have different radii. 8.86 MeV has an increased radius, the rest of the states have a non-increased radius. Thus, some of the predicted rotational bands may actually exist. It should be mentioned that negation of at least one rotational band predicted within the D'3h symmetry raises doubts on the applicability of this symmetry to ^{13}C.

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SIZE ISOMERS IN LIGHT NUCLEI

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The size of a nucleus defined by the radius of its nucleon (proton and neutron) density distribution and the proton charge distribution is one of the most fundamental and important nuclear characteristics. Nuclear radius determines the basic properties of nuclei and is a consequence of the fundamental features of the strong interaction.

The development of methods of measuring the radii of nuclei in their short-lived excited states led to discovery of new classes of states, which were named "the size isomers".

Up to now two groups of the size isomers were identified: the excited states with halos (^{9}Be, ^{11}Be, ^{13}C, ^{13}N) and some specific alpha cluster states (^{11}B, ^{12}C, ^{13}C). All the observed states are diluted, however, some indication to possible existence of more compact than the ground states was obtained as well (in ^{13}C).

The phenomenon of size isomerism occurred to be not a rare one especially if one takes into account that rotational bands are based on some of such states. The structure of size isomers is related with some new features, e.g., rotating halos, halos in continuum, different types of quasimolecular configurations. Some rudimentary signs of alpha particle condensation (a "ghost"of condensate) were observed (in the Hoyle state of ^{12}C), however, one cannot speak about confirmation of this ambitious theory.

EXPERIMENTAL MANIFESTATION OF THE STRONG NUCLEAR INTERACTION IN THE OPTICAL SPECTRA OF SOLIDS

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The primary task amongst other nuclear physics fundamental tasks is experimental measuring of nuclear force interacting between nucleons (protons and neutrons) and their dependence on nucleons' distance in between. The discovery of the neutron by Chadwick in 1932 may be viewed as the birth of the strong nuclear interaction In 1935 Yukawa have tried to develop a theory of nuclear forces. The most important feature Yukawa' forces is they have a small range ($\sim 10^{-15}$ m). However, up to present time phenomenological Yukawa potential can not be directly verified experimentally. We should remind that the strong nuclear interaction - the heart of Quantum Chromodynamics (QCD) which is the part of the Standard Model (SM). According to SM the nuclear force is a result of the strong force binding quarks to form protons and neutrons [1]. Residual part of it holds protons and neutrons together to form nuclei. There are common place in nuclear and high energy physics that the strong force does not act on leptons.

Our report is devoted to study the strong nuclear interaction via measuring the low - temperature (2 K) photoluminescence spectra of LiH (Eg = 4.992 eV) (without strong interaction in hydrogen nucleus) and LiD (Eg = 5.095 eV) (with strong interaction in deuterium nucleus) single crystals.

The uniqueness of the LiH and LiD compounds is that they differ in only one neutron, i.e. lithium ions, electron and proton are the same for them and, therefore they have the same gravitational, weak and electromagnetic interactions. The additions of a neutron to hydrogen nucleus, generates according to Yukawa, a strong interaction between a proton and a neutron, the effect on which on electron is manifested in the isotope shift (0.103 eV) of the zero-phonon photoluminescence line of free excitons in LiD crystals (see Fig 1 in Ref.2.). The experimental observation of isotope shift (0.103 eV) of the phononless free exciton emission line in LiD crystals is a direct manifestation of the long-range nuclear strong interactions on the leptons [3]. Moreover, we have measured the dependence of the nuclear strong force on the distance between nucleons in deuterium nucleus.

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^{8}He SPECTROSCOPY IN STOPPED PION ABSORPTION REACTION

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Level structure of heavy helium isotope ^{8}He is studied in the reactions of stopped pion absorption ^{9}Be(π^{-},p)X, ^{10}B(π^{-},pp)X, ^{11}B(π^{-},pd)X, ^{12}C(π^{-},p^{3}He)X, ^{14}C(π^{-},d^{4}He)X, ^{14}C(π-,t^{3}He)X. The experiment was carried out at the LANL with a two-arm semiconductor spectrometer. The ground and excited states have been observed. The assumption that the excited state $E_x \approx 3$ MeV is a soft dipole mode is made. The states $E_x \approx 9.3$ MeV, 11.5 MeV, 12.2 MeV have been observed for the first time. Parameters of excited states have been compared with data of other experimental and theoretical works.

ANALYSIS OF M1 EXCITATIONS IN ^{28}Si USING INELASTIC PROTON SCATTERING

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Isovector and isoscalar spin-flip excitations in even-even *sd*-shell nuclei excited by inelastic proton scattering were considered in [1]. Recently *M*1 excitations in *sd*-shell were also analyzed in [2]. In [2] only strongest excitations of ^{28}Si were discussed. Shell model predicts for ^{28}Si a few of 1^+ states with excitation energy lower than 20 MeV. Nearly all of these states can be identified with experimentally observed levels excited in (p,p') and (e,e') reactions. Here we analyze the spectrum of 1^+ states in ^{28}Si excited in (p,p') reaction in comparison with theoretical spectroscopic predictions. The calculations were carried out in the *sd* model space with the USDA Hamiltonian [3] using the code NuShellX [4].

The *M*1 excitations in light nuclei are mainly determined by the spin transition density. Current transitions density play only minor importance in observed B(*M*1) value. The B(*M*1) value can be extracted from the (e,e') scattering experiments. On the other hand only spin transition density determine forward cross section of (p,p') reaction with excitation of *M*1 states. We analyze forward cross sections of (p,p') reaction with excitation of 1^+ levels in ^{28}Si and determine the possible impact of current density in the B(*M*1) value.

In the excitation of *M*1 states with protons both *T=1* and *T=0* states are excited and only *T=1* states can be excited in (e,e'). The theoretically predicted states can be identified with the observed 1^+ levels according to their excitation energy but the strength of the excitations can considerably differ from the theoretical prediction. The possible explanation of this difference may be the isospin mixture.

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STUDY OF ^{209}Bi(γ,xn) REACTIONS IN ENERGY REGION UP TO 100 MeV

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In order to follow relative yields of ^{209}Bi(γ,xn) reactions, samples of natural bismuth were exposed in LINAC 200 bremsstrahlung beam at several different energies (40 MeV, 60 MeV, 80 MeV and 100 MeV). Activities of eight obtained products of photonuclear reactions with different neutron multiplicity, from (γ,2n) to (γ,9n) were detected. Relative yields were calculated for all of them. All measurements were normalized on ^{206}Bi yield.

Obtained yields were compared with the results already available in literature. The data in the literature are not very abundant and in some cases the yields differ by a two orders of magnitude. In all measurements, including this one, it was confirmed that the reaction yield decreases very sharply with the number of neutrons emitted. It has also been observed that for a given multiplicity of neutrons, the relative yield does not depend significantly on maximal energy of the bremsstrahlung.

Yields obtained by measurements are compared with the results of theoretical calculations. Calculation have been performed using the combination of evaporation and exciton models [1]. The level densities employed in the model have been calculated microscopically to take into account shell effects and their dependence on excitation energy [2].

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SPECTROSCOPY EXPERIMENTS ON GABRIELA

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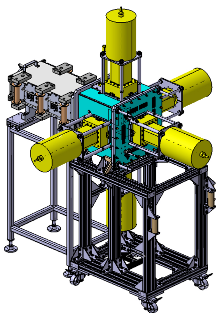
GABRIELA [1] is a detection system installed at the focal plane of the SHELS [2–3] recoil separator for α-, β- and γ-spectroscopy of heavy and superheavy nuclei.

In recent years experiments have been devoted to complete fusion reactions, like as ^{48}Ca+$^{204\text{-}208}$Pb [4] and ^{50}Ti+^{204}Pb [5], the cross sections of those reactions have the order of nanobarns. For the first time isotope of ^{249}No was synthesized in the reaction ^{204}Pb(^{48}Ca,3n)^{249}No, it has half-life 38.3±2.8 ms[6]. GABRIELA has recently been upgraded, named of GABRIELA-II (see Fig. 1. left). Instead 4 single crystals Ge-detectors were installed 5 Clover-detectors, the lets to fix gamma-quanta with best efficiency (see Fig. 1. right).



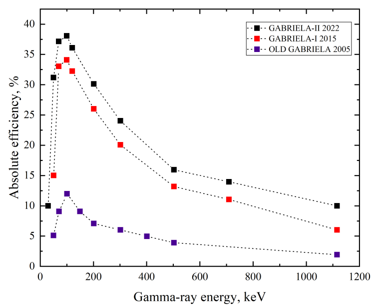


Fig. 1. Left. GABRIELA-II; Right.Absolute efficiency registration of gamma-quanta by detector in different variation of GABRIELA.

The first test experiment ^{206}Pb(^{48}Ca,2n) ^{252}No will be carried out with GABRIELA-II setup soon.

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PRECISION MEASUREMENT OF THE PROTON CHARGE RADIUS IN AN ELECTRON–PROTON SCATTERING EXPERIMENT

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The project is motivated by the discrepancy (4%) between precise measurements of the proton charge rms-radius $R_p = \langle R_{pE}^2 \rangle^{1/2}$ in the muonic hydrogen (μH atoms) Lamb shift experiments performed at Paul Scherrer Institute by the CREMA Collaboration (R_p = 0.84184(87) fm [1], R_p = 0.84087(39) fm [2]) and the radius determined in the electron–proton (ep) elastic scattering experiments: R_p = 0.879(5)stat(6)syst fm, A1 Collaboration at Mainz [3], and Rp = 0.875(10) fm, Thomas Jefferson National Accelerator Facility (Jefferson Lab) [4].

The experiment described in this project will use an innovative method allowing for detection of recoil protons and scattered electrons at low Q^2 with high accuracy and resolution, thus leading to a completely new approach for extraction of the proton radius. The goal is to measure the ep differential cross sections in the Q^2 range from 0.001 to 0.04 GeV^2 with 0.1% relative and 0.2% absolute precision and to determine the proton radius with a sub-percent precision. An important advantage of the applied method is considerably lower radiative corrections inherent to the recoil proton method controlled, in addition, by the absolute measurement of the differential cross sections.

The experiment will be performed at the Mainz electron accelerator MAMI. This accelerator can provide an electron beam with practically ideal for this experiment parameters, as it was demonstrated in a special test runs. The proposal was approved by the MAMI Program Advisory Committee, and a special Agreement aimed at realization of this experiment was signed between PNPI and Institute for Nuclear Physics (Mainz).

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DIRECT ONE-NEUTRON DECAY OF THE ISOSCALAR GIANT DIPOLE RESONANCE IN MEDIUM-HEAVY SPHERICAL NUCLEI: A SEMI-MICROSCOPIC DESCRIPTION

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Direct one-nucleon decay of giant resonances (GRs) is the subject of permanent (but not-too-intensive) experimental and theoretical studies. They allow one to get information on GR structure and decay mechanisms. Decay probabilities are usually deduced from a common analysis of cross sections of direct inclusive and "decay" reactions. In Ref. [1], direct one-neutron decay of Isoscalar Giant Dipole Resonance (ISGDR) in ^{90}Zr, ^{116}Sn, and ^{208}Pb have been studied via the (α, α')- and $(\alpha, \alpha' n)$-reactions. To some extent, this study has been stimulated by predictions made in Ref. [2] for partial branching ratios b_μ of direct one-neutron ISGDR decay accompanied by population of neutron-hole states μ^{-1} in product nuclei. A simple extension of standard and nonstandard continuum-RPA versions to taking phenomenologically the spreading effect into account has been exploited in Ref. [2]. The experimental values $b = \sum_\mu b_\mu$ (the sum is taken over a few valence neutron-hole states) were found in Ref. [1] to be essentially less than the respective predicted values.

In the present work, we, first, specify the approach of Ref. [2], employing for evaluation of b_μ values the semi-microscopic Particle-Hole Dispersive Optical Model (see, e.g., Ref. [3] and references therein) and, secondly, use the alternative definition for b_μ employed in Ref. [1]. These points allow us to reduce markedly the difference between theoretical and experimental b values related to direct one-neutron decay of ISGMR in the above-mentioned nuclei.

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THE HALF-LIFE OF ^{229m}Th ISOMERS IN ACID SOLUTION

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The ^{229m}Th isomeric state with an energy of about 8 eV is formed in 2% of the cases of ^{233}U α-decay (see ref. [1] and references therein). For neutral ^{229m}Th atoms, the main decay channel is nonradiative – it is either electronic conversion or decay via an electronic bridge. An estimate of the probability of a decay with photon emission γ_{Th} gives a half-life $T_{1/2} \approx 2$ h and is much smaller than the probability of a nonradiative transition. Photons can only be observed for ^{229m}Th ions when the nonradiative channel is closed.

Here we give a detailed analysis of work [2], where γ_{Th} photons were observed for 4^+ ions of ^{229m}Th in HCl acid solution obtained in an ion exchange column from 0.1 g U (the relative α-activities of ^{233}U and ^{232}U were 99.8% and 0.02%, respectively). In each of several experiments four samples were sequentially prepared with ^{229m}Th in 7*M* HCl aqueous solution by eluting once an hour fresh Th from U, which was previously purified from Th and its daughters. Sources for α-spectrometry were prepared from the second and third samples; for each of them the α-activity of Th daughters increased with time. Thus, the α-activity of the samples could not lead to their damped photon emission.

The first and fourth liquid samples of ^{229m}Th were placed into thin-layer quartz cuvettes, and $t = 60$ min after Th elution, the photon counting intensity *N(t)* from the samples was measured by a photomultiplier with a Sb-Na-K-CS photocathode, the photo efficiency was about 1% in the wavelength range of 300 – 800 nm. The time dependence of *N(t)* averaged over all experiments was approximated as $N(t) = N_0 \times (A \times e^{-0.69 \times t/T1} + e^{-0.69 \times t/T2})$, where $A = 9 \pm 3$, $T1 = 22 \pm 3$ min, $T2 = 290 \pm 50$ min (errors are one standard deviation). N_0 was proportional to the α-activity of ^{229}Th in the samples with an accuracy of 20% and did not correlate with their total α-activity. It can be assumed that for the ^{229m}Th isomer in an HCl solution, $T_{1/2}$ is in the range of 20 – 400 min. To refine $T_{1/2}$ and the isomeric transition energy, it is necessary to study the photon spectrum of such samples.

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MULTI-STEP NEUTRON EMISSION PROBABILITIES IN HEAVIEST NUCLEI

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The probability of realization of xn channel is calculated for superheavy nuclei with $Z > 114$ using Monte Carlo method. The result is compared with the analytical expression based on assumption of Maxwellian distribution for neutron energy. The kinetic energy distribution of neutrons in multi-step decay process is analyzed and applied for the estimation of survival probabilities under *x*n, p*x*n, and α*x*n channels. Nuclear level densities are calculated with the superfluid formalism using the single-particle energies obtained with the Woods–Saxon potential diagonalization at the ground state and fission saddle point. This allows us to take into account pairing and shell effects in the calculation of energy dependent widths for various decay channels.

STUDY OF EXCITED STATES IN ATOMIC NUCLEI ^{46}Ti AND ^{45}Ti IN REACTIONS WITH ^{3}He BEAM AT 29 MeV

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The results of measurements of the angular distributions of deuterons in the ^{45}Sc(^{3}He, *d*)^{46}Ti reaction are presented, from which the cross sections for population of the ground and excited states in the ^{46}Ti nucleus were determined [1]. The energy of the bombarding ^{3}He particles was 29 MeV.

The measured angular distributions for the excited states in the ^{46}Ti nuclei are compared with the results of other measurements at several values of ^{3}He energy. A comparison of the angular distributions for the ground and excited states of ^{46}Ti with DWBA calculations showed that the pickup of a proton from ^{3}He to the target nucleus mainly results in transfer of 3 or 1 units of angular momentum, which corresponds to the population of $1f_{7/2}$ and $2p_{3/2}$ shells, respectively. It was shown that rearrangement of nucleons in the unfilled $1f_{7/2}$ and $2p_{3/2}$ shells leads to excitation of both collective and particle-hole states with different angular momenta. The energy spectra of ^{46}Ti obtained in the experiment were analyzed within the framework of the dinuclear system model [2].

For the ^{45}Sc(^{3}He, *t*)^{45}Ti reaction, the spectrum of excited states of ^{45}Ti was measured for the first time [3]. Significantly fewer excited states in the resulting

^{45}Ti nucleus are populated compared to ^{46}Ti; moreover, mainly low-lying single-particle states are populated.

The experiments were carried out at the accelerator of the Institute of Nuclear Physics, Řež, Czech Republic.

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NATURAL WIDTHS OF ATOMIC LEVELS IN THORIUM DETERMINED BY THE ICES METHOD

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The overwhelming majority of the experimental atomic-level widths in thorium (see, e.g., the compilation [1]) were determined by the X-ray emission spectroscopy and only several N-subshell values were obtained by the XPS method. There are no available relevant experimental data determined by another methods. Therefore, we used suitable conversion electron lines of the 9.2, 15.1 and 24.3 keV nuclear transitions in ^{227}Th (generated in the β-decay of ^{227}Ac) measured in the works [2,3] for the determination of the M_1, M_2, M_3, N_1, N_2, and N_3 atomic-level widths using the approach and the computer code [4]. The values obtained are given in the table (in eV).

	Atomic subshell					
	M_1	M_2	M_3	N_1	N_2	N_3
This work	14.1±0.5	11.4±0.5	6.9±0.4	11.4±1.4	8.6±1.2	6.0±0.7
Ref. [1]	15.5±2.0	13.2±(5÷25)%	8±(5÷25)%	11.5±(10%)	8.8±0.8	7.5±1.0

As can be seen, the agreement within 2σ (or better) is found between the present and compilated data [1] and for the most of the atomic subshells in question our values are more precise. Thus, our data represent a valuable contribution to the database of the experimental natural atomic-level widths of thorium.

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EXPERIMENTAL INVESTIGATIONS OF THE 9.2, 15.1, AND 24.3 keV NUCLEAR TRANSITIONS IN ^{227}Th AND CONSEQUENCES OF THEIR RESULTS FOR SPIN-PARITY ASSIGNMENTS TO LOW-LYING STATES OF ^{227}Th

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The 9.2, 15.1, and 24.3 keV nuclear transitions in ^{227}Th were studied in the β^--decay of ^{227}Ac by means of the internal conversion electron spectroscopy (ICES) using the combined electrostatic electron spectrometer [1] and the computer code SOFIE (see, e.g., Ref. [2]) to clarify the spin-parity assignment of the ground state and the two lowest excited states in ^{227}Th. Results obtained were published in [3,4,5].

Energies of (9244.6±0.8), (15098.6±1.0), and (24343.1±1.1) eV were determined for the 9.2, 15.1, and 24.3 keV transitions, respectively, as well as the mixed character (M1+E2) for each of them with the δ^2(E2/M1) values of (0.695±0.248), (0.0012±0.0003), and (0.0116±0.0004), respectively. An agreement within ±0.1 eV was found among the above transition energy values and those obtained from their interlinked relations based on the decay scheme. Using the gamma-ray spectroscopy, energy values of (24342.9±1.2), (28613.3±1.7), and (37860.2±2.0) eV were obtained for the 24.3, 28.6, and 37.8 keV transitions in ^{227}Th, respectively. The almost zero difference of (0.2±1.6) eV for the 24.3 keV transition energies determined by the ICES and gamma-ray methods demonstrates a reliability of the transition energy determination in the present work.

Our investigation removed the uncertainty in the multipolarity character of the 15.1 keV transition. Determined [4] nonzero value of δ(E2/M1) parameter for the 9.2 keV transition questioned the current theoretical interpretation of low-lying levels of ^{227}Th. Our calculations [4] prefer the $1/2^+$, $3/2^+$, and $3/2^+$ sequence instead of the adopted $1/2^+$, $5/2^+$ and $3/2^+$ one for the 0.0, 9.2, and 24.3 keV levels, respectively. In such a case, the assignment $I^\pi=5/2^+$ for any of these levels is excluded. Nevertheless, it is necessary to use more precise theoretical approaches to prove the proposed interpretation of the current experimental data. New experimental information on low-energy transitions connecting low-lying levels in similar nuclei is desirable as well.

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GENERALIZATION OF THEORY OF FINITE FERMI-SYSTEMS FOR PYGMY- AND GIANT MULTIPOLE RESONANCES

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The generalized equation for the main notion of the self-consistent theory of finite Fermi-systems (TFFS) [1,2] effective field (vertex) $\tilde{V}$, which describes nuclear polarizability, has been derived for the case of consistent accounting for phonon coupling (PC) in the energy region of pygmy-and giant resonances (GDR, GMR) in magic nuclei [3,4]:

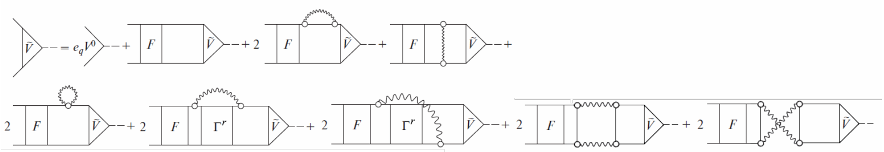

Figure 1. F – effective interaction, Γ^r – regular part of the full interaction amplitude Γ [1], circles and wavy lines – phonons. The known terms are from the first to the fourth from the right, the new ones are all the others. All terms with δF are omitted.

The formulae for observable characteristics of these resonances have been obtained. New PC effects have been found and discussed: 1) numerous three- and four correlations in the ground state, 2) various induced interactions caused by the exchange of phonon, 3) (for the first time in TFFS) two-phonon configurations, 4) dynamic effects of tadpole, 5) the first and second variations of the effective interaction δF in the phonon field. These effects should have many manifestations, in particular, for the description of the fine structures of PDR and GMR. Most of these effects should give a noticeable numerical contribution. Self-consistency gives a great predictive strength of the theory, which is necessary for unstable nuclei, astrophysics and nuclear data.

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MICROSCOPIC DESCRIPTION OF ISOSCALAR GIANT MONOPOLE RESONANCE: THE CASE OF ^{48}Ca

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A comprehensive analysis of the isoscalar giant monopole resonance (ISGMR) has long been a subject of extensive theoretical and experimental research [1,2]. The ISGMR properties are presently an important problem not only from the nuclear structure point of view [2,3] but also because of the special role they play in many astrophysical processes such as prompt supernova explosions [4] and the interiors of neutron stars [5].

One of the successful tools for describing the ISGMR is the quasiparticle random phase approximation (QRPA) with the self-consistent mean-field derived from Skyrme energy density functionals (EDF) [2,3]. The study of the monopole strength distribution in the region of giant resonance involves taking into account a coupling between the simple particle-hole excitations and more complicated (two- and three-phonons) configurations [3,6]. The main difficulty is that the complexity of calculations beyond standard QRPA increases rapidly with the size of the configuration space, and one has to work within limited spaces. Using a finite rank separable approximation for the residual particle-hole interaction derived from the Skyrme EDF one can overcome this numerical problem [7,8].

In the present report, we study the effects of the coupling between one-, two- and three-phonon terms in the wave functions on the monopole strength distribution in the double-magic nucleus ^{48}Ca. Using the same set of parameters, we describe available experimental data [9,10]. The effects of the phonon-phonon coupling leads to a redistribution of the main monopole strength to lower energy states and also to higher energy tail [11].

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PROPERTIES OF GAMOW-TELLER AND CHARGE-EXCHANGE GIANT SPIN-MONOPOLE RESONANCES IN MEDIUM-HEAVY CLOSED-SHELL PARENT NUCLEI: A SEMIMICROSCOPIC DESCRIPTION

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Properties of giant resonances (GRs) associated with high-energy particle-hole (p-h) excitations in medium-heavy nuclei are described by a number of characteristics and parameters. Main characteristics include the energy-averaged strength function and "projected" transition density, both related to an appropriated single-particle external field (probing operator), and strength functions of direct one-nucleon decay. Being considered in a wide excitation-energy intervals, these characteristics determine, in particular, the GR peak energy, fractions of the respective sum rule, probabilities of direct one-nucleon decay.

In this work, we present a theoretical study of the main properties of Gamow-Teller and charge-exchange (isovector) giant spin-monopole resonances (GTR and IVGSMR$^{(\mp)}$, respectively) in a few medium-heavy closed-shell parent nuclei. The study is performed within the semi-microscopic p-h dispersive optical model (PHDOM), in which the main relaxation modes of p-h states associated with GRs are together taken into account. Actually, PHDOM is a microscopically-based extension of the standard and nonstandard versions of the continuum-random-phase-approximation on taking (phenomenologically and in average over the energy) the spreading effect into account. Formulation of PHDOM and its implementations to describing a few of isoscalar and isovector GRs in medium-heavy closed-shell nuclei can be found in Ref. [1] and references therein. Within the model. a realistic partially self-consistent phenomenological mean field and Landau-Migdal p-h interaction are used as input quantities.

In this work, PHDOM is adopted and then implemented to describing main properties of GTR and IVGSMR$^{(\mp)}$ in the 48Ca, 90Zr, 132Sn, and 208Pb parent nuclei. Calculation results are compared with available experimental data. Most of the results can be found in Ref [2].

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NUCLEUS SURFACE TENSION AND ITS MICROSCOPIC RESONANCE DESCRIPTION

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Deviations of nuclear properties from shell model predictions are very sensitive to value of nuclear surface tension [1]. Although the quantitative estimation of these deviations is not yet possible, a level of deviation is indicated by the values of the nuclear surface tension coefficient σ. These deviations are minimal for nuclei with high values of the coefficient σ. The nuclei of iron isotopes with even numbers of neutrons are characterized by relatively small values of σ (see Fig. 1). The maximum value of σ for the ^{54}Fe nucleus is 9 times less than the surface tension of the ^{48}Ca nucleus [1]. The calculation of resonant excited states of nuclei with small values of σ within the framework of the traditional many-particle shell model (MPSM) [2] does not lead to an adequate description of the energy distribution of the excitation probabilities. Agreement with experiment can be achieved using the method "particle-core coupling shell model" (PCCSM) [3], where experimental values of spectroscopic factors are taken into account. For the ^{54}Fe nucleus, this method has led to a satisfactory theoretical description of the GDR [4]. The role of "magic numbers" in the formation of the value of σ is shown in Fig. 1: the surface tension of the ^{54}Fe nucleus is more than 2 times higher than its values for other stable iron isotopes. The influence of proton "magic numbers" is clearly seen from the comparison of Ni and Fe surface tension coefficients (Fig. 1).

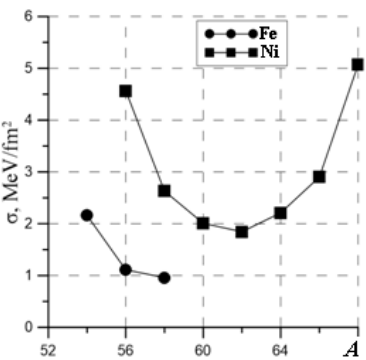

Fig. 1. Values of surface tension coefficients for Fe and Ni isotopes.

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INFLUENCE OF NUCLEON PAIRS ON THE NUCLEAR SURFACE TENSION

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The calculation of the surface tension coefficients σ of even-even nuclei [1] showed the decisive role of shell effects in the formation of the value of σ. The addition of neutron pairs to the "magic" nucleus leads, as a rule, to a decrease in σ (Fig. 1). Low values of σ change little upon addition of neutron pairs until a neutron-closed subshell is obtained, when the surface tension sharply increases (Fig.1a).

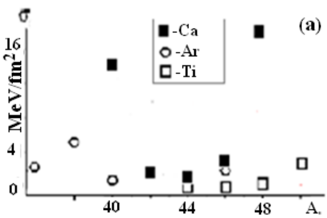

Fig.1a. Surface tension of Ca, Ar and Ti nuclei

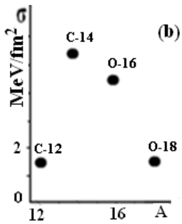

Fig.1b. Surface tension of C and O

The role of proton pairs in the formation of surface tension is more controversial. Adding a pair of protons to a closed protons shell leads to a significant decrease in σ [σ(^{18}O)/σ(^{20}Ne)≈4.5; σ(^{48}Ca)/σ(^{50}Ti)≈5.5]. The surface tension of the nucleus, as a rule, increases if the addition of a pair of protons completes the shell to closeness [σ(^{40}Ca)/σ(^{38}Ar)≈3.3;], however, the addition of a pair of protons to the ^{14}C nucleus leads to a decrease in σ (Fig. 1b), although in this case a closed proton subshell is formed. The relatively low value of σ for the ^{16}O nucleus is the source of the formation of a complex structure of giant resonance in this nucleus, which has not been adequately explained in terms of the many-particle shell model [2,3].The influence of the shell structure on the surface tension of heavy stable nuclei is clearly manifested in mercury and lead isotopes: the surface tension coefficient σ more than triples when a pair of protons (3s)^2 is added to the ^{204}Hg nucleus and the "magic" number of protons 82 is formed. Completing the construction of the lead's neutron shell up to N = 126 leads to an even sharper increase in σ and the achievement of the maximum of this coefficient among all nuclei: σ(^{126}Pb)≈34MeV/fm^2.

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LOCAL MAGIC NUCLEI: PROPERTIES AND STRUCTURE

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A new kind of atomic nuclei, local magic nuclei (l.m.n.), have been discovered recently [1]. We present in this report a current state of relevant research.

L.m.n. have the same observable features as traditional magic nuclei, i.e. elevated energies of the first 2+ excitations, increased nucleon separation energies, and so on. However, unlike the traditional magic nuclei, l.m.n. do not have magic isotopes or isotones, and, in addition, they manifest at non-conventional magic numbers. They are described not by ‘magic numbers’ but by ‘miraculous pairs’, such as ($\underline{N}$, Z) and similar, where the underline denotes a number that loses its magicity in another pair. Examples of observed pairs are (N, Z) = ($\underline{32}$, 20), ($\underline{40}$, 28), ($\underline{56}$, $\underline{40}$), ($\underline{64}$, 50), (82, $\underline{64}$) etc.

L.m.n. arise due to the compact (like a hole) gaps inside the traditional shells. This conclusion follows from our studies of the one-nucleon stripping and pick-up reactions. As we suppose this shell evolution is due to nucleon-nucleon interactions, and the proton-neutron tensor force makes a decisive contribution. On this basis, we have constructed the diagrams of the nucleon orbit energies, which successfully describe above processes. These diagrams predict new magic numbers as well.

As a result, we obtain the two-dimensional (N, Z) shell scheme, which develops the traditional Goeppert-Mayer–Jensen scheme.

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INFLUENCE OF NUCLEAR SURFACE DIFFUSENESS ON HALO STRUCTURE OF Zr ISOTOPES NEAR THE NEUTRON DRIP LINE

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More pronounced increase in the neutron surface diffuseness with increasing of neutron excess is expected for the nuclei far from the β-stability valley [1,2] in comparison with the stable ones. Earlier, the halo and giant halo were predicted for the Zr isotopes near the neutron drip line by the relativistic Hartree-Bogoliubov theory [3]. We studied the halo structure of these isotopes within the dispersive optical model. Influence of the diffuseness parameters of the volume and surface components of the dispersive optical model potential on the root-mean-square radii of Zr isotopes and its halo states, and their population was investigated. The influence of the increase in the diffuseness a_{HF} of the Hartree-Fock component, for example, was appeared to be double: root-mean-square radius r_{nlj} of 3p halo states decreased, but the number of neutrons n_{nlj} in these states increased (see Fig. 1). It was shown also that the number of neutrons in halo states differed significantly from the number of neutrons in the halo region where there was no spatial correlation of neutrons in halo states with the core of the nucleus.

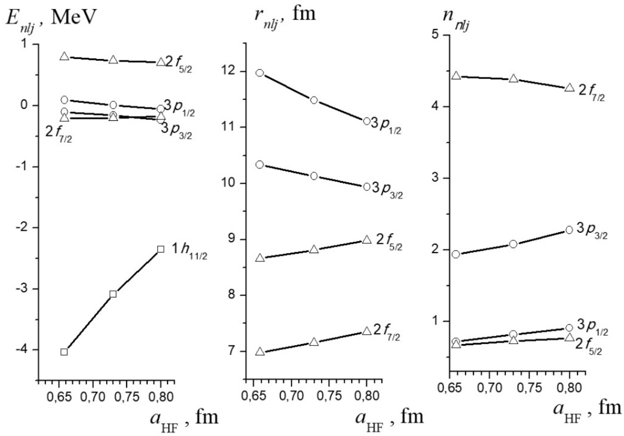

Fig. 1. Single-particle energy E_{nlj}(left), root-mean-square radius r_{nlj} (middle) and number of neutrons n_{nlj} in the single-particle states near the Fermi energy (right) in ^{130}Zr.

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ROLE OF QUARKS IN NUCLEAR STRUCTURE

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We propose semi-empirical quark model of nuclear structure that is based on the quark model of nucleon structure, Strongly Correlated Quark Model (SCQM). Nuclei are constructed due to junctions of SU(3) color fields of quarks of neighbor nucleons [1]. According to SCQM, arrangement of nucleons within nuclei reveals the emergence of the face-centered cubic (FCC) symmetry [2]. The model of nuclear structure becomes isomorphic to the shell model and, moreover, composes the features of cluster models. Binding of nucleons in stable nuclei are provided by quark loops which form three and four nucleon correlations. On the quark level the nuclear shell closures starting from s-shell correspond to the octahedral symmetry. The closure of a subsequent shells (p, d, f, ...) leads to rearrangement and disappearance of the previous ones, i.e. to no-core shells. Quark loops leading to four-nucleon correlations are responsible for the binding energy enhancement in even-even nuclei which are formed by virtual alpha-clusters. Two neighbor virtual alpha-clusters possess one common nucleon which couples them. The model describes the "magic" numbers without spin-orbital coupling of the shell model. According to the model "halo" nuclei emerge according to quark loops resulting in three nucleon correlations. The model allows to describe nuclear deformation, predict the boundary on nuclear stability and etc.

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CONTRIBUTION OF INDUCED DIPOLE INTERACTION TO THE ASYMPTOTIC BEHAVIOR OF WAVE FUNCTION COMPONENTS FOR THE SCATTERING IN THREE BODY COULOMB SYSTEMS

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We consider the scattering of a charged particle with a two-particle target system which is bound by the attractive Coulomb interaction. The Faddeev-Merkuriev set of equations is used for describing the scattering process [1,2]. Although, the leading contribution to the asymptotic form of the wave function and its components comes from the asymptotic Coulomb interaction between the two-particle target and the spectator particle, the next long-range terms of the multipole expansion of this interaction plays important role in energy regions where the excited state channels are open [3]. In this contribution we derive the explicit asymptotic representations for the wave function components which take into account as the Coulomb as well as the induced dipole interactions between the two-body target and the spectator particle. The general method from [4] is used for constructing asymptotic solutions. The derived asymptotics is then intended for the use in electron and positron scattering off the hydrogen atom and helium cation calculations in the energy region above the thresholds of exited states of the targets where the induced dipole interaction produces specific effects in scattering data [4].

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OPTIMAL BOUNDS ON THE SPEED OF SUBSPACE EVOLUTION GOVERNED BY A TIME-DEPENDENT HAMILTONIAN

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By a quantum speed limit one usually understands an estimate on how fast a quantum system can evolve between two distinguishable states. The most known quantum speed limit is given in the form of the celebrated Mandelstam-Tamm inequality that bounds the speed of the evolution of a state in terms of its energy dispersion. In contrast to the basic Mandelstam-Tamm inequality, we are concerned not with a single state but with a (possibly infinite-dimensional) subspace which is subject to the Schroedinger evolution. By using the concept of maximal angle between subspaces we derive optimal bounds on the speed of such a subspace evolution. Our present study extends the results obtained in [1,2] for time-independent Hamiltonians to the case of subspace evolution governed by a (possibly unbounded) time-dependent Hamiltonian.

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UNION OF DISCRETIZED SPECTRA FOR SCATTERING CALCULATIONS

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Solving scattering problems in L_2 bases is a perspective way which allows to treat problems for continuum nearly on the same footing as the discrete spectrum ones. Recently we have suggested a new technique for reconstructing scattering amplitude directly from discretized spectra of the total and asymptotic Hamiltonians found with variational method [1]. It was shown also how the discretized spectra of the Hamiltonians obtained using different bases of the same dimension can be united into the common set. Apart other advantages, such a union of discretized spectra (UDS) leads to a much denser grid for spectrum discretization without increasing an actual basis dimension.

In this study, the technique based on the UDS is generalized to multichannel problems with degenerated continuum. For practical calculations, a non-orthogonal Gaussian basis is used which is known to be very convenient for few-body bound-state problem. It is expected that it is for Gaussian basis sets that the UDS method will be effective for calculations in few-body continuum, as was shown for the single-channel case [1]. As illustrations, we consider the use of UDS for solving two-body multi-channel scattering problems, as well as for finding multi-channel resonances.

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RECENT PROGRESS IN DESCRIPTION OF *NN* SCATTERING WITH THE DIBARYON MODEL

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We review the recent results obtained within the dibaryon model for *NN* interaction [1-4]. The model takes into account the formation of the intermediate six-quark (dibaryon) state in each partial wave. The respective mechanism leads to an energy-dependent term in the interaction which reflects the coupling with the internal non-nucleonic channel.

The substantial progress in the description of elastic and inelastic *NN* scattering in different partial channels has been achieved by taking into consideration the parameters of the dibaryon resonances found from experiments and partial wave analyses (PWA). As an illustration, elastic and inelastic *NN* scattering amplitudes for all the lowest partial configurations with the total angular momentum up to J = 3 are presented in comparison with the *NN* PWA data in a broad energy range from zero to T_p = 0.7–1.2 GeV. Simultaneously, the model gives the dibaryon resonance parameters very close to the experimental ones for the *NN* channels where the respective data exist and predicts new resonances in the *NN* channels $^3P_1$, $^1P_1$, $^3D_2$ and $^1F_3$, where dibaryon states have not been detected to date.

Important inelastic processes such as pion production in *NN* scattering can also be described within the model [3,4]. The recent results for pion production with account of particular dibaryon resonances are discussed as well.

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THEORETICAL STUDY OF ANTIHYDROGEN FORMATION REACTIONS IN THE THREE BODY $e^-e^+\bar{p}$ SYSTEM VIA FADDEEV-MERKURIEV EQUATIONS IN TOTAL ORBITAL MOMENTUM REPRESENTATION

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We present the results of calculations of low-energy reaction in the three body $e^-e^+\bar{p}$ system with the emphasis on the process of the antihydrogen formation from the ground and excited states of the positronium. This reaction is important for some of the current antimatter experiments [1, 2]. The multichannel scattering calculations are based on a new highly efficient method of solving the Faddeev-Merkuriev equations in total orbital momentum representation [3]. We discuss the effects that originate from the long-range dipole interaction between the excited atom and the spectator particle [4, 5]. Among them are the Gailtis-Damburg oscillations in the total and partial cross sections.

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BOSE-HUBBARD MODELS WITH ON-SITE AND NEAREST-NEIGHBOR INTERACTIONS: EXACTLY SOLVABLE CASE

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We study the discrete spectrum of the two-particle Schrodinger operator depending on the quasi-momentum associated to the Bose-Hubbard Hamiltonian of a system of two identical bosons interacting on one site and nearest-neighbor sites in the two-dimensional lattice with arbitrary interaction magnitudes. We completely describe the spectrum of Schrodinger operator with zero quasi-momentum and establish the optimal lower bound for the number of eigenvalues of Schrodinger operator outside its essential spectrum for all non-zero values of quasi-momentum.

Namely, we partition the interaction parameters plane such that in each connected component of the partition the number of bound states of Schrodinger operator with non-zero quasi-momentum lying below or above its essential spectrum cannot be less than the corresponding number of bound states of the operator with zero quasi-momentum lying below or above its essential spectrum, respectively.

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MINLOS-FADDEEV REGULARIZATION OF ZERO-RANGE INTERACTIONS IN THE THREE-BODY PROBLEM

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Application of zero-range two-body interactions in the three-body problem is not a trivial task, which manifests in appearance of Efimov or Thomas effects. One particular modification of zero-range interactions was suggested in the influential paper by Minlos and Faddeev [1] and was further analyzed in [2]. A main idea is to regularize the three-body problem by adding the effective three-body force, which reduces the interaction strength near the triple-collision point. As a result, the Efimov and Thomas effects are prohibited if the strength of regularizing term s exceeds the critical value s_c. Recently, it was claimed that the condition $s > s_c$ provides the unambigouos description of the problem for three identical bosons [3] and for N identical bosons interacting with a distinct particle [4].

The proposed modification is studied and it is shown that to regularize the three-body problem, the parameter s should exceed another critical value $s_r > s_c$. More detailed analysis is given for the interval $s_c \le s < s_r$, for which unambiguous description requires one to set a boundary condition at the triple-collision point.

These considerations are explicitly demonstrated for two-component system consisting of two identical bosons interacting with a distinct particle and for three identical bosons. To elucidate the description, the bound-state energies of three identical bosons are calculated as a function of *s* and an additional parameter *b*, which determines the boundary condition.

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ABSENCE OF THE THREE-BODY BOUND STATES FOR SMALL MASS RATIO IN THE TWO-COMPONENT SYSTEM

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It is of interest to determine the mass-ratio, below which there are no bound states, for two-component system of two identical particles interacting with a distinct particle via contact interaction. Using the hyperradial expansion and taking into account that interaction is of zero range, the two-variable inequality was derived, which provides absence of bound states. The variable are mass ratio and the lowest eigenvalue of an auxiliary eigenvalue problem on hyper-sphere. This inequality is analyzed for different sectors of total angular momentum and parity. As a result, desired values of the mass ratio for few lowest angular momenta are obtained. Till now, this problem was considered for the sector of unit total angular momentum and negative parity by analysing momentum-space integral equation [1].

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POTENTIAL SPLITTING APPROACH FOR SCATTERING PROBLEM FOR FEW-BODY QUANTUM SYSTEMS

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Scattering problem for few-body quantum systems is of great importance for various fields of modern quantum physics. The complicated boundary conditions at large distances, especially for slowly decreasing potentials, represent the main difficulty for this problem [1]. While several methods have been developed for constructing solutions to the scattering problem, mathematically sound and computationally effective approaches are still in demand.

We present an approach based on splitting the reaction potential into a finite range part and a long range tail part to describe scattering in the case of the Coulomb interaction [2,3]. The solution to the Schrödinger equation for the long range tail is used as an incoming wave. The scattering problem is then reformulated into an inhomogeneous Schrödinger equation with asymptotic outgoing waves. This equation is solved with the exterior complex scaling technique. The developed approach has been illustrated with calculations of scattering processes in few atomic and molecular systems.

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SIMPLE MODEL OF DISSOCIATION BASED ON TIME-DEPENDENT FADDEEV EQUATIONS

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Faddeev equations play an important role as a backbone of computational and theoretical models of quantum few-body systems in nuclear, atomic and molecular physics. Traditionally, they are used in the context of bound state and scattering calculations in stationary approach. The Faddeev decomposition of the operator can also be efficiently used for theoretical and numerical modeling of essentially non-stationary processes, such as dissociation and ionization of molecular ions in the external non-stationary fields. Here we take a step towards more extensive usage of the Faddeev decomposition for non-stationary systems by giving an example of a simple model of the positive Hydrogen ion dissociation in a short intense laser field.

As is mentioned by Belyaev [1], the Faddeev decomposition allows us to formulate the simplest possible model of interatomic interaction by using a single two-body state projection of different components of the interaction, which, unlike the traditional quantum chemistry approach, gives the results that are qualitatively comparable to the exact treatment of the problem. By including a non-stationary interaction with an external field we come to a system of non-stationary Faddeev equations that we solve numerically. We compare the dissociation probability and the kinetic energy release (KER) for the dissociated state obtained in the new and the more traditional time-dependent Schroedinger equation approaches [2].

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NUCLEAR SHAPE EVOLUTION IN THE LEAD REGION: NEUTRON-DEFICIENT BISMUTH AND GOLD ISOTOPES

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The shape and the size of a nucleus are among its most fundamental properties. Usually, isotopic dependence of nuclear radii is smooth, however the neutron-deficient isotopes in the lead region (near $Z = 82$) exhibit the richest manifestation of shape evolution and shape coexistence phenomena which lead to marked irregularities in the radii isotopic trends. The behavior of the ground and isomeric states shape differs noticeably for different Z in this region. While in Hg isotopic chain ($Z = 80$) jump-like odd-even shape staggering was observed at $N = 101$–105 [1], for Po nuclei ($Z = 84$) an early onset and gradual increase of deformation was found at N < 113 [2]. At the same time the neutron-deficient Tl and Pb nuclei ($Z = 81$, 82) remain essentially spherical, up to and beyond the neutron mid-shell at $N = 104$ [3].

Recently a successful investigations of bismuth and gold isotopes were performed at ISOLDE facility (CERN) using the in-source resonance-ionization spectroscopy technique. This highly efficient method provides information about isotope shift (IS) and hyperfine structure (hfs) of optical lines. Changes in nuclear mean-squared charge radius ($\delta\langle r^2\rangle$) and the nuclear electromagnetic moments can be deduced from the IS and hfs. These nuclear observables are sensitive to the radial distribution of the nuclear wavefunction, and thus to the shape evolution across the nuclear landscape.

In this work, we present the results of the IS and hfs measurements for neutron deficient Bi ($Z = 83$, $N = 104$–108) and Au isotopes ($Z = 79$, $N = 97$–104).

The most interesting findings are as follows:

1) The huge staggering in radii was observed for ^{188}Bi^{g} relative to ^{187,189}Bi^{g} at the same neutron number ($N = 105$) and with the same amplitude as in the famous Hg case [1]. Quadrupole moment of ^{188}Bi^{g} confirms the strong prolate deformation in this nucleus [4].

2) The isotopes ^{180,181,182}Au keep the strong deformation, observed earlier for the heavier gold isotopes ($^{183–186}$Au), whilst the lightest isotopes (^{176,177,179}Au) return to near-spherical shape which is inherent to Au isotopes with A>186.

3) Shape coexistence was found in ^{178}Au which have ground and isomeric states with different deformation.

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EVOLUTION OF THE PHENOMENOLOGICALLY DETERMINED COLLECTIVE POTENTIAL ALONG THE CHAIN OF Zr ISOTOPES

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The properties of the collective low-lying states of Zr isotopes indicate that some of these states are mainly spherical and the other are mainly deformed ones. In our previous works [1,2], it was shown that the structure of low-lying collective states of ^{96}Zr can be satisfactorily described within the framework of a geometric collective model based on the Bohr Hamiltonian with a potential that supports the existence of various forms of the nucleus. Based on these results, the question arises about the possibility of investigating the properties of low-lying collective states of $^{92-102}$Zr on the basis of a five-dimensional geometric quadrupole collective model.

The quadrupole-collective Bohr Hamiltonian depending on both β and γ shape variables with a potential having spherical and deformed minima, is applied. The relative depth of two minima, height and width of the barrier, rigidity of the potential near both minima are determined so as to achieve the best possible description of the observed properties of the low-lying collective quadrupole states of $^{92-102}$Zr.

Satisfactory agreement with the experimental data on the excitation energies and the E2 reduced transition probabilities is obtained. The evolution of the collective potential with increase of A is described and the distributions of the wave functions of the collective states in $\beta-\gamma$ plane are found.

It is shown that the low-energy structure of $^{92-102}$Zr can be described in a satisfactory way within the Geometrical Collective Model with the Bohr Hamiltonian. The β-dependence of the potential energy is fixed to describe the experimental data in a best possible way. The resulting potential evolves with A increase from having only one spherical minimum in ^{92}Zr, through the potentials having both spherical and deformed minima, to the potential with one deformed minimum in ^{102}Zr. A β-dependence of the wave functions is presented in a set of figures illustrating their distribution over β [3].

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ON SHORT-RANGE CORRELATIONS IN ATOMIC NUCLEI

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Atomic nuclei, to be drops of a Fermi liquid, have a number of properties in common with liquid drops of ^{3}He atoms, as well as with electrons in metal clusters. For example, their energy levels have a similar shell structure and are characterized by the same magic numbers: 2, 8, 20 etc. [1]. Besides, they all contain an admixture of the two-fermion short-range correlations (2F-SRC) which are pairs of fermions having a momentum up to 2.5 times greater than the Fermi momentum, though a magnitude of their sum takes values expectable in the ideal Fermi gas model. The 2F-SRC arise naturally as corrections to the ideal Fermi gas model at taking into account a repulsion of fermions in the form of a non-zero scattering length at short ditances [2]. Since most of the time such fermions are in the free flight, it was natural to assume that there must also exist a quasi-free knocking out one of them from a 2F-SRC pair at its hard collision with a projectile. Until now this mechanism has been considered the most plausible at the interpretation of experimental data on the scattering of leptons and hadrons in atomic nuclei within the framework of the 2F-SRC model, see, e.g., [3,4]. Our analysis of the experiment [4], however, has shown that the nucleons of the SRC pair which had large momentum (of the order of 550 MeV/*c*) were in a mutual potential well with a depth of about 300 MeV at the instant of their knocking-out. It is easy to calculate that before entering the potential well, the nucleons must have had a momentum much less than the Fermi one. It follows from this that the generally accepted interpretation of the short-range correlations in atomic nuclei is hardly applicable.

In the presented report, the question is discussed to what extent the assumption of the existence of such a deep potential well is compatible with modern phenomenological models of the N-N interaction. It is indicated that there is a natural possibility of estimating the size of the potential well from the registration of quasi-bound states with a nonzero orbital momentum, formed by multiple reflections of nucleons from its boundary. This physical picture can be also appropriate for interpreting experimental hints on the existence of light dibaryons with a mass below the meson production threshold [5].

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STUDY OF COULOMB BREAKUP OF ^{11}BE WITHIN THE NON-PERTURBATIVE SEMICLASSICAL AND QUANTUM-QUASICLASSICAL TIME-DEPENDENT APPROACHES

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We investigate the Coulomb breakup of ^{11}Be halo nuclei on a heavy target (^{208}Pb) from intermediate (70 MeV/nucleon) to low energies (5 MeV/nucleon) within the non-perturbative semiclassical and quantum-quasiclassical time-dependent approaches.

To quantify how good the semiclassical approach with decreasing the projectile energy is, we also performed calculations with quantum-quasiclassical approach, which includes the effect of deformation of the projectile trajectory and the transfer of energy from target to projectile and vice versa during a collision. We also analyse in the frame of this model the influence of the ^{11}Be resonant states $5/2^+$, $3/2^-$ and $3/2^+$ on the breakup processes. This analysis demonstrates the possibility of studying low-lying resonances in halo nuclei using their breakup reactions. The method can potentially be useful for interpretation of low-energy breakup experiments on different targets in studying the halo structure of nuclei.

POSSIBILITIES TO IMPROVE VARIATIONAL CALCULATIONS USING OSCILLATOR BASIS

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Oscillator basis is widely used in nuclear structure studies, e. g., within *ab initio* No-Core Shell Model (NCSM) [1]. A problem faced by the NCSM calculations is an exponential grows of the many-body basis dimension and of the number of non-zero Hamiltonian matrix elements which restricts the accuracy of the results and the NCSM applicability to heavier nuclei. This difficulty can be overcome by using the complete Hamiltonian matrix up to some excitation quanta $N_{\max}$ and extending it to a larger excitation quanta $N'_{\max}$ by kinetic energy T matrix elements only (T-extension). The T-extension can be considered as a simplified version of the Symmetry-Adapted NCSM (SA-NCSM) [2] which utilizes the Sp(3,R) symmetry to extend the Hamiltonian matrix since T is one of the Sp(3,R) generator. The T-extended Hamiltonian matrix has an essentially smaller number of non-zero matrix elements and improves predictions for binding energies. The Hamiltonian matrix extended up to infinite $N'_{\max}$ in a channel that is supposed to dominate in the asymptotics of the wave function of bound state of interest, can be used to calculate the *S*-matrix by means of the HORSE formalism [3] and to locate numerically its pole associated with the bound state that makes it possible to obtain a very accurate prediction for the binding energy and asymptotic normalization coefficient (ANC). The utilization of the complete HORSE formalism within the NCSM is impractical because it requires calculation of extremely large number of the NCSM eigenstates; however, one can use its simplified version SS-HORSE [4] to design an extrapolation technique for binding energies and ANC. An interesting and important convergence acceleration of the above approaches is the smoothing of potential energy matrix elements suggested in Ref. [5]. We illustrate the above possibilities using a model problem.

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AB INITIO CALCULATIONS OF BRANCHING RATIOS OF ALPHA PARTICLES, NEUTRONS AND PROTONS IN THE DECAY OF EXCITED STATES OF BERYLLIUM ISOTOPES

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The modern theory of the structure of light nuclei is actively developing due to the introduction of ab initio (from first principles) methods of describing nuclear systems. An essential place among such methods is occupied by various versions of No-Core Shell Model (NCSM) (see, for example, [1]) that uses huge multi-nucleon bases and realistic NN potentials to describe the interaction of nucleons. Usually, these potentials are derived from Chiral Effective Field Theory. The discussed approach makes it possible to successfully describe the spectra of nuclei up to masses $A \sim 16$ in a wide range of energies.

In the literature, there are also several successful attempts to describe the total widths of the nucleon and cluster decay of nuclear states [2,3]. In our works (see Ref. [4] and Refs. therein), we developed a method that makes it possible to solve the problem of multichannel decay of nuclei and calculate the partial widths of decay into a variety of channels. The subsequent publication [5] demonstrates the efficiency of the method for unstable nuclei.

The current report presents the results of a study of the decay properties of highly excited states of beryllium isotopes. Such a detailed calculation of the spectral characteristics of these nuclei – level energies, total decay widths and branching ratios of decays into radically different channels in a wide energy range has been carried out for the first time. A large list of predictions is given.

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AB INITIO STUDY OF RADII AND COULOMB SHIFTS OF SIX-NUCLEON ISOBAR ANALOGUE STATES

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The problem of describing the size parameters (matter, charge, neutron radii) of nuclei attracts a wide range of researchers. The size parameters of exotic nuclei have the greatest physical significance.

In the theoretical studies of light nuclei significant role is occupied by ab initio (from first principles) methods of describing nuclear systems. An important place among such methods is taken by different versions of No-Core Shell Model (NCSM) [1]. Two different NN-potentials are exploited in the calculations, the first of which was obtained from the chiral effective field theory [2], and the second one – from nucleon-nucleon scattering data using the *J*-matrix inverse scattering method [3]. Both of these potentials are universal, they have been tested in calculations of binding energies, spectra, and other characteristics of nuclei.

In the current work material, charge, and neutron radii as well as Coulomb shifts of isobar analogue states of six-nucleon systems are computed and compared. These values and rate of their convergences with the grows of used basis size allow one to obtain some information about the properties of nuclear matter in the peripheral region of weakly coupled nuclear systems.

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SS-HORSE APPROACH: FURTHER DEVELOPMENT AND APPLICATION TO THE STUDY OF LIGHT NUCLEI

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We have proposed the SS-HORSE approach [1] which makes it possible to calculate scattering phase shifts and *S*-matrix based on variational results in the oscillator basis. Within SS-HORSE, one can locate the *S*-matrix poles to obtain resonance parameters [1] and improve the description of bound states [2].

We discuss the results of our recent applications of the SS-HORSE approach combined with the No-Core Shell Model (NCSM) to the studies of resonant states in exotic light nuclei. In particular, we present calculations of resonances in ^{7}He nucleus with realistic *NN* interactions JISP16 [3] and Daejeon16 [4]. The energies and widths of ^{7}He resonances are calculated in the channels of elastic scattering of neutron by ^{6}He nucleus in the ground and first excited 2^+ states. With Daejeon16 we obtain generally smaller or the same resonance energies and widths than with JISP16; however, the results obtained with these *NN* interactions agree with each other and with available experimental data on $3/2_1^-$, $1/2^-$, and $5/2^-$ resonances in ^{7}He. We obtain also wide overlapping resonances $3/2_2^-$, $3/2^+$, and $5/2^+$ which make up an experimentally observed resonance of unknown spin-parity at the energy of 6.2 MeV with the width of 4 MeV [5].

We perform also NCSM calculations with Daejeon16 of the ^{9}Li nucleus and use the SS-HORSE to improve description of its bound state energies and to obtain asymptotic normalization coefficients in these states. The ground state energy is well described while the excitation energy of the first excited state is overestimated. Resonant ^{9}Li states are examined in the channels of elastic scattering of neutrons by ^{8}Li in the ground and first excited states. We obtain $5/2^-$, $3/2^-$, and $7/2^-$ resonances with energies and widths in good correspondence with experimentally observed resonances in ^{9}Li which spin-parities are unknown.

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SEARCH FOR ALPHA-CONDENSATE EFFECTS IN DISSOSIASION OF RELATIVISTIC NUCLEI

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The BECQUEREL experiment is aimed at solving topical problems in nuclear cluster physics [1]. Due to its unique sensitivity and spatial resolution the used method of nuclear track emulsion (NTE) makes it possible, to study in a unified approach multiple final states arising in the dissociation of relativistic nuclei. The focus is a concept of α-particle Bose-Einstein condensate (αBEC) – the extremely cold state of several S-wave α-particles near the coupling threshold. The unstable ^{8}Be nucleus is described as 2αBEC, and the $^{12}C(0^+_2)$ excitation or Hoyle state (HS) as 3αBEC. The state $^{16}O(0^+_6)$ above the 4α threshold, considered as 4αBEC, can sequentially decay $^{16}O(0^+_6) \to \alpha^{12}C(0^+_2)$ or $^{16}O(0^+_6) \to 2^8Be(0^+)$.

In NTE layers longitudinally exposed to relativistic nuclei the invariant mass of ensembles of He and H fragments can be determined from the emission angles in the approximation of conservation of initial momentum per nucleon. ^{8}Be and HS decays, as well as $^9B \to {}^8Be\,p$ decays, are identified in fragmentation of light nuclei by an upper constraint on the invariant mass [2]. Photos and videos of characteristic interactions are available on the site http://becquerel.jinr.ru/. This approach has been used to identify ^{8}Be and HS and search for more complex states of αBEC in fragmentation of medium and heavy nuclei. Recently, based on the statistics of dozens of ^{8}Be decays, an enhancement in the probability of detecting ^{8}Be in an event with an increase in the number of relativistic α-particles in it was found [3]. A preliminary conclusion is drawn that the contributions from ^{9}B and HS decays also increase. The exotically large sizes and lifetimes of ^{8}Be and HS suggest the possibility of synthesizing αBEC by successively connecting the emerging α-particles $2\alpha \to {}^8Be$, $^8Be\alpha \to {}^{12}C(0^+_2)$, $^{12}C(0^+_2)\alpha \to {}^{16}O(0^+_6)$, $2^8Be \to {}^{16}O(0^+_6)$ and further with a decreasing probability at each step, when γ-quanta or recoil particles are emitted. Nowadays, the main task is to clarify the relation between the appearance of ^{8}Be and HS and the multiplicity of α-ensembles and to search on this basis for decays of the $^{16}O(0^+_6)$ state. In this regard, the BECQUEREL experiment aims to measure multiple channels of ^{84}Kr fragmentation at energies up to 950 MeV per nucleon. There are a sufficient number of NTE layers, the transverse scanning of which on a motorized microscope makes it possible to achieve the required statistics. A status of the ongoing research is presented.

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EXTRAPOLATION OF THE LOWEST STATE ENERGIES IN SUPERHEAVY EVEN-EVEN NUCLEI

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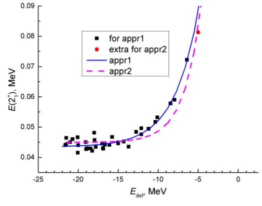
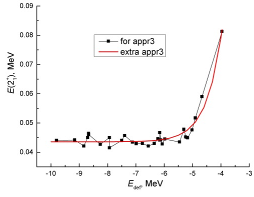
In this report the various approaches [1,2,3] to the 2_1^+ state energy estimations for superheavy nuclei are discussed. In [1,2], for even-even nuclei, a correlation between the 2_1^+ state energies and the deformation energies was found and parametrization of the correlation curve was obtained. For determination of extrapolation parameters the experimentally known energies of 2_1^+ states were applied. If the proposed parametrization is successful, then it can be used to predict the unknown 2_1^+ energies. For such prediction it is necessary to have data on deformation energies obtained within the framework of a unified technique. In different versions of the calculation, the deformation energies may differ, but its correlations with the 2_1^+ energy – remain. In different versions of the calculation the deformation energies differ, but this leads only to a change in the scale along the energy axis, and don't change the form of the correlation curve. Our estimations show, than determination of the unknown energies 2_1^+ for superheavy nuclei from the correlation curve have the accuracy corresponding to the accuracy of the discussed extrapolation curves. In [3] the microscopic variant of the Grodzins relation derived based on the geometrical collective model and a microscopic approach to the description of excitation energies of the 2_1^+ states for $Z > 100$ nuclei. In this case, the starting point of the prediction is not the deformation energy, but the value of the deformation parameter.

In this paper, we consider several variants [4, 5] of the deformation energy calculations. Obtained extrapolations are presented in two figures. At the first the deformation energies in accordance with [4] and two extrapolations are considered – without and taking into account nuclei with 2_1^+ state energies greater than 60 keV. The second figure shows the extrapolation according to the data from [5]. From the presented correlation curves, the estimations of the unknown energies of lowest states are obtained.





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ROTATIONAL SPECTRA OF EVEN-EVEN ACTINIDE AND RARE-EARTH NUCLEI

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An approach based on the idea that the spinning nucleus being stretched out along the symmetry axis under the influence of some sort of centrifugal force has been proposed. Our approach led to the modified formula to describe the dependence of the moment of inertia on the angular momentum. This formula has shown a good fitting up to I=16 for all even-even nuclei in the atomic mass range 150<A<190 and 228<A<248 whose energy ratio range between 2.9 and 3.33.

In the strong coupling adiabatic model, Bohr and Mottelson [1] showed that the rotational spectrum is given by the simple formula

$$E_I = E_0 + \frac{\hbar^2}{2\Im}\left[I(I+1) - K^2\right]. \quad (1)$$

Two different explanations to interpret such deviations were proposed; in one of them such deviations were assumed to be produced from the rotation-vibration interaction. The authors in this group suggest E_I to be written in terms in powers of $I(I+1)$ as [2]:

$$E_I = AI(I+1) + B\left[I(I+1)\right]^2 + C\left[I(I+1)\right]^3 + D\left[I(I+1)\right]^4 + \ldots \quad (2)$$

where A, B, C D,… are parameters, which can be determined by fitting this equation with the experimental data. The ground rotational bands of actinide and of rare–earth even-even nuclei were analyzed using the first four terms of Eq. (2) in reference [3], where the parameters A, B, C, and D were obtained using the least–squares method.

The rotational energy of actinide and of rare–earth even-even nuclei have been calculated by

$$E(I) = \frac{\hbar^2 I(I+1)}{2J_I} = \frac{\hbar^2 I(I+1)}{2J_0\left[1 + \frac{5}{4\pi}\frac{\hbar^2 I(I+1)}{4J_0 C + \frac{5}{4\pi}\hbar^2 I(I+1)}\right]} \equiv \frac{AI(I+1)}{\left[1 + \frac{BI(I+1)}{1 + BI(I+1)}\right]}, \quad (3)$$

we will call this Eq. (3) quantized $\beta-$ stretching equation. The simple expression Eq. (3), has been used to evaluate the level energies up to spin I=16. The parameters A and B have been determined by the least square fitting method involving the first three experimentally measured energy levels (i.e., I=2, 4,

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PROBING MICROSCOPIC PROPERTIES OF SUPERDEFORMED NUCLEI

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We analyse superdeformed (SD) bands in ^{192}Hg with the help of modified variable moment of inertia (VMI) model [1,2]. In this, we obtain the values of unknown band-head spin (I_0) along with the level spin. The band-head spin so estimated is not known experimentally in band-3. A total of 3 experimentally known SD bands of ^{192}Hg have been analyzed. Quantitatively good results of the γ energies and the spins for Hg band are successfully obtained. The band-head spin for the ^{192}Hg (b3) superdeformed band is reported. We propose the spin assignments and level energies of the ^{192}Hg (b3) as an essential outcome of this work. It has now been resolved the tentative nature of the assignments and present a unique level scheme. These outcomes are important in near future experiments.

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THE FAYANS ENERGY-DENSITY FUNCTIONAL. NEW CONSTRAINTS FROM THE EQUATIONS OF STATE

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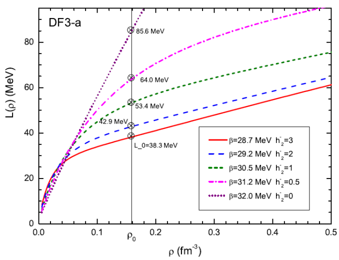
The equations of state for infinite, symmetric nuclear matter and pure neutron matter are analyzed in terms of the Fayans energy density functional parameters: $a^{+,-}_{1,2}$, $h^{+,-}_{1,2}$. Fitting procedure of the DF3-a functional [1] is redone involving the previously unused parameter h^{-}_{2}. Additional constraint is implemented from the upper bound of the giant dipole resonance energy in ^{208}Pb. A quality of the previous global fit of the Fayans EDF has been basically kept for the nuclear densities, masses of nuclei, single-particle levels and charge radii. Recently the constraints on symmetry energy and its derivative has been obtained in [6] using the data on nuclear masses, results of ab initio calculations with N3LO, ΔRnp values from PREXP-II, CREX experiments, as well as the latest data from the radii of neutron stars and registration of gravitational waves. The symmetry energy slope at saturation $L(\rho_0)$ calculated for different h^{-}_{2} with the relativistic corrections taken into account (Fig.1) is compared with its allowable range derived from the set of restrictions [6]. As it can be seen, for DF3-a, the EOS is softer than the ones obtained from the $FANDF^0$ functional [2], as well as from APR [3], AFDMC [4], N2LO(D2,E1) and N2LO(D2,Eτ) [5] (Fig.2).

Supported by the grant of Russian Scientific Foundation (RSF 21-12-00061).



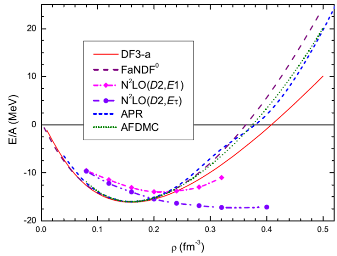


Fig.1. The L(ρ) for symmetric nuclear matter. Calculation with the DF3-a functional for various value of parameter h_{-2} . Fig. 2. Energy per nucleon for a symmetrical nuclear mater (SNM) as a function of density. our calculation with the $FaNDF^0$[1], DF3-a[2] as well as for APR [3], AFDMC [4], N2LO[5] functionals.

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NEUTRON MULTIPLICITY OF TRANSPLUTONIUM NUCLEI

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The calculations of neutron multiplicity distributions were carried out with the improved scission point model (ISPM) [1] for ^{252}Cf, ^{248}Cm, and ^{246}Fm nuclei. Within the ISPM the probabilities of formation of different scission configurations as well as the available excitation energy at scission were found based on the calculation of the potential energy as a function of mass and charge numbers of the fragments and their deformation parameters. In order to account for pre-equilibrium effects, the energy distribution between fission fragments and evolution of the deformation of the fragments are taken into consideration. The necessity of account for pre-equilibrium processes for the considered nuclei is discussed. The results are compared with the experimental data provided in Ref. [2] and with other models [3]. The average number of neutrons per spontaneous fission process and the corresponding uncertainties are presented.

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QUANTUM-QUASICLASSICAL APPROACH FOR FEW-BODY PROBLEMS IN ATOMIC AND NUCLEAR PHYSICS

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We discusses the efficient quantum-quasiclassical method developed by V.S. Melezhik with co-authors [1–4], which has been successfully applied to calculate various few-body processes and has made it possible to resolve a number of topical problems in atomic [1,3–5], mesoatomic [2], and nuclear physics [6]. In this approach, a few-body quantum problem is reduced to the simultaneous integration of a system of coupled quantum and classical equations: the time-dependent Schrödinger equation, which describes the quantum dynamics of slow light paricles, and the classical Hamilton equations, describing the fast variables of heavy particles.

Recently [5], the approach was extended and adapted for quantitative description of pair collisions of light slow Li atoms with heavy Yb^{+} ions in the confined geometry of the hybrid atom-ion trap. On the basis of these calculations, a new method for sympathetic cooling of ions in a RF Paul trap was proposed: to use cold buffer atoms for this purpose in the region of atom-ion confinement-induced resonance [5].

This approach also made it possible to perform calculations of the breakup cross sections into the low-energy region (up to 10 MeV/nucleon), inaccessible so far to other methods, for the ^{11}Be breakup on a heavy target [6].

The developed quantum-quasiclassical method opens new possibilities in the investigation of other hot few-body quantum systems.

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HYDROGEN ATOM IN STRONG ELLIPTICALLY POLARIZED LASER FIELDS WITHIN DISCRETE-VARIABLE REPRESENTATION

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The nondirect product discrete variable representation (npDVR) is developed for the time-dependent Schrödinger equation with non-separable angular variables and is applied to a hydrogen atom in elliptically polarized strong laser fields. The 2D npDVR is constructed on spherical harmonics orthogonalized on the 2D angular grids of the Popov and Lebedev 2D cubatures for the unit sphere [1]. With this approach we have investigated the dynamics of a hydrogen atom initially in its ground state in elliptically polarized laser fields with the intensity up to I=10^{14} W/cm^2 and wavelength of λ=800 nm. For these parameters of the laser field and the entire range of ellipticity variation, we have calculated the total excitation and ionization yields of the atom. The performed analysis of the method convergence shows that the achieved accuracy of our calculations significantly exceeds the accuracy of recent works of other authors relevant to the problem [2], due to the high efficiency of the 2D npDVR in approximating the angular part of the 3D time-dependent Schrödinger equation. We also propose a new simple procedure for infinite summation of the transition probabilities to the bound states of the hydrogen atom in calculating the total excitation yield and prove its accuracy by comparison with conventional methods. The obtained results show the potential prospects of the 2D npDVR for investigating atomic dynamics in even stronger laser fields, where it is required to go beyond the dipole approximation and take into account relativistic effects.

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THE REPROJECTION METHOD FOR INELASTIC COLLISION PROCESSES

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The standard Born-Oppenheimer approach to theoretical treatments of inelastic collision processes is the most widely used approach, despite many other methods have been proposed as well. It solves the problems into two steps: (1) the electronic structure calculations for fixed nuclei, and (2) nonadiabatic nuclear dynamical studies based on the potentials and couplings computed at the first step. Various quantum methods have been developed for the both steps and applied to a large variety of collisional partners (atoms, ions, molecules, clusters, etc) and to a huge number of physical processes. The approach looks to be well developed and reliable.

However, the detailed analysis shows that the conventional applications of the Born–Oppenheimer approach encounter severe problems. They are: ambiguity of nonadiabatic couplings and coupled channel equations, nonvanishing asymptotic nonadiabatic couplings, divergence of state-to-state transition probabilities and cross sections with respect to some parameters of problems, to mention a few. The most severe is probably nonzero asymptotic couplings. In the past, these and other problems have been ignored as being negligible, and final results (transition probabilities, cross sections, rate coefficients) were assumed to have low error bars, since usual practical calculations were performed with a number of approximations. The development of modern computer facilities and soft wear allow one to increase accuracy of calculations. Nevertheless, [1] shown that attempts to extend parameters of calculations within the conventional application of the Born-Oppenheimer approach result in divergence instead of expected convergence, and the results have no sense.

The reprojection method [1–3] within the standard Born-Oppenheimer approach solves the problems. It treats the nonadiabatic nuclear dynamics with nonzero asymptotic nonadiabatic coupligs, as they come from ab initio electronic structure calculations. In addition, the method distinguishes interatomic and internuclear distances, as well as the scattering channels and molecular states. It turns out that the nonzero asymptotic couplings are responsible for correct asymptotic wave functions. Moreover, Ref. [4] shows that the correct asymptotic wave functions can be constructed from the coupled asymptotic solutions of the dynamical equations.

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PECULIARITIES OF THE ENERGY SPECTRUM OF THE ^{12}C NUCLEUS IN A 3α MODEL

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The aim of present work is to study peculiar properties of the ^{12}C(0^+) and ^{12}C(2^+) energy spectrum associated with removal of Pauli forbidden states from the 3α functional space. A deep $\alpha\alpha$-potential of BFW [1] will be employed which has two Pauli forbidden states in the *S* wave and a single forbidden state in the *D* wave. A variational method on symmetrized Gaussian basis is employed. For the elimination of the 3α Pauli forbidden states we use the same direct orthogonalization method from [2]. As a possible origin of non-analytical behavior of the ^{12}C spectrum, consequences of the quantum phase transition (QPT) in the ^{12}C nucleus will be discussed.

The direct orthogonalization method [2] is based on the separation of the complete Hilbert functional space into two parts. The first subspace L_Q, which we call allowed subspace, is defined by the kernel of the complete three-body projector $\hat{P}$. The rest subspace L_P contains 3α states forbidden by the Pauli principle. After the separation of the complete Hilbert functional space of 3α states into the L_Q and L_P subspaces, at next step we solve the three-body Schrödinger equation in L_Q.

In Fig. 1 we display the calculated lowest 0^+ spectrum of the ^{12}C nucleus as a function of ϵ, the maximal allowed eigen value of the Pauli projection operator.

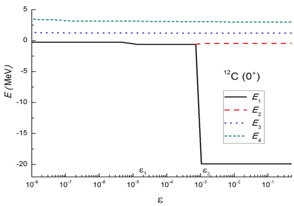

Fig. 1. Energy spectrum of ^{12}C(0^+) as a function of ϵ.

As can be seen from the figure, there exist a special eigen value of the projector $\hat{P}$, which play a decisive role for the 0^+ energy spectrum of the ^{12}C nucleus. The corresponding eigen state of $\hat{P}$ creates a ground state of ^{12}C in a deep phase, while from the left side of this point the lowest energy is close to the energy of the Hoyle state. The situation in the 2^+ spectrum is similar.

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BEHAVIOR OF MOMENT OF INERTIA IN HIGHLY DEFORMED ^{24}Mg AND ^{20}Ne

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We suggest the self-consistent description of the ground-state moment of inertia (MI) in highly prolate light nuclei ^{24}Mg and ^{20}Ne (with experimental equilibrium axial quadrupole deformations β_2=0.605 and 0.72, respectively [1]). These nuclei provide an interesting opportunity to explore dependence of MI on the pairing, ground-state correlations and nuclear shape at extreme deformations. The calculations are performed with Skyrme forces SVbas, SkM*, and Sly6 for deformation range $0.3 < \beta_2 < 0.9$. Three approaches are applied [2]: Inglis-Belyaev (within Hartree-Fock-Bogoliubov method), QRPA Thouless-Valatin (within Quasiparticle Random-Phase Approximation method [3]) and ATDHF (Adiabatic Time-Dependent Hartree Fock method). For Inglis-Belyaev and ATDHF calculations, the code SKYAX [4] was used. All three approaches show that, near the equilibrium deformation, the pairing in ^{24}Mg and ^{20}Ne vanishes and we get the maximum of MI. With further grow of the deformation above the equilibrium values, we see decrease of MI. Such behavior of MI is explained by rearrangement of single-particle levels with deformation. The analysis reveals main two-quasiparticle contributions responsible for the behavior of MI in different regimes.

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INTERPLAY OF ORDER AND CHAOS IN NUCLEAR STRUCTURE

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We demonstrate the universality of the Random Matrix approach as a tool to detect the chaos-order transition in atomic nuclei. In particular, shell structure phenomenon in octupole deformed nuclei is discussed as the example of the interplay of regular and chaotic dynamics within the harmonic oscillator model with octupole deformations as the effective nuclear structure shell model [1]. It is shown that the chaos-order transition can occur at certain conditions which give rise to dynamical symmetries in chaotic dynamics of nucleons, and may explain the dominance of prolate nuclear shape in nature.

Naturally, one would expect that chaotic component of intrinsic structure of a finite many-body quantum system, exhibited in its spectral properties at low excitation energy, may transform from the secondary constituent to the dominant one in basic characteristics of the considered system with increase of the excitation energy. This might be primarily true in the description of decay widths of nuclear giant dipole resonances, highly excited collective states which centroids are located above the neutron threshold. Indeed, our analysis of the dipole strength distribution in the lead region indicates on the onset of statistical properties close to those of the Gaussian Orthogonal Ensembles. We show that employment of the random distribution for the coupling between microscopic one-phonon states and two-phonon states, generated by the Gaussian Orthogonal Ensembles distribution, gains a better insight into the description of general properties of the spreading widths [2].

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STUDY OF NUCLEAR MATTER DENSITY DISTRIBUTION IN LIGHT EXOTIC NUCLEI FROM PROTON ELASTIC SCATTERING IN INVERSE KINEMATICS

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The proton-nucleus elastic scattering at intermediate energies is a well-established method of investigating the nuclear matter distribution in stable nuclei. When performed in inverse kinematics with radioactive beams, it can be applied to the investigation of unstable nuclei as well.

Recently, differential cross sections for small-angle proton elastic scattering on the ^{12,14}Be [1], ^{8}B [2] and $^{14\text{-}17}$C [3] nuclei were measured in inverse kinematics using secondary radioactive beams with energies near 700 MeV per nucleon produced with the fragment separator FRS at GSI, Darmstadt. The main part of the experimental setup was the active target IKAR, which was used for recoil protons detection. Auxiliary detectors for projectile tracking and isotope identification completed the setup. The measured differential cross sections were analyzed using the Glauber multiple scattering theory. For the evaluation of the data several phenomenological nuclear matter density parametrizations were used. The nuclear matter radii and radial density distributions were deduced. Extended nuclear matter density distributions were observed in ^{12,14}Be isotopes and halo structure of ^{14}Be was confirmed. Proton halo structure was observed for ^{8}B. A possible neutron halo structure in ^{15,16}C and ^{17}C is discussed.

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NUCLEAR DATA AND THE STANDARD MODEL PARAMETRS

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We consider fundamental aspects of nuclear physics and particle mass spectrum. The Standard Model with representation: $SU(3)_{col} \times SU(2)_L \times U(1)_Y$ [1] is the basic theory of all interactions. The Nonrelativistic Constituent Quark Model is a part of hadronic physics – an important component of the Standard model. The main NRCQM parameters are the pion mass m_π = 140 MeV, the initial constituent quark mass $M_q = m_\Xi / 3 = m_e(\alpha/2\pi)^{-1}$ = 441 MeV, introduced as "gammon" by P. Kropotkin, and the standard estimate of the constituent quark mass $M^\omega_q = m_\omega/2$ = 391 MeV, were recently confirmed by the observation of the exact representation of the nucleon masses by integers m_e and an additional shift $dm = k\ (\delta m_N/8)$ with $k = 1$ and $k = 9$ for neutron and proton, respectively (CODATA relations [1] with $\delta m_N = m_n - m_p$):

$m_n = 115\cdot16m_e - m_e - \delta m_N/8$; $m_p = 115\cdot16m_e - m_e - 9(\delta m_N/8)$; $dm_\pi = (\alpha/2\pi)m_\pi$.

These relations contain integer representation of particle masses with a period $16m_e = \delta$: $m_\mu = 13\delta - m_e$, $m_\pi = 17\delta + m_e$, $M^\omega_q = 3\cdot16\delta = 48\delta$, $M_q = 3\cdot18\delta = 54\delta$.

The QED radiative correction $\alpha/2\pi = 116\cdot10^{-5}$ (together with fermion masses) is an important parameter of the Standard model and is responsible for the influence of physical vacuum on the magnetic moment and particle mass [1,2].

Stable nuclear intervals 161 keV = $\delta m_N/8$, 1293 keV = δm_N and 3067 keV = $6m_e$ were found as maxima in independent spacing distributions in many nuclei. The interval 3067 keV / 2 = $3m_e$ is close to m_d / 3 (m_d = 4670(48) keV). The mass of *c*-quark m_c = 1270(20) MeV is close to $9m_\pi$, and the mass of *b*-quark m_b = 4180(30) MeV is close to $9M_q$. The analysis of particle masses and nonstatistical effects in nuclear data, carried out in the 1960s, showed the coincidence of the ratios between the electron mass m_e (the main parameter of the Standard model) and the mass of the constituent quark M_q with QED radiative correction $\alpha/2\pi = 115.96\cdot10^{-5}$. Simultaneously, the same relationship was found empirically between the stable intervals of fine (ε` = 1.2 eV) and hyperfine (ε`` = 1.34 eV = 5.5 eV/4) structures in neutron resonances and nuclear levels in the works of IAE and ITEP. In this paper, we show confirmation of the dimensionless ratio, close to the QED radiative correction, in modern high-precision data on neutron resonances ^{232}Th, ^{234}U, ^{238}U and $^{240\text{-}242}$Pu [3]. Correlation analysis of nuclear data provides independent confirmation of integer relations in parameters of Standard model, a theory of all interactions.

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4G MODEL OF FITTING RMS RADIUS OF PROTON

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In our 4G model of final unification [1,2,3,4], along with three large atomic gravitational constants pertaining to electromagnetic, strong and weak interactions, we have proposed the existence of a strong nuclear charge of magnitude $e_s \cong 2.9463591e$ and existence of electroweak fermion of rest energy $M_w c^2 \cong 584.725$ GeV [5]. With reference to protons, pions and weak bosons, we noticed that, $\frac{m_p}{M_w} \cong \frac{\sqrt{(m_\pi)^0 (m_\pi)^\pm}}{\sqrt{(m_z)^0 (m_w)^\pm}} \cong 0.0016$ and this number seems to play a crucial role in understanding nuclear stability and binding energy [6]. Increasing number of free nucleons, increasing nuclear radii and increasing asymmetry about stable mass number play important role in reducing the nuclear binding energy. Unified binding energy coefficient can be expressed with, $B_0 \cong \sqrt{\left(\frac{e_s^2}{8\pi\varepsilon_0 (\mathrm{h}/m_p c)}\right)\left(\frac{e^2}{8\pi\varepsilon_0 (\mathrm{h}/m_p c)}\right)} \cong 10.1\ \mathrm{MeV}$. A four term nuclear binding energy relation for $(Z \geq 3 \text{ and } \mathrm{N} \geq Z)$ can be expressed as

$BE \cong \left\{ A - \left[1 + \left(0.0016 \left(\frac{Z^2 + A^2}{2} \right) \right) \right] - A^{1/3} - \frac{(A_s - A)^2}{A_s} \right\} (10.1 \text{ MeV})$ where $A_s \cong 2Z + 0.0016(2Z)^2 \cong 2Z + 0.0064Z^2$ = Estimated mass number close to stability zone. Based on these relations, we noticed a relation for fitting RMS radius of proton as, $R_p \cong \sqrt{\frac{4\pi\varepsilon_0 \text{h}^3}{e_s^2 m_p^2 c}} \cong \sqrt{\frac{\alpha_s}{\alpha}} \left(\frac{\text{h}}{m_p c} \right) \cong 0.835 \text{ fm}$ where $\alpha_s \cong 0.1152$ represents the strong coupling constant. It needs further study.

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IS ELECTROWEAK INTERACTION – A KIND OF COSMOLOGICAL LAMBDA TERM IN MAINTAINING NUCLEAR EXISTENCE AND STABILITY?

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Considering the interaction scheme associated with Up quarks, Down quarks and pions and interaction scheme associated with electroweak bosons, we have developed a new model of nucleus. We would like to emphasize the point that atomic nucleus cannot exist without the support of electroweak interaction. Clearly speaking, analogous to the cosmological Lambda term, electroweak interaction helps in maintaining the existence of atomic nucleus without collapsing due to strong interaction. Interesting points to be noted are: 1) Up quark and Down quark play a vital role in understanding nuclear structure. 2) Mass ratio of pions and weak bosons is 0.0016 and it is approximately twice the product of Fine structure ratio and strong coupling constant. 3) Twice the proton number and the coefficient 0.0016 play a significant role in understanding nuclear stability line. 4) Currently believed harmonic oscillator coupling and spin-orbit coupling seem to be a natural manifestation of Up and Down quark arrangement. 5) Number range associated with harmonic oscillator coupling and spin-orbit coupling can be considered as a representation of mass number range of a proton number having magic behaviour. 6) Coefficient of proportionality being 0.0016, number of free nucleons increases with half the sum of squared number of protons and squared number of nucleons. 7) Increasing number of free nucleons, increasing nuclear radii and increasing asymmetry about stable mass number play an important role in reducing nuclear binding energy. 8) Nuclear binding energy can be addressed with four simple terms and single energy coefficient. 9) Unified nuclear binding energy coefficient is associated with the average rest energy of 3 Up quarks and 3 Down quarks. 10) Nuclear stability line, proton drip lines and neutron drip lines can be understood in a unified approach.

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DYNAMIC THREE-QUASIPARTICLE CORRELATIONS IN THE GROUND STATE

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Earlier, three-quasiparticle correlations in the ground state (GSC_3) were studied in [1,2] for static characteristics in the calculations of quadrupole moments in first excited 2^+ and 3^- states of Sn isotopes. Here we discuss GSC_3 for transitions with the energy $\boldsymbol{\omega} \neq \mathbf{0}$ between these excited states. Calculations were performed for a large number of Sn isotopes. It was shown that, similar to the [1,2,3] results, and to the contrary to GSC_2 of the RPA case, GSC_3 give a considerable contribution to the B(E1) values for transitions between first excited 2^+ and 3^- states. However, there is a specifity for the pairing case: it turned out that here the GSC_3 role is decreased as compared with the static case [1,2], but nevertheless it is rather noticeable. A comparison with the similar physical problems within the Quasiparticle-Phonon Model was performed.

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LITHIUM-10 AS BORROMEAN NUCLEUS SUBSYSTEM

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The Borromean system have a wide spread near nuclear driplines. These systems are of strong interest for theoretical and experimental studies because of their exotic properties, such as strong nuclear matter asymmetry and anomalous nuclear density (halo effect).

The cluster three body models usually provide good description of the borromean nuclei structure. In particular, three-body model reproduce nuclear halo effect and anomalous matter radius for bound states of borromean nuclei and partial width for two-proton / two-neutron decays for continuum states. Obviously, cluster models require accurate treatment of interaction between clusters. When one have reasonable description for nucleon-nucleon interaction, treatment of interaction of the core (which is also dripline nucleus) with nucleon is complex problem.

On example of nuclear system ^{10}Li and ^{11}Li two quite general problems will be discussed: how structure of borromean system connected with structure of it binary subsystems; and how interaction in binary subsystems can be experimentally studied.

STUDY OF THE BETA DECAY STRENGTH FUNCTION STUCTURE BY TAGS AND HIGH RESOLUTION NUCLEAR SPECTROSCOPY METHODS

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The β-decay 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 for the Gamow-Teller (GT) β-transitions describes $[\pi p \otimes \nu h]1^+$ or $[\nu p \otimes \pi h]1^+$ excitations. Successful applications of the total absorption γ-spectroscopy (TAGS) for $S_\beta(E)$ resonance structure study and methods of TAGS spectra analysis were summarized in [1]. Development of the experimental technique allows application of methods of nuclear spectroscopy with high energy resolution for the $S_\beta(E)$ fine structure measurement [2–5]. It was demonstrated [2–6] that the high-resolution nuclear spectroscopy methods give conclusive evidence of the resonance structure of $S_\beta(E)$ both for the GT and First Forbidden (FF) β-transitions. High-resolution nuclear spectroscopy methods [3–6] made it possible to observe 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 *M*1 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 [9] of the weak axial-vector constant g_A^{eff}, and 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 discussed.

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RELATIVISTIC INVESTIGATION OF LOW NUCLEON SYSTEMS IN THE FORMALISM OF BETHE-SALPETER-FADDEEV

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The relevance of the study of few-nucleon systems is motivated by the fact that there is a large amount of experimental data for the reactions of nucleon scattering on deuterons, both elastic and inelastic. New corresponding experiments with increased accuracy and at high energies are also planned (JLab, NICA). Accordingly, a theoretical study is required. There are a large number of theoretical studies of three-nucleon systems, but at low and medium energies. Most of them are based on the Faddeev equation and its modifications. One of the main problems of modern physics of low-nucleon systems is their theoretical study at high energies. One of the approaches used in this paper to study few-nucleon systems (primarily three-nucleon nuclei) is the Bethe–Salpeter–Faddeev (BSF) formalism [1–2]. Within the framework of this approach, the binding energy of three-nucleon nuclei and their electromagnetic form factors were calculated [3–6]. The calculations were carried out using various nucleon-nucleon interaction potentials and various models of nucleon form factors. Comparison of these calculations with calculations within the framework of other approaches and with experimental data shows that these studies are in good agreement with experiment. So for the binding energy of the triton, the experiment gives the value 8.48 MeV, the solution of the nonrelativistic equation – 11.55 MeV, the calculation using the BSF equation – 8.44 MeV, which is much closer to the experiment. Based on this, one can reasonably assume that this approach will lead to valuable results in the case of scattering reactions as well.

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INCOHERENT NEUTRAL PION PHOTOPRODUCTION ON THE TENSOR-POLARIZED DEUTERON AT VEPP-3

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The results of measurement of the T_{20} component tensor analyzing powers in incoherent π^0-meson photoproduction on the deuteron in the proton energy range of 50–150 MeV are presented. Experimental statistics of the reaction under study was isolated from the experiment that was designed to investigate coherent neutral pion photoproduction on deuteron [1-3]. In this experiment, protons and two photons were recorded by the upper and lower arms of the detecting system, respectively. The measured asymmetries of the yields with regard to the change in the sign of tensor polarization of deuterons were used to calculate the T_{20} component of the tensor analyzing power of the reaction under investigation. A detailed description of the experimental setup and detection equipment is provided in [1–3].

The obtained experimental data are compared with the results of statistical simulation. The event generation was followed by verification that it belongs to the permissible region of the kinematic phase space. After the generation of independent kinematic variables, the reaction amplitude was calculated. The model described in [4] was used to calculate the amplitude of the neutral pion photoproduction. In the framework of the model, the quasi-free pion photoproduction on nucleons that form the deuteron and the contribution of nucleon-nucleon and pion-nucleon rescattering were considered. The measurements cover the photon energy range of (300–600) MeV. In general, there is a qualitative agreement between experimental and available theoretical predictions. It is planned to give further attention to extraction of the experimental data on the reaction from the experimental statistics accumulated at VEPP-3 in 2021 using the photon tagging system.

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DEFORMATION PROPERTIES AND NUCLEAR RADII OF Hg ISOTOPES

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The deformation properties of the long chain of Hg isotopes: deformation energies, quadrupole moment and charge radii are calculated. The deformed HFBTHO framework [1] is employed with the Fayans energy density functional FANDF^0 [2] in the approximation $\rho_{ch}(r) \simeq \rho_p(r)$ [3]. It turns out that heavy isotopes ^{204}Hg – ^{208}Hg have spherical form in the ground state (g.s.). In the medium region ^{188}Hg – ^{200}Hg a weakly deformed oblate form in the g.s. appears along with a weakly deformed prolate form in a metastable state (Fig.1). The calculated quadrupole moments of ^{187}Hg, ^{189}Hg, ^{191}Hg, ^{193}Hg agree well with the experimental data confirming oblate deformation of the g.s. in this region. In the domain of the ^{178}Hg – ^{186}Hg we predict two metastable states with weakly and strongly prolate form and the g.s. with weakly deformed oblate form. It is shown (Fig.2) that the g.s. of odd isotopes ^{181}Hg, ^{183}Hg, ^{185}Hg should have strongly prolate form indicating a subtle competition between different energy minima [4]. Anomalous odd-even staggering of the radii may be modulated by occupancy of neutron orbitals in odd- and even-A partners augmented by quasiparticle-phonon coupling in odd-A nuclei [5]. For the other isotopes the experimental charge radii are reproduced showing the kink region near N=126. Supported by the grant of Russian Scientific Foundation (RSF 21-12-00061).

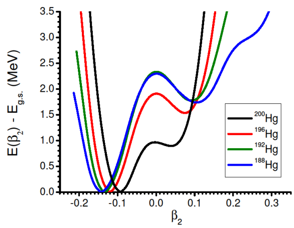
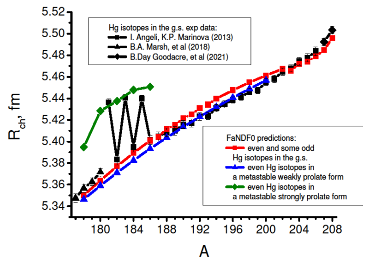


Fig.1: Energy as a function of the quadrupole deformation parameter



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DEPENDENCE OF THE CONVERSION WIDTHS ON THE FINE STRUCTURE OF THE ELECTRON SHELL

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Usually internal conversion (IC), and IC coefficients (ICC) in particular, are considered under the assumption of a closed shell of the initial atom. Its angular momentum is then zero. As a rule, this approximation is sufficient for the purposes of experiment in neutral atoms or ions of low multiplicity. However, modern experiments on storage rings, for example, in GSI or Lanzhou, are carried out with few-electron ions, for example, with helium (He)- or lithium (Li)-like ones. In this case, the electron shell has an angular momentum other than zero, which will certainly affect the probability and coefficient of the IC. To illustrate, consider as an example a *E*2 transition of a nucleus from the initial excited state with spin $I_1 = 2$ to the final state with spin $I_2 = 0$ in a beryllium-like ion $1s^2 2s 2p_{1/2}$. Then the total momentum of the electron shell J_1 can take on the values $J_1 = 0$ or 1, and the conversion probability on the 2*p* electron will be proportional to $2J_1+1$. A similar conclusion can be drawn in the case of the Li-like initial configuration $1s^2 2p_{1/2}$. As a result, the conversion probabilities and, accordingly, the ICC in these states will be related as 1 : 3 : 2, respectively. The issue of total angular momentum is of fundamental importance in the case of a reverse IC (NEECxe [1]). The report develops the theory of the question as applied to the conventional and inverse IC.

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STRUCTURE AND SYNTHESIS OF MAGNETIZED HEAVY NUCLEI

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Nucleosynthesis at large magnetic induction relevant for core-collapse supernovae, and neutron star mergers is considered. For respective magnetic fields of a strength up to ten teratesla atomic nuclei exhibit linear magnetic response due to the Zeeman effect. Such nuclear reactivity can be described in terms of magnetic susceptibility [1]. Susceptibility maxima correspond to half-filled shells. The neutron component rises linearly with increasing shell angular momentum, while the contribution of protons grows quadratically due to considerable income from orbital magnetization. For a case $j = l + 1/2$ the proton contribution makes tens of nuclear magnetons and exceeds significantly the neutron values which give several units. In a case $j = l - 1/2$ the proton component is almost zero up to g-shell. Respectively, a noticeable increase in the generation of corresponding explosive nucleosynthetic products with antimagic numbers is predicted for nuclei at charge freezing conditions. In the iron group region new seeds are created also for the *r*-process. In particular, the magnetic enhancement of the volume of ^{44}Ti isotopes is consistent with results from observations and indicates the substantial increase in the abundance of the main titanium isotope (^{48}Ti) in the Galaxy's chemical composition. Magnetic effects are proved to result in a shift of the r-process path towards smaller mass numbers, and an increase in the volume of low mass nuclides in peaks of the r-process nuclei.

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ON THE ELASTIC ELECTROWEAK SCATTERING OF POLARIZED LEPTONS BY SPIN 7/2 NUCLEI

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In [1,2], in the framework of a general approach to the covariant description of the structure of half-integer spin nuclei, analytical expressions were found for the multipole expansion of the structure functions W_k in the differential cross section for elastic scattering of longitudinally polarized leptons

$$\frac{d\sigma}{d\Omega} = \sigma_{Mott}\left\{W_1 + 2\,\mathrm{tg}^2\frac{\theta}{2}W_2 - \zeta\tau\left[\frac{M}{E} + \left(1 + \frac{M}{E}\right)\mathrm{tg}^2\frac{\theta}{2}\right]W_4\right\}.$$

Here θ is scattering angle of lepton with energy E and helicity ζ, and M is nucleus mass; $\tau = -q^2/4M^2$.

Using Rarita-Schwinger formalism to describe nuclei with spin $J = 7/2$, we generalize results of [3] and construct explicit expressions for covariant electromagnetic and weak vertex functions $\Gamma^{\mu;\,\alpha\beta\delta\sigma\omega\varphi}_{em,\,weak}$, as well as for the density matrix of an unpolarized nucleus state

$$\Lambda^{7/2}_{\alpha\beta\delta\sigma\omega\varphi}(p) = \sum_m U^{7/2}_{\alpha\beta\delta}(p,m)\bar{U}^{7/2}_{\sigma\omega\varphi}(p,m),$$

where summation runs over all spin projections m.

Then with multipole expansion technique in the Breit zero energy transfer system, we get formulas for traditional multipole form factors: vector $F_{Cl}(\tau)$ $(l = 0,2,4,6)$ and $F_{Ml}(\tau)$ $(l = 1,3,5,7)$, as well as axial $F_{5El}(\tau)$ and $F_{5Ll}(\tau)$ $(l = 1,3,5,7)$ in terms of covariant vertex form factors.

Finally, we obtain and discuss expressions for the parity violating right-left asymmetry A_{RL}, as well as the spin correlations of transversely polarized incident and scattered leptons.

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NEW LOCAL MAGIC NUCLEUS ^{146}Gd

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A new type of atomic nuclei – local magic nuclei – in the region Z = 20-50 were discovered and explained in [1]. Here we present a new local magic nucleus outside this region, ^{146}Gd, which has a '*miraculous pair*' of nucleons (N, Z) = (82, 64). The number of protons 64 is magic only when paired with the number of neutrons 82. This property follows from the data on the energies of the first excited states 2+, showing a maximum at Z = 64 in isotones N = 82 and its disappearance in neighboring isotones.

The formation of local magic nuclei was explained in [1] using special diagrams showing the change in the energies of (π/ν)-orbits by tensor π-ν forces with a change in the number of (ν/π)-nucleons. It is remarkable that the diagram of this kind successfully explain the corresponding properties of ^{146}Gd as well (see Fig. 1). The diagram shows the mechanism of formation of a compact (like a hole) gap inside the proton shell 50-82, leading to the formation of the magic number of protons 64 paired with N = 82, and the disappearance of this gap at other N. The present research confirms our previous discoveries as well indicates new directions of further studies.

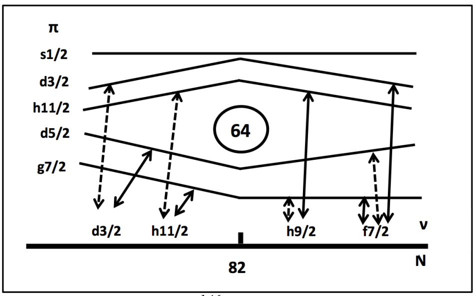

Fig. 1. Formation of the local magic nucleus ^{146}Gd: the change in the energies of proton orbits in the nuclei near (N, Z) = (82, 64) by tensor forces leads to the formation of hole-like gap Z = 64.

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IMPROVED STUDY OF THE COLLISIONAL QUENCHING OF THE PIONIC HELIUM LONG-LIVED STATES

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The existence of long-lived states in exotic helium atoms ($\pi^-, K^-, \underline{p} - He^+$) predicted by Kondo [1] about 60 years ago made it possible to conduct various series of unique high-precision laser spectroscopic experiments: thus, direct observations of E1-transitions between anti-proton helium states and M1-transitions between its superfine structure levels [2-4] were performed. Then similar experiments were continued on pionic helium atoms, where it was possible to observe transitions between atomic states [5,6]. The purpose of the conducted experiments is to obtain highly accurate fundamental characteristics of quantum objects: the antiproton magnetic moment, and upper limits on laboratory constraints on the muon antineutrino mass.

To interpret the obtained results, many theoretical questions arise; in particular, the very possibility of carrying out high-precision laser spectroscopic experiments with hadronic helium atoms depends on the destruction rate of metastable states during collisions in a medium. The rate of Stark collisional quenching of highly excited states is the highest. We use the Potential Energy Surface (PES) of three-electron $\pi^- He^+ - He$ system in which the three electrons move in the field of three heavy particles (two α-particles and π^-) to obtain an interaction between the colliding systems and then the rates. The PES was calculated by Unrestricted Hartree-Fock (UHF) method in Dunning's aug-cc-pV5Z basis with counterpoise correction and with account of electron-electron correlations by Moller-Plesset (MP2) method.

The numerical calculations of PES and then the numerical solution of the system of close-coupling equations are improved, especially in the region of small distances between the colliding $\pi^- He^+$–He subsystems, where some peculiarities and unusual behavior arise due to the strong interchannel interaction, and whose contribution to the rates of collisional transitions is significant. The cross sections for these transitions are systematically calculated, and the obtained results are compared to the experimental ones.

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SMOOTHNESS OF MASS SURFACE OF ODD ACTINIDE NUCLEI AND PAIRING ENERGIES

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As it was shown in [1,2], the mass surface M of odd deformed atomic nuclei with 150<A<190 in the vicinity of a given number of protons can be described with good accuracy by the sum of two terms:

1) μ–a Tailor series expansion up to the second order by degrees of deviation of the number of nucleons from the given values:

2) P_N (P_Z) – neutron (proton) pairing energy, depending on the state of odd nucleon.

For example, for odd neutron number (N') nuclei:

$M(N',Z) = \mu(N',Z) + P_N(N',Z)$,

hereafter the apostrophe denotes an odd number (N-neutrons, Z-protons).

A smooth part of the mass surface $\mu(N',Z)$ can be defined from masses $M(N'+s',Z+t)$ of a few adjacent even-even nuclei using the second-order decomposition:

$$\mu(N',Z) = M(N'+s',Z+t) - s'd_{1n} - td_{1p} - \frac{1}{2}s'^2 d_{2n} - \frac{1}{2}t^2 d_{2p} - std_{1n,1p}.$$

There is some uncertainty in the values of $\mu(N',Z)$, d_{1n}, d_{1p}, d_{2n}, d_{2p}, $d_{1n,1p}$ due to the different sets of reference even-even nuclei.

The first set (s-approximation) includes masses of even-even nuclei with the same Z and neutron numbers $N' \pm 1, N' \pm 3$. In this case $t = 0$ and

$d_{1n} = [M(N'+1,Z) - M(N'-1,Z)]/2$;

$d_{2n} = [M(N'+3,Z) + M(N'-3,Z) - M(N'+1,Z) - M(N'-1,Z)]/2$.

Then $\mu(N',Z) = M(N'+1,Z) - d_{1n} - d_{2n}/2$.

The second set (st-approximation) uses reference even-even nuclei with charges $Z \pm 2,\ Z \pm 4$ and neutron numbers $N' \pm 1, N' \pm 3$ so that the mass number of these nuclei differs from the mass number of odd nucleus under consideration by 1 or 3, i. e. $(N' \pm 1, Z \mp 2)$, $(N' \pm 1, Z \pm 2)$, $(N' \pm 1, Z \mp 4)$, $(N' \pm 3, Z \mp 2)$. This approximation leads to another formulae for d_{1n} and d_{2n}.

The calculations of these parameters for U and Th odd actinide nuclei have been conducted. The results show that values of d_{1n} and d_{2n} slightly differ for different sets of reference even-even nuclei, however the values of neutron pairing energies for both approximations are withing the empirical error limits.

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UNDERSTANDING THE BINDING ENERGY OF PROTON RICH ATOMIC NUCLIDES WITH STRONG AND ELECTROWEAK BINDING ENERGY FORMULA

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By considering strong and electroweak interactions, recently, we have proposed an unified and simplified formula for estimating nuclear binding energy [1,2,3]. It constitutes four simple terms and one energy coefficient. Increasing number of free nucleons, increasing nuclear radii and increasing asymmetry about stable mass number seem to play an important role in reducing nuclear binding energy. In this paper, by considering the expression [N(Z-N)/A] where N < Z as 5th term, an attempt is made to understand the binding energy of proton rich light and medium atomic nuclides [4]. It needs further study with respect to currently believed protons coulombic repulsion.

Unified Nuclear Binding Energy Formula for Z=3 to 118 where N>=Z

$$BE \cong \left\{ A - \left[1 + \left(0.0008\left(Z^2 + A^2 \right) \right) \right] - A^{1/3} - \frac{\left(A_s - A \right)^2}{A_s} \right\} \left(B_0 \cong 10.1 \text{ MeV} \right)$$

$$\text{where } \begin{cases} A_s \cong 2Z + 0.0016\left(2Z\right)^2 \cong 2Z + 0.0064Z^2 \\ \cong \text{Mass number close to stability zone.} \end{cases}$$

Extended Unified Nuclear Binding Energy Formula for light atomic nuclides where N<Z

$$BE \cong \left\{ A - \left[1 + \left(0.0008\left(Z^2 + A^2 \right) \right) \right] - A^{1/3} - \frac{\left(A_s - A \right)^2}{A_s} - \frac{N\left(Z - N \right)}{A} \right\} \left(B_0 \cong 10.1 \text{ MeV} \right)$$

$$\text{where } \left\{ A_s \cong 2Z + 0.0064Z^2 \text{ and } N < Z \right.$$

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Section 2. Experimental and theoretical studies of nuclear reactions

OBSERVATION OF THE SHAPE ISOMER STATES IN FISSION FRAGMENTS FROM (γ, *f*) REACTIONS

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The experiments were performed at the beam of the MT-25 microtron, FLNR, JINR, using VEGA (V–E Guide based Array) setup. Fission fragments (FFs) from the $^{235, 238}$U (γ, *f*) reactions are captured by the electrostatic guide system (EGS). The EGS constitutes a cylindrical capacitor of four meters long with a thin wire as a central electrode. Some part of the ions emitted from the target at one end of the guide can be involved in the spiral-like movement along the guide axis [1]. By this way the FFs are transported to the time-of-flight mass-spectrometer consisted of the microchannel-plates based timing detector and the mosaic of four PIN diodes. The mean time-of-flight of the FFs in the EGS exceeds 400 ns.

The peculiarities of the two dimensional FFs mass correlation distributions observed let us to suppose the following nature of such peculiarities (linear structures) [2]. Very deformed FF from binary (γ, *f*) reaction undergoes a break-up crossing the Lexan foil of the timing detector due to inelastic Coulomb scattering. It is possible if the fragment was born in the shape isomer state with a typical life time of more than 400 ns. Earlier, manifestations of similar process in ^{252}Cf(sf) and ^{235}U(n_{th}, *f*) we discussed in Ref. [3].

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CHARGE DISTRIBUTIONS FOR NUCLEI-ISOBARS DURING ^{238}U PHOTOFISSION

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An experimental and theoretical study of the charge distribution for isobar nuclei during photofission of 238U nuclei has been carried out. To study fragments of photofission of 238U nuclei, a gamma-activation method was used, that is, a method in which the radioactivity induced in the target by a beam of γ-quanta from an accelerator is analyzed. An experiment on the irradiation of a uranium target was carried out on the bremsstrahlung of the RTM55 accelerator of the Institute of Nuclear Physics, Moscow State University, with a beam energy of 55 MeV. The charge distributions of fission fragments were obtained for chains of nuclei with mass numbers: 131,132,133 and 139. The results obtained in the experiment were compared with the results of work performed on bremsstrahlung beams of gamma quanta and proton beams and hypotheses of unchanged charge distribution (UCD) and minimum potential energy (MPE).

The most probable Zp charges obtained experimentally, as well as deviations from the predictions of the UCD and MPE models, are presented in Table 1 below.

A	Zp(exp)	Z(UCD)	Zp-Z(UCD)	Zp(MPE)
131	51,102±0,271	51,068	0,035±0,271	50,428±0,057
132	51,290±0,101	51,457	-0,167±0,101	51,153±0,064
133	51,530±0,209	51,848	-0,317±0,209	51,768±0,140
139	54,125±0,001	54,186	-0,061±0,001	54,131±0,072

Table 1. Comparison of experimental and theoretical values of the most probable charge for chains of nuclei with mass numbers 131, 132, 133, and 139.

PHOTOFISSION OF ^{238}U IN THE ENERGIES RANGE OF GIANT DIPOLE RESONANCE

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The yields and average cross sections of the photonuclear reactions ^{238}U(γ, n) and ^{238}U(γ, *f*) are measured at a maximum bremsstrahlung energy of 55 MeV. Based on the analysis of the residual activity spectra of the products of the ^{238}U(γ, *f*) photofission reaction, the cumulative yields were measured for about 40 mass chains. The cross sections for the reactions ^{238}U(γ, n) and ^{238}U(γ, *f*) are estimated and compared with the results of experiments on quasi-monochromatic beams, estimated cross sections, and calculations using the TALYS program. The post-neutron mass yield distribution of ^{238}U(g,F) photo-fission has been obtained (Fig. 1). The behavior of the symmetric and asymmetric modes of photofission is analyzed as a function of the average excitation energy of the fissile nucleus.

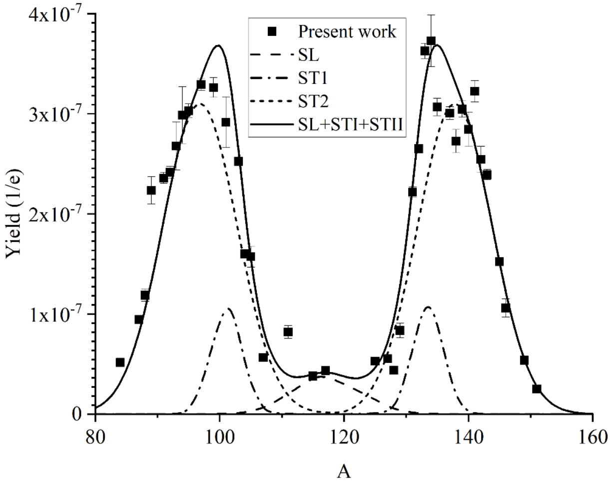

Fig. 1. Approximation by five Gaussian functions of the total mass distribution $Y_M(A)$ of products formed as a result of ^{238}U photofission induced by bremsstrahlung photons at an electron accelerator energy of 55 MeV.

INFLUENCE OF THE ENTRANCE CHANNEL ASYMMETRY ON THE FISSION PROPERTIES OF EXCITED ^{180}Hg NUCLEI

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Fission of the pre-actinide nuclei is characterized as predominantly symmetrical even at low excitation energies. Recently, in experiments on the β^+-delayed fission of the ^{180}Tl nucleus [1], an asymmetric mass distribution of the fission fragments of its daughter nucleus ^{180}Hg with an excitation energy E^* <

10.8 MeV was found. Note that the formation of two fragments – semimagic nuclei ^{90}Zr (N = 50, Z = 40) – should be expected in the symmetric fission of this strongly neutron-deficient nucleus. However, the formation of a light fragment with a mass of 80 u and a heavy one of 100 u was found in the fission of ^{180}Hg. Therefore, the study of the fission properties of pre-actinide nuclei is extremely important.

Thus, we propose to study reactions ^{36}Ar + ^{144}Sm and ^{90}Zr + ^{90}Zr, leading to the formation of the compound nucleus ^{180}Hg in the wide range of excitation energies. In the ^{36}Ar + ^{144}Sm reaction fusion-fission and fast fission are observed. Special M-TKE matrix subtraction procedure [2] allowed to separate these two processes. The reaction ^{90}Zr+^{90}Zr was measured in wide energy range. The mass asymmetry of the entrance channel in this reaction is equal to zero. At high incident energies all three possible reaction mechanisms - fusion-fission, quasifission and fast fission – contribute to the M-TKE distributions of the fissionlike reaction products. The separation of the two-dimensional M-TKE distributions of binary fragments corresponding to different reaction mechanisms allowed to obtain the main characteristics of each process. Double-arm time-of-flight spectrometer CORSET was used to measure M-TKE distributions.

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MODELLING OF THE CLUSTER FORMATION IN HEAVY NUCLEI FISSION

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This paper presents a study on the microscopical modelling of the cluster formation in the cold fission of actinides. In the last three decades, the situation in experimental and theoretical investigation of clustering effects in multimodal fission has changed dramatically [1–3].

Based on our cold fission multi-valley calculations in the framework of Strutinsky shell correction method, a theoretical study of various cluster structures emerging in the process of fission has been carried out. Results have demonstrated the effect of the arrangement and rearrangement of magic clusters in the fission process [4, 5].

This type of the cluster formation modelling has been successfully implemented for the flow turbulence control using air pressure sensors and aircraft wing surface modifying actuators [6]. For the first time a new approach to the emergent cluster aggregation by the local rules of interaction has been proposed in highly-cited work [7].

Our computable microscopical modelling of the clustering can contribute to understanding of the fission process dynamical features such as a time scale, an interplay between collective and single-particle degrees of freedom and a degree of equilibration on the fission path.

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NEW MODES OF COLLINEAR CLUSTER TRI-PARTITION OF ^{252}Cf(sf)

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In our previous publications [1–4] we discussed various manifestations of a new decay channel of the low excited heavy nuclei called collinear cluster tri-partition (CCT). In the frame of the essentially modified experimental method, additional linear structures corresponding to the relations $M_1 + M_2 = \text{const}$ and $M_1 - M_2 = \text{const}$ for the masses M_1 and M_2 of the fission fragments (FFs) from ^{252}Cf(sf) detected in the opposite spectrometer arms form the rhombic-like configurations with the vertices corresponding to the magic nuclei. The structures are statistically reliable, they are conditioned by a pronounced and complex correlation between the masses of the FFs measured independently. Possible physical scenario standing behind the structures are discussed.

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YIELDS AND ENERGY DISTRIBUTIONS OF α-PARTICLES IN SPONTANEOUS TERNARY NUCLEAR FISSION

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In [1, 2] a virtual mechanism of ternary fission of the nucleus (A, Z) which is considered as a two-stage process, when at the first stage an α-particle with kinetic energy T_α close to the height of its Coulomb barrier emits from the specified nucleus, with the formation of a virtual state of the intermediate nucleus ($A-4$, $Z-2$), which at the second stage is involved in binary fission, was proposed. Part of the energy of the emitted long-ranged α-particle is taken by reducing the heat of fission of the intermediate nucleus ($A-4$, $Z-2$) by ($T_\alpha - Q_\alpha$), where Q_α is the heat of the true α-decay of the nucleus (A, Z). The energy distribution $W_{\alpha f}(T_\alpha)$ and yield N_α of the α-particles for a one binary fission of the nucleus (A, Z), taking into account the proximity of the fission widths of the nuclei (A, Z) and ($A-4$, $Z-2$) from the configuration (0) of these nuclei with a neck of radius R_{neck} between two fission prefragments, are defined as

$$W_{\alpha f}\left(T_\alpha\right)=\frac{1}{2\pi}\frac{\left(\Gamma_\alpha^A\left(T_\alpha\right)\right)^0}{\left(Q_\alpha^A-T_\alpha\right)^2}=\omega_\alpha\frac{\hbar c\sqrt{2T_\alpha}}{2R_{\text{neck}}\sqrt{\mu c^2}}P\left(T_\alpha\right), N_\alpha=\int W_{\alpha f}\left(T_\alpha\right)dT_\alpha,$$

where $\left(\Gamma_\alpha^A\left(T_\alpha\right)\right)^0$ is the width of the decay of the parent nucleus from the configuration (0), $P\left(T_\alpha\right)$ is α-particle permeability factor of the Coulomb barrier formed by the sum of the non-spherical nuclear $V_n\left(\vec{r}\right)$ and Coulomb $V_c\left(\vec{r}\right)$ potentials of α-particle and deformed fission prefragments interactions, ω_α is the probability of α-particle formation in the parent nucleus neck, μ is the reduced mass of ternary fission products. Calculating the permeability factor of the Coulomb barrier by an α-particle as

$$P\left(T_\alpha\right)=\exp\left(-\frac{2}{\hbar c}\int_{R_A}^{R}\sqrt{2\mu c^2\left(V_n\left(\vec{r}\right)+V_c\left(\vec{r}\right)-T_\alpha\right)}d\vec{r}\right),$$

when using the non-spherical Saxon-Woods and proximity potentials [4] as the nuclear potential, the energy distributions and yields of α-particles for ^{248}Cm, ^{250}Cf and ^{252}Cf nuclei are obtained, which are satisfactory consistent with the experimental energy distributions and yields of α-particles for these nuclei [5–6] .

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TIME-PICKOFF METHOD TO THE PIN DIODE SIGNAL BASED ON THE MATHEMATICAL FORMALISM OF SUBJECTIVE MODELING

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The report discusses a new method and algorithm for solving the problem of determining the velocity of a heavy ion using a semiconductor detector (PIN diode) [1, 2], using the mathematical formalism of subjective modeling (MFSM) [3, 4], which allows to mathematically formulate both a subjective model of the object under study and a subjective mathematical model of its measurements and their subjective interpretation.

In experimental practice, the ion velocity is measured by "time-of-flight". To measure the time-of-flight, it is necessary to obtain the timestamps "start" and "stop" corresponding to the moments of the beginning and end of the ion movement along the flight path. The "stop" timestamp is often obtained from a so-called PIN diode. A signal (voltage pulse) appears at the output of the diode, can be represented as the sum of the actual voltage pulse caused by the recorded ion and additive probabilistic noise. The physics of the interaction of a heavy ion with a semiconductor is such that the waveform first represents a slowly growing function, the graph of which is *unknown*, then comes out to an almost linear dependence (the length of this section is also *unknown*). It is required to determine the moment of time when the ion hits the detector ("absolute time reference") - despite the fact that the initial part of the pulse leading edge lies inside the area with a high noise level.

To solve the problem of determining the velocity of a heavy ion, an algorithm based on the mathematical formalism of subjective modeling has been developed and implemented, which allows to restore the unknown shape of the pulse leading edge by a smoothing spline with the following special condition: the initial part of the spline (on the left) is given by the parabola equation, and the vertex of this parabola should lie on the averaged noise line, since in the absence of noise the leading edge begins to grow from the zero line. To determine the optimal smoothing factor of the spline, subjective optimality criterion [4] was used. Correctness of new time pick-off algorithm was tested in experiment at the accelerator in the Laboratory of Nuclear Reactions of the Joint Institute for Nuclear Research (Dubna).

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PROBLEMS OF DESCRIPTION OF P-EVEN T-ODD ASYMMETRIES IN NUCLEAR FISSION REACTIONS WITH THE EMISSION OF LIGHT PARTICLES IN THE FRAMEWORK OF THE SEMICLASSICAL APPROACH

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In [1–2], the coefficients $D^{\exp}_{nf,p}(\theta)$ of P-even T-odd asymmetries in the cross sections for nuclear fission reactions by cold polarized neutrons with the emission of light $N^{\pm}_{p}(\theta)$ particles p were found, expressed in terms of experimental particle count rates p in coincidence with light fission fragments for the directions of polarization vector either along $\boldsymbol{\sigma}^{+}_{n}$ or $\boldsymbol{\sigma}^{-}_{n}$ against the Y axis. For the theoretical description of these coefficients in the case of α-particles using the semiclassical method of trajectory calculations, was proposed [1]

$$D_{nf,\alpha}(\theta) = \Delta_{\alpha} \cdot \left(dP^{\{0\}}_{\alpha}(\theta)/d\theta\right) \Big/ P^{\{0\}}_{\alpha}(\theta) + D_{TRI} \,. \quad (1)$$

The first term in (1), expressed through the rotation angle, took into account the influence of the Coriolis interaction of the spin of a compound fissile system (CFS) rotating around an axis perpendicular to its symmetry axis on the angular distributions of both fission fragments (Δ_{LF}) and α-particles ($\overline{\Delta}_{\alpha}$). The appearance of the second term D_{TRI} in (1) was based on the hypothesis [1] about the change in the angular distribution of α-particles under the action of the Coriolis interaction associated with the collective rotation of the CFS around the fission axis, which turns out to be possible when the axial symmetry of the CFS is violated due to taking into account its collective transverse oscillations, in the vicinity of the rupture point. The coefficients $D_{nf,\alpha}(\theta)$ calculated in [1] using (1), for the positive values of the angles Δ_{α} found in the trajectory method, turned out to be in satisfactory agreement with the corresponding experimental coefficients $D^{exp}_{nf,\alpha}(\theta)$ [1] for target nuclei ^{233}U, ^{235}U, ^{239}Pu и ^{241}Pu. Formula (1) can be generalized to the case of emission of evaporative neutrons and γ -quanta, taking into account the fact that the influence of two types of Coriolis interaction on the angular distributions of these particles can be neglected, since these interactions are small at the moment of emission of evaporative particles due to very large values of the moment of inertia CFS. This leads to the exclusion of the quantity D_{TRI} in (1) and the replacement of the angle Δ_α by the angle Δ_{LF}. The coefficients $D_{nf,n'(\gamma)}(\theta)$ calculated using the obtained formula turned out to be in satisfactory agreement with similar experimental coefficients $D^{\exp}_{nf,n'(\gamma)}(\theta)$ from [2] in the case of the ^{235}U target nucleus, but has opposite signs for the ^{233}U target nucleus. The last result demontrates the need to look for an alternative approach to the description of the coefficients $D_{nf,n'(\gamma)}(\theta)$, different from the semiclassical approach.

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RESULTS OF SIMULATION OF TOTAL AND DIFFERENTIAL CROSS SECTIONS FOR ^{236}U FISSION BY NEUTRONS WITH ENERGY UP TO 200 MeV

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In [1], it was rightly noted that "nuclear fission remains the most complex topic in applied nuclear physics". The current state of the theory based on the model of transition states at fission barriers does not allow one to reproduce the fission cross section of a nucleus by neutrons as a function of their energy without using a significant number of fitting parameters. This is partly due to the lack of information about the spectra of transition states. In our opinion [2, 3], the understanding of the fission mechanism can be improved by using data on the angular distribution of fragments or, in other words, on the ratio of the differential fission cross section to the total one. The idea is that the angular distribution of fragments is determined by the distribution of the fission probability over the projection K of the nuclear spin on the axis of deformation on a barrier, which in turn depends on what values of K characterize the rotational bands of transition states on the barrier. Thus, the angular distribution of fragments can provide important information about the spectrum of transition states.

Previously, we analyzed data on fission cross sections and angular distributions of fission fragments in the reactions ^{237}Np(n, f) [3] and ^{240}Pu(n,f) [2]. The present work is devoted to the reaction of ^{236}U(n, f). The parameters of the fission barriers taken from [1] were slightly changed, which made it possible to reproduce, using the TALYS-1.9 program [4], the energy dependence of the total fission cross section in the range of incident neutron energy from 0.5 to 120 MeV. Using a modified version of the same program gives a good description of the angular anisotropy W(0º)/W(90º) of the fission fragments within the statistical model of the probability distribution of fission over the number K in a wide range from 2.5 to 300 MeV. Of particular interest is the low-energy region from 0.5 to 2.5 MeV, in which the energy behavior of angular anisotropy may be related to the structure of the transition state spectrum at the ^{237}U fission barrier.

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PROMPT FISSION NEUTRON SPECTRA OF ^{235}U AND ^{239}Pu

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Pre-fission neutrons influence the observed prompt fission neutron spectra (PFNS), TKE, average number of prompt fission neutrons, (*n*, *f*) and (*n*, *xn*) reaction cross sections. Though pre-fission neutrons in ^{235}U(*n*, *f*) were first observed around E_n ~ 14 MeV [1] and then at E_n ~ 7 MeV [2], only now measured data base [3–6] allows to demonstrate the complex influence of fissility of nuclides ^{236}U and ^{240}Pu on the PFNS shape. The model parameters are fixed at thermal neutron energy [7] and the renormalized for the TKE measured data.

The PFNS shapes at E_n ~ 6–7 MeV are strongly correlated with nuclide fissilities in ^{235}U(*n*, *xnf*) and ^{239}Pu(*n*, *xnf*) reactions and competition of (*n*, *xnX*) reactions. Calculated exclusive (*n*, *n*γ), $(n, 2n)^{(1, 2)}$ and $(n, nf)^{(1)}$ pre-fission neutrons spectra allow to demonstrate that the amplitude of (*n*, *nf*) spectra is the largest for ^{235}U(*n*, *f*) at E_n ~6.5 MeV (Fig.1) while for ^{239}Pu(*n*, *f*) at E_n ~ 6.0 MeV (Fig. 2). When (*n*, *nf*) reaction competes only with (*n*, *n*γ) reaction, the pre-FNS shapes are rather similar (E_n ~ 5.5 MeV), though the contribution of $(n, nf)^{(1)}$ is much higher in case of ^{235}U(*n*, *f*) reaction. When the (*n*, 2*n*) reaction channel opens, the pre-FNS shapes reveal drastic influence of $(n, 2n)^{(1)}$ and $(n, 2n)^{(2)}$ neutron spectra. The fig. 1 demonstrates partials for ^{235}U(*n*, *f*) reaction, the numerical data [8] are compatible with data [4,5]. The fig. 2 demonstrates partials for ^{239}Pu(*n*, *f*) reaction, while the data [3–6] are compatible with predicted (*n*, *xnf*) contributions [9]. The lower curves and data points show the partitioning of the PFNS into the (*n*, *f*), (*n*, *nf*) and $(n, nf)^{(1)}$ contributions.

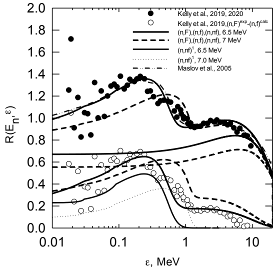
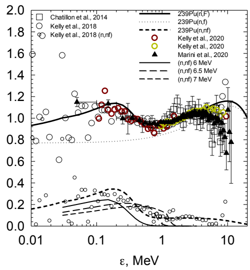


Fig. 1



Fig, 2

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OPTICAL MODEL ANALYSIS OF PROTON ELASTIC SCATTERING ON ^{6}Li NUCLEI WITH RESONANCE CONTRIBUTION

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Optical model analysis [1] of proton elastic scattering on ^{6}Li nuclei at proton energy from 50 keV to 185 MeV was continued with the use of the optical-model program code OptModel [2] taking into account the resonance contribution. Polarization data [3] in 1.21 < E_p < 3.22 MeV proton energy range were added into set of the early used elastic scattering experimental data.

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OPTICAL MODEL ANALYSIS OF PROTON ELASTIC SCATTERING ON ^{7}Li NUCLEI WITH RESONANCE CONTRIBUTION

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Optical-model analysis with taken into account resonance contribution of proton elastic scattering on ^{7}Li nuclei experimental data at proton energies E_p from 50 keV to 200 MeV was performed. Program code OptModel [1] was used. All existing in the world experimental data of proton elastic scattering on ^{7}Li nuclei differential cross sections and polarizations were analyzed. ^{7}Li+p reaction total cross section data presented in [2] at 23< E_p< 49 MeV were used in analysis as well as data stored in our SaBa electron library of nuclear data [3].

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OPTICAL MODEL ANALYSIS OF PROTON ELASTIC SCATTERING ON ^{9}Be NUCLEI WITH RESONANCE CONTRIBUTION

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Optical-model analysis with taken into account resonance contribution of proton elastic scattering on ^{9}Be nuclei experimental data (differential cross sections and polarizations) at proton energies E_p from 50 keV to 200 MeV was performed. Program code OptModel [1] was used. ^{9}Be + p interaction total cross section data were analyzed as well, cross section values at 0.05 < E_p< 10 MeV were taken from our SaBa electron library of nuclear data [2]. Total cross section values at 10 < E_p < 200 MeV projectile energies were taken from literature.

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ELASTIC PROTON SCATTERING BY NUCLEI ^{7}Be AND ^{8}B AT ENERGY 700 MeV

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In this paper, based on Glauber's diffraction theory, we analyze the results of a recent experiment [1] on the scattering of protons by ^{7}Be and ^{8}B nuclei at an energy of 0.7 GeV/nucleon, in the range of momentum transfer 0.002 ≤ |t|≤ 0.05 (ГэВ/*c*)2. The experiments were carried out by the GSI-PNPI collaboration (Germany–Russia) on the GSI radioactive beam (Darmstadt, Germany) in inverse kinematics.

In our calculations, the internal state of the ^{7}Be and ^{8}B nuclei under study are described on the basis of (α-τ) two- and (α-τ-*p*) three-particle cluster models, respectively. The wave functions of these nuclei [2], obtained on the basis of the above cluster models, describe well their static characteristics.

The parameters of the elementary *NN*- and *N*α-amplitudes required for our calculations are taken from other works. However, there are currently no data on elementary *N*τ-amplitudes in the scientific literature. In this connection, we separately considered elastic p^3He scattering in the kinematic region in which it corresponds to our calculations for proton scattering by ^{7}Be and ^{8}B. We succeeded in describing satisfactorily the experimental data on p^3He scattering [3]. Further, the calculation scheme used here was transferred to calculations on p^7Be and p^8B scattering.

Our calculations of proton scattering by ^{7}Be and ^{8}B are in good agreement with the data of [1]. However, these experiments were performed for small scattering angles. We carried out calculations up to scattering angles θ of ~ 50° and determined the contributions to the cross section from one-, two-, and three-fold scattering. At small angles, single scattering dominates, the contribution of double scattering is compared with it in the region θ of 25°. The contribution of triple scattering in elastic p^8B scattering appears at θ ~ 40°. In the future, it is planned to carry out similar calculations on the scattering of π- and K-mesons and to carry out a comparative analysis of the obtained calculations.

This work is carried out within the framework of the scientific project AP08855589

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PROTON INDUCED PROCESSES ON STRONTIUM ISOTOPES

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In this study, proton capture and (*p*, *xn*) nuclear reactions on natural isotopes of Sr were investigated at incident protons up to 30–35 MeV. Taking into account all nuclear reaction mechanisms, cross sections, angular distributions, and isotope productions have been analyzed. A Hauser–Feshbach formalism was employed to describe compound processes, an approximation of Distorted Wave Born Approximation for direct mechanisms, and an exciton model to explain pre-equilibrium processes [1–3]. In this study, the contribution of the nuclear reaction mechanisms to the cross sections and angular distributions is discussed. These theoretical evaluations were compared with experimental data from literature and with those obtained from FLNP JINR Dubna facilities. Experimental data of fast proton-induced reactions are consistent with theoretical results. Based on the good agreement between theoretical and experimental results, it was possible to derive the dependence of the isomer ratios on the protons' energy. Several calculations use isotope ratios to evaluate spin distributions of reaction products, densities of nuclear states, and nuclear deformation in final states. Computer simulations were conducted to evaluate the production of Yttrium, Rubidium, and other isotopes using angular distributions of incident protons for different targets and intensities of incident protons. Calculations for isotopes and isomer production were compared with experimental data gathered from the literature.

For future experiments at JINR's Dubna facilities involving fast neutron induced reactions, the present data will be used.

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VELOCITY DISTRIBUTIONS OF PROJECTILE-LIKE FRAGMENTS IN FRAGMENTATION REACTIONS AT FERMI ENERGIES

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Fragmentation reactions at Fermi energies are studied for decades since 1970^{th}. They are of interest because in these reactions nuclei far from stability line are produced. The properties of these exotic nuclei can shed light on better understanding the nature of nuclear forces. The striking feature of heavy-ion induced fragmentation reactions is that the velocities of projectile-like fragments are peaked at projectile velocity. This would be natural for the reactions at relativistic energies in which direct processes prevail, but not so evident at lower ones which have dissipative nature. It is therefore of interest to understand in detail the production mechanism of these fragments. In this report we analyze velocity distributions of forward emitted fragments for several reactions on Be and Ta targets at energies in the vicinity of Fermi energy in terms of microscopic approach [1]. We also deduce the ratio of direct and dissipative components [2] as a function of mass fragment and study its dependence on the projectile energy and other characteristics of the reaction. This can be helpful in planning future experiments with radioactive beams.

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FISSION MODES IN ^{238}Np POPULATED BY ^{6}Li+^{232}Th

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The mass-total kinetic energy(M-TKED) of fission fragments of the reaction ^{6}Li + ^{232}Th were measured at two laboratory energies $E_{\rm lab}$ = 28.5 and 40 MeV [1] using the CORSET set up at the Flerov Laboratory of Nuclear Reaction. The transfer induced fission and/or the breakup of ^{6}Li mainly into α and d clusters contributes to the incomplete fusion in this reaction. The binary events within the gate of 180° ± 3.5° in the fission fragment folding angle distribution have only been considered discarding the incomplete fusion events, for multimodal analysis.

Two dimensional M-TKEDs of the binary fragments of ^{6}Li + ^{232}Th, have been described by the multi-modal random neck rupture (MM-RNR) model [3]. Three modes were necessary to fit the data properly. Channel probabilities and the characteristics of different fission modes are obtained and discussed. The average kinetic energy <TKE> release in fission obtained from Viola systematic [4] matches well with that of the Standard 2 mode, but not with that of broad liquid drop like Superlong mode. This is associated with the decrease of the total kinetic energy associated with asymmetric fission with increasing excitation [5, 6] due to fading out of shell effects at high excitation energies. The slope of asymmetric to symmetric fission yields (when plotted against the excitation energy) of ^{6}Li + ^{232}Th is found to be similar to that of previously reported ^{18}O + ^{208}Pb.

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TIME-DEPENDENT MICROSCOPIC DESCRIPTION OF FAST ALPHA PARTICLES EMITTED IN NUCLEUS-NUCLEUS COLLISIONS

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Appearance of new experimental data on the energy spectra of fast alpha particles emitted in heavy-ion reactions [1, 2] requires development of microscopic models of such processes. The mechanism of nonequilibrium emission of alpha particles after capture of the projectile nucleus by the target nucleus is studied within the microscopic approach based on the time-dependent Schrödinger equation for the wave function of an alpha particle [1, 3] (Fig. 1). Transfer of energy from the colliding nuclei to the alpha particle is studied in the quantum three-body one-dimensional time-dependent model [4]. The possibility of cooling of superheavy compound nuclei via emission of fast alpha particles (e.g., in the reaction ${}^{54}\mathrm{Cr} + {}^{249}\mathrm{Cf} \to {}^{299}_{120}\mathrm{X} + {}^{4}\mathrm{He}$) is discussed.

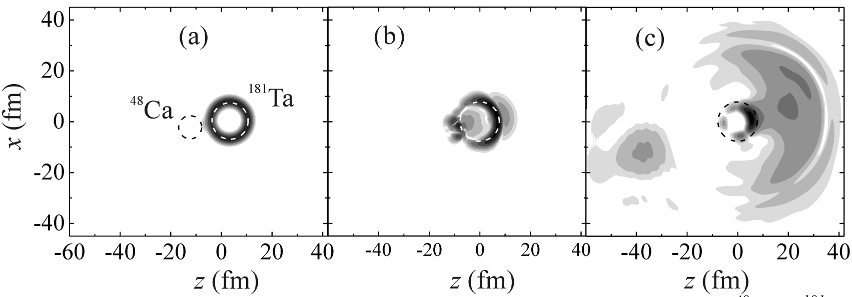

Fig. 1. Evolution of the wave function of emitted alpha particle in the collision of ^{48}Ca + ^{181}Ta at beam energy 280 MeV.

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SUB COULOMB BARRIER d+^{208}Pb SCATTERING IN THE TIME-DEPENDENT BASIS FUNCTION APPROACH

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We investigate the scattering of the deuteron on ^{208}Pb below the Coulomb barrier based on the non-perturbative time-dependent basis function (tBF) approach [1]. We obtain the bound and discretized scattering states of the projectile, which form the basis representation of the tBF approach, by diagonalizing a realistic Hamiltonian in a large harmonic oscillator basis.

We find that the higher-order inelastic scattering effects are noticeable for sub barrier scatterings with the tBF method. By considering all the possible electric dipole ($E1$) transition paths among all the states involved in the tBF approach and taking into account the corrections of the polarization potential to Rutherford trajectories, we have successfully reproduced experimental sub Coulomb barrier elastic cross section ratios with the tBF approach. We find that both the internal $E1$ transitions of the deuteron projectile and the corrections of the polarization potential to the classical Rutherford trajectories are essential for reproducing experimental data in these sub barrier experiments. More specifically, the correction of the polarization potential to the Rutherford trajectory is dominant in reproducing the data at very low bombarding energies, whereas the role of internal transitions of the deuteron projectile induced by the E1 interaction during the scattering becomes increasingly significant at higher bombarding energies.

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ANALYSIS OF CLUSTER RADIOACTIVITY USING Q-VALUE DEPENDENT RELATIVE SEPARATION

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The spontaneous disintegration of an unstable nucleus to attain a relatively stable configuration is known as radioactivity. Generally, it is considered that the radioactive decay happens via emission of the alpha particle, beta particle and gamma radiation. Apart from this, cluster radioactivity (CR), heavy particle radioactivity (HPR) and spontaneous fission (SF) are also probable ground state emission modes. The spontaneous splitting of unstable parent nucleus into fragment heavier than the alpha-particle but lighter than the fission fragments is known as cluster radioactivity (CR). It was theoretically predicted in [1], and then experimental verification is done by Rose and Jones [2], where ^{14}C was detected from ^{223}Ra radioactive parent nucleus. In past few decades, different experimental and theoretical attempts [3, 4] were made to explore the cluster radioactive emission modes. Numerous theoretical models are introduced to explore such complex decay mode on the basis of different nuclear properties (size, shape, magicity etc.). The preformed cluster model (PCM) is one such model [5] which is successfully employed to address the cluster radioactivity and other competing ground state decay modes. PCM works out in terms of the mass asymmetry coordinate η and relative separation distance R. The preformation probability (η-motion) and the penetration probability (R-motion) are calculated at a fixed turning point R_a, which is the sum of the relative separation at touching configuration and the neck length parameter "ΔR". In the present work, we have estimated Q-value dependence of R_a, which can be further utilize to calculate the decay half-lives and other decay properties of the radioactive modes. The work includes the study of CR by taking spherical choice of the decaying fragments. It will be of further interest to extend this work to study the comparative analysis of cluster dynamics with other ground state channels such as alpha-decay, hpr, and sf etc.

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INFLUENCE OF CLUSTER STRUCTURE TO THE MECHANISM OF NUCLEAR REACTIONS

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In the interaction reactions of weakly bound cluster nuclei, the structure of these nuclei can manifest itself with a high probability. It is expressed in cross sections for these processes, in particular, in the multinucleon transfer reaction and the transfer reaction of individual clusters [1, 2].

In order to study the influence of the cluster structure on the mechanism of nuclear reactions, we studied the interaction reactions ^{6}Li + ^{9}Be,^{12}C at an energy of 68 MeV. The experiment has been performed at the U-400M cyclotron, FLNR JINR. The angular distributions of the products formed in these reactions were measured in the range of 10°–120º in the c.m system. The following reaction channels were studied: ^{9}Be(^{6}Li, ^{6}Li)^{9}Be, ^{9}Be(^{6}Li, ^{7}Li)^{8}Be, ^{9}Be(^{6}Li, ^{6}He)^{9}B, ^{9}Be(^{6}Li, ^{4}He)^{11}B, ^{12}C(^{6}Li, ^{6}Li)^{12}C, ^{12}C(^{6}Li, ^{7}Be)^{11}B in ground and excited states. The obtained experimental data were analyzed within the framework of the optical model and the DWBA method [3].

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ENERGY DEPENDENCE OF TOTAL REACTION CROSS SECTIONS FOR ISOTOPES OF Be ON TARGETS ^{28}Si, ^{59}Co, ^{181}Ta

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Energy dependence of the total cross sections $\sigma_R(E)$ for reactions ^{10,11,12}Be + ^{28}Si, ^{59}Co, ^{181}Ta are presented. The 4π-methods of σ_R measurements are based on registration of prompt γ-quanta and neutrons using a 12-module 4π-spectrometer [1]. The results of the two methods for calculating the total reaction cross sections are presented.

The values of σ_R were calculated taking into account:

1) the mean detection efficiency <ε> of the 4π-spectrometer, which does not depend on γ-multiplicity M_γ [2];

2) the distribution of the numbers of triggered detectors during registration of the cascades of particles at a fixed value of multiplicity M_γ.

Measurement of the detection efficiency $\varepsilon(M_\gamma)$ for various values of γ-multiplicity M_γ was carried out using the method described in [3].

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ASYMPTOTIC NORMALIZATION COEFFICIENTS AND THE NEUTRON WIDTHS FOR ^{30}Si+n → ^{31}Si FROM THE PERIPHERAL ^{30}Si(d, p)^{31}Si REACTION

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Usually the differential cross sections (DCSs) of nucleon transfer reactions (NTR) are analyzed within the conventional DWBA for determination of a nucleonic spectroscopic factor S (SF) by normalization of the calculated DCS to the experimental data ([1] and references therein). The SF have strong dependence on the single-particle potential parameters. In contrast of the SF, the values of the asymptotic normalization coefficients (ANCs) [2] found from the analysis of the peripheral NTR are fairly weakly dependent on the single-particle potential parameters. The modified DWBA [3] and the dispersion peripheral pole model (DPPM) [4] can be used for determination of the ANCs from the analysis of the DCSs of the peripheral NTR. In both of these methods, the DCS is expressed in terms of the ANC for the removed nucleon from the residual nuclei. Nevertheless, the modified DWBA [3] can be applied when the residual nucleus in the reaction under consideration is formed only in bound (nonresonance) states, whereas the DPPM allows analyzing the DCS of the peripheral NTR populating to both bound and unbound states of the residual nucleus.

In the present work, the results of the analysis of the experimental DCSs for the ^{30}Si(d, p)^{31}Si reaction populating to the bound and unbound (resonance) states of the residual nuclei measured at the projectile deuteron energy 12.3 MeV [5] are presented. The analysis was performed within the framework of the DPPM [4] and MDWBA [3] with correct taking into account the three-body Coulomb dynamics in the transfer pole mechanism and Coulomb-nuclear distorted effects in the exit and entrance channels [6].

The analysis shows that the DCSs calculated within MDWBA [3] and DPPM [4] are in a good agreement with the experimental data. The new values of the ANC for ^{30}Si + n → ^{31}Si with their uncertainties corresponding to the bound states of the ^{31}Si nuclei are obtained from the analysis of the experimental DCSs of the reaction ^{30}Si(d, p)^{31}Si within DPPM [4] and MDWBA [3]. The neutron widths for the resonance states of the ^{31}Si nuclei are obtained from the analysis of the experimental DCSs of the reaction ^{30}Si(d, p)^{31}Si within DPPM [4].

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STOPPING EFFICIENCY SIMULATION OF CRYOGENIC GAS STOPPING CELL

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The mass is a fundamental property of an atom comprising all information on its constituents and their interactions. Thus, it carries information on the internal structure of the nucleus, reveal the quantum mechanical shell structure within complex nuclei and determine the energy available for nuclear transformations in radioactive decay processes. Mass measurements allow us to benchmark nuclear models and thus contribute to investigations of the nature of the strong interaction itself. With the aim of high-precision mass measurement (HPMM) of heavy and super heavy elements, a new experimental setup is being built in FLNR, Dubna. The setup consists of the following parts: target unit; gas-filled separator of complete fusion reaction products; cryogenic gas stopping cell (CGSC); a radio-frequency system for transporting and cooling a low-energy beam; and a multi-reflection time of flight mass spectrometer (MR-TOF MS). CGSC is responsible for the final slowing down and thermalizing the energy-bunched fragments produced and selected in the Gas Filled Separator. The thermalization is achieved in a volume filled with ultra-pure helium gas at cryogenic temperatures. After the thermalization, the fragments are extracted and transported with a radio frequency quadrupole (RFQ) to the MR-TOF MS. The stopping and thermalization of the incoming fusion-evaporation residuals (EVRs) is a key step in HPMM of the heaviest elements. Due to the typically low incoming ion rates and low particle integrals CGSC has to be as efficient as possible. The HPMM requires at least a few ions for a measurement any loss should be avoided. The kinetic energy of the incident EVR, the entrance window foil type and thickness as well as the buffer-gas type and density of the CGSC condition the stopping efficiency. Only the ions that are stopped within the active gas volume of the CGSC can be extracted. The stopping efficiencies for EVRs cannot be tested on-line and one have to rely on simulations. To use the CGSC on ion beam the optimal entrance window foil thickness for every reaction is necessary evaluate. The Geant4 and SRIM software packages was used in these simulations with different entrance window materials and beam and target combinations.

SIMULATED AND EXPERIMENTAL CHARACTERISTICS OF A GAS-FILLED RECOIL SEPARATOR DGFRS-II

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For further physical and chemical studies of superheavy elements (SHEs), SHE Factory was constructed at FLNR JINR. The facility is based on a new DC-280 heavy-ion accelerator that can deliver ^{48}Ca beams with a projected intensity of $6\cdot10^{13}$ ions per second. The first experimental setup of the SHE Factory is a gas-filled recoil separator DGFRS-2 with a $Q_vD_hQ_hQ_vD$ magnet configuration. Basic characteristics of DGFRS-2, as well as the results of the first test experiments, are presented. The test results for collection efficiency of evaporation residues (ERs) from reactions with accelerated ^{48}Ca ions and background suppression showed that the new separator allows us to study the properties of superheavy elements formed in complete fusion reactions in the femtobarn cross-section range.

A model of the DGFRS-2 was created using a GEANT4 toolkit. The main methods of trajectory simulations of heavy ions in gaseous media are presented:

1. Forming of a compound nucleus in the target layer;
2. Evaporation of several neutrons from an excited nucleus;
3. Modeling of multiple scattering of ERs in the target and other separator's media (filling gas, a Mylar window between the separator and detector volumes, pentane in the detector chamber);
4. Calculation of energy losses in the target and gaseous media;
5. Modeling of ERs recharge process in gas;
6. Calculation of recoil trajectory in the magnetic fields of the separator.

The calculated data agreed well with the experimental data generated in test experiments.

STUDY OF THE ^{16}O(α, α)^{16}O(3$^-$) AND ^{15}N(α, *t*)^{16}O(3$^-$) REACTIONS MECHANISM AT E_α = 30.3 MeV

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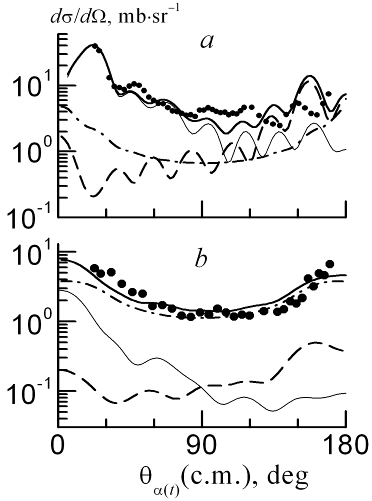
The study of the differential cross sections angular dependence of the reactions ^{16}O(α, α′)^{16}O(3$^-$) [1] and ^{15}N(α, *t*)^{16}O(3$^-$) [2] at E_α = 30.3 MeV was carried out. Both magnitude and shape of the measured cross sections and large value of *E*3 transition between the ground and 3$^-$ level of ^{16}O nucleus justify the use of CCBA formalism, when both couple channels method (CC) and DWBA are combined (FRESCO [3]) as well as the compound nucleus (CN) mechanism (TALYS [4]) in the theoretical analysis. The strength of coupling factors were introduced from the experimental reduced transition probability *B*(*E*3). The exchange of ^{12}C cluster with summation over all states allowed by the selection rules for transfer mechanism at both reactions and proton stripping for the (α, *t*)-reaction were taking into account. The spectroscopic amplitudes are obtained in the shell model. The calculated angular distributions, together with the experimental ones, are shown in Figs. It can be seen that in (α, α′)-scattering, the cross section is determined by collective excitation in the front hemisphere and by ^{12}C exchange at large angles. The CN contribution is not noticeable. In the reaction (α, *t*), the main contribution is made by the CN mechanism, else the contribution of the proton stripping is noticeable at forward hemisphere. The ^{12}C exchange mechanism is important at θ_t > 90°. The performed analysis showed that the calculated cross sections of both reactions agree with the experimental one without introducing normalization factors only when all considered mechanisms are taken into account.



Cross sections of (α, α′) (a) and (α, t) (b) reactions: thin solid line – CC (stripping), dotted – exchange of ^{12}C, dot-dash – CN, fat solid – sum, black dots – experiment

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STUDY OF MUON CATALYZED ^{3}He*d* FUSION

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The thermonuclear reaction $d(^3\text{He}, \alpha)p$ is a very rich playground to study various phenomena in different fields of science. Astrophysicists use data of the cross section to build and tune a theory of primordial nucleosynthesis. Most nuclear reactions data doesn't contain energy dependencies below several keV, the most interesting region for astrophysics.

From a practical point of view, the reaction is extremely efficient in energy generation. While producing 18.3 MeV worth of energy, one of the highest energy outputs among nuclear reactions, it doesn't contain nor produce radioactive elements. It makes possible the construction of the safest and efficient thermonuclear reactor.

The use of muons expands studies even more. It makes possible to investigate the reaction at extremely low energy (several eV) that has never been done before. Bombarding a gas mixture of ^{3}He and D_2 (HD) with energetic muons results in the formation of exotic muonic molecules such as $^3\text{He}\mu d$. It was theoretically shown [1] that ^{3}He*d* fusion can occur in the formation.

The experiment aimed to investigate muon catalyzed ^{3}Hed fusion is being carried out at PSI (Switzerland) by the PNPI group (Gatchina, Russia). It enables the study of processes involving mesomolecules.

The experimental setup adopted from the previous experiment MuSun [2] includes the cryogenic TPC, muon beam detectors, kicker and detection system of electrons coming from muon decays. The kicker allows muons to enter the fiducial volume only one by one. The data collected enables to determine a muon stop position, detect tracks of electrons created via the muon decay as well as tracks of fusion products. Information about the energy of each particle is also stored.

The formation rates of the $d\mu d$ and $^3\text{He}\mu d$ molecules, the probability of the muon transfer from μd^* to μd, the upper limit for "effective" $^3\text{He}\mu d$ fusion decay rate, yields of $^3\text{He}\mu d$ molecules have been obtained and presented.

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THUNDERSTORM FLASHES AS THE MECHANISM OF ^{14}C RADIOISOTOPE GENERATION

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An atmospheric production of ^{14}C radioisotope goes by the ^{14}N(n, p)^{14}C reaction under cosmogenic fluxes and this process is considered as the main source of radiocarbon creation which rate of accumulation is evaluated as ~ 6.6 kg per year. An exclusively opportunities of dating based on the analysis of ^{14}C concentration in the very old and ancient organic samples led to the discovery of short-term secular variation of radiocarbon in tree rings [1] and to the hypothesis of ^{14}C generation under thunderstorms flashes. The nature of the lightning phenomena in fact is connected with the development of electron avalanche in the strong atmospheric electric fields (~ 300 kV/m and more) [2]. The very fast electron avalanche growth in the cloud electric fields ensures the phenomenon of terrestrial gamma-ray bursts [2, 3]. These energetic γ-rays generate the photonuclear reactions on atmospheric isotopes (with significant yield for hard photons $E_γ$ = 20–60 MeV) as ^{14}N(γ, n)^{13}N, ^{16}O(γ, n)^{15}O, ^{40}Ar(γ, n)^{39}Ar. An increase of neutron flux causes the next series of (n, γ), (n, α), (n, p)-reaction and the ^{14}N(n, p)^{14}C is the top important for dating problem. For evaluating of the radiocarbon generation under thunderstorm conditions (and creation of another atmospheric isotopes too) it was proposed the model (realized in the spherical-layer geometry). The calculations were made at the several altitudes of the lower part of the atmosphere at the altitudes from 1 up to 15 km (covering the possible heights of detected lighting) [4, 5]. Decrease of the atmospheric densities at increase of the altitude is critical for electron avalanche evolution and is included in the model. It was obtained the yield from thunderstorm ^{14}C generation evaluated as 1e – 4% relative to cosmogenic one. The results support the hypothesis that radiocarbon rise in the old tree rings (at AD 774–775) [1] can be explained by increased Sun activity of the Sun at this time interval.

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TIME-DEPENDENT DESCRIPTION OF THE REACTION ^{28}Si(^{11}Be, ^{10}Be) AT LOW ENERGIES

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The evolution of the probability density of the outer weakly bound neutron of the ^{11}Be nucleus (Fig. 1) in collision with the ^{28}Si nucleus is described based on numerical solution of the time-dependent Schrödinger equation [1, 2]. The probabilities of outer neutron removal due to the processes of neutron transfer and nuclear breakup are determined. The results of calculating the cross sections for removal of the outer neutron from the ^{11}Be nucleus are close to the experimental data [3]. Numerical solution of the time-dependent Schrödinger equation taking into account spin-orbit interaction [4−6] makes it possible to study the dynamics of removal of the outer weakly bound neutron of the ^{11}Be nucleus and to determine the contributions of the neutron transfer channels and nuclear breakup in low-energy collisions with a target nucleus.

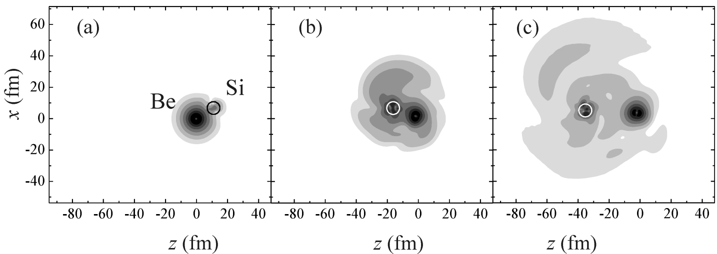

Fig. 1. Evolution of the probability density for the outer neutron of the ^{11}Be nucleus in the collision ^{11}Be + ^{28}Si at beam energy 55 MeV in the reference frame moving relative to the laboratory frame with a constant velocity equal to the velocity of the projectile nucleus at a sufficiently large distance from the target nucleus. The course of time corresponds to the direction from left to right.

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ASYMMETRY EFFECTS MODELLING IN SLOW NEUTRONS INDUCED PROCESSES ON ^{35}CL NUCLEUS

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Asymmetry and spatial parity non-conserving effects were investigated in slow neutrons induced processes on ^{35}Cl nucleus. Forward–backward, left–right and parity non conservation effects were evaluated in the (*n*, *p*) reaction for neutrons energy up to 1 keV. Cross sections, necessary angular correlations, asymmetry and spatial parity breaking effects were evaluated in the frame mixing parity of compound nucleus states with the same spin and opposite parities [1, 2]. Theoretical evaluations of the effects were compared with experimental data obtained at JINR Dubna and Peterburg Nuclear Physics Institute [3,4]. Forward–backward, left–right and parity non conservation effects are important because using theoretical evaluations and experimental results, matrix element of weak non leptonic interaction can be obtained [4].

For each investigated effect, angular correlations were obtained using (*n*, *p*) reaction amplitudes from [1, 2]. Further, applying direct Monte-Carlo method theoretical expressions and numerical evaluation of protons angular distributions were obtained considering different possible terms in the expressions of angular correlations. Using protons angular distribution, computer simulation of the asymmetry and parity breaking effects were realized considering targets with finite dimensions and different densities. For each analyzed effect, precision of the experiment was determined and, from computer modeled asymmetry coefficients, weak matrix elements was extracted.

The present results will be applied in the investigations of new experiments proposed at intense neutrons source IREN, from FLNP JINR Dubna dedicated to measurements of asymmetry effects in the ^{35}Cl(*n*, *p*)^{35}S nuclear reaction with slow neutrons.

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ESTIMATION OF THE REACTION CROSS SECTION Li(n, α)T

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The presented work is carried out analyzes and evaluation of available experimental data on the Li(*n*, α)T reaction cross section in order to obtain the recommended data. The cross section $\sigma_{n\alpha}$ (E_n) of Li(*n*, α)T reaction in neutron physics is often used as a reference quantity. In the neutron energy range E_n from 0.025–100 keV, $\sigma_{n\alpha}$ (E_n) is known with an accuracy of 1–3%. In the energy range 500 KeV $<E_n<$1.7 MeV, the accuracy is about 15%. As for the energy interval from 100–500 keV, there are significant uncertainties due to the strong resonance around the neutron energy of 250 keV. In estimating [1] for this energy range, the values of the cross section were recommended, which were obtained from the condition of the best description of the total cross section, the neutron elastic scattering cross section, and the reaction (*n*, α) cross section. Recently, new data on the Li(*n*, α)T reaction cross section have appeared. The behavior in the energy range 100 keV ≤ E_n ≤ 500 keV was studied in particular detail. As noted at the meeting on neutron data, the results of work performed in the energy range 150 KeV≤ E_n ≤400 KeV are consistent with each other within ±4%, if we accept a systematic shift in energy (about 5 KeV) of the work results and renormalize the cross sections obtained in work [2] down by 5%.

In this paper, was compared the results of parametrization of experimental data for the energy range 2 KeV ≤ E_n ≤ 1500 KeV by the least squares method using a number of different approximations. In this case, the results of different authors are accepted as equal and the errors they cite are not taken into account. As a first approximation, an expression was used that includes the resonant term in the dependence 1/ν:

$$\sigma_{n\alpha}\left(E_n\right)=\frac{A\sqrt{E}}{\left(E-E_0\right)^2+\left(\Gamma/2\right)^2}+\frac{B}{\sqrt{E}}-\Delta\sigma, \qquad (1)$$

where *A*, *B* and $\Delta\sigma$ are constants, E_0 – the resonance energy, Γ – the resonance width. All ot these values and are fitting parameters. As a result of processing, the following values were obtained for them: A = 0.0141; B = 0.1350; E_0 = 0.2410; Γ = 0.1050, and $\Delta\sigma$ = 0.0260.

In this case, the value of χ^2 at the point, averaged in region 2–1500 keV, was 3.5, and the root-mean-square deviation δ_0, calculated as:

$$\delta_0=\sqrt{\frac{\left(\sigma_{\text{calc.}}-\sigma_{eksp}\right)^2}{\sigma_{eksp}}}\times 100\%$$

and δ_0 over the same energy range was 7.5%. The calculation results together with the experimental data are given in the works [2, 3]. In the energy range 2 KeV ≤ E_n ≤ 500 KeV, expression (1) describes the experimental data quite well. For E_n ≤ 500 KeV, the description is much worse.

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TALYSLIB: A ROOT-BASED TOOLKIT FOR NUCLEAR DATA ACCESS

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Information about nuclear reactions and properties of nuclei is often needed during nuclear data processing. Access to the nuclear databases from applied software is often difficult because of complex file format or database structure. To simplify usage of the nuclear data a specific toolkit TalysLib was developed.

TalysLib is a ROOT-based C++ object-oriented library. It uses wide capabilities of ROOT [1] for data visualization and transformations. The main source of the evaluated data for TalysLib is the TALYS [2] program. Information about nuclear structure is extracted from RIPL-3 [3]. Work on the ENDF [4] data and preprocessed EXFOR data [5] support is in process.

TalysLib can be used for optimization of the theoretical model parameters using MINUIT package which is included in ROOT.

The structure of the TalysLib and its main features will be presented. Current version of the TalysLib is available on https://github.com/terawatt93/TalysLib.

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THE METHOD AND SET UP FOR THE MEASUREMENT OF DELAYED NEUTRON TEMPORAL CHARACTERISTICS FOR THE FISSION OF HEAVY NUCLEI IN THE COMPLEX PRIMARY NEUTRON FIELDS

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Present work is dedicated to the description of the set-up designed for precise measurements of the energy dependence of aggregate delayed neutron characteristics in the energy range of primary neutrons from thermal to 20 MeV. The set-up constructed on the base of Tandem-3M accelerator of SSC RF – IPPE consisted of high-efficiency neutron detector, spectrometer of primary neutrons, pneumatic transport system of the sample under investigation, experimental control and data acquisition system. Special emphasis is made to study the influence of the primary neutron flux on performance characteristics of the neutron detector and to the measurements of the primary neutron spectra generated from the reaction D(d,n) on the solid neutron target. The results of measurements of delayed neutron relative abundances and half-lives are presented for the fission of ^{235}U by the neutrons in energy range from 0.42 to 8 MeV, including insufficiently known range from 4 to 8 MeV.

SEGMENTED HPGe DETECTOR FOR NUCLEAR REACTIONS RESEARCH

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This work presents the results of a study of the new true coaxial high-purity germanium p-type detector with a segmented n+ region [1]. The detector crystal size is 50mm in diameter and 50 mm in height. One of the main features of the detector is flowing endcap, which is allow to place a source or target inside of the detector. Thanks to it and six-fold segmentation of the crystal, it is possible to determine the direction of individual photons emitted from the source or during a nuclear reaction between ion beam and a target inside the ionizing radiation source. At the same time the flowing endcap give's possibility to study not only γγ, but also αγγ- or βγγ- correlations, by the possibility to install the six-fold Si-detector inside of the HPGe detector. Using the Eu-152 and Eu-155 source, the following detector characteristics were determined: detection efficiency and energy resolution (FWHM), depending on the applied bias voltage, as well as the angular resolution and sensitivity of the HPGe segment detector (step is 2–3 degrees).

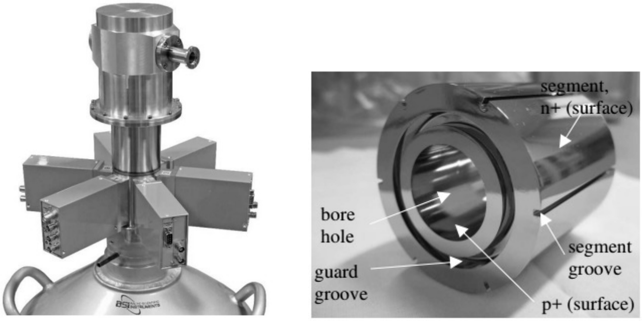

Fig. 1. Six-section segmented HPGe detector in the special cryostat developed for this study (Left). Photo of the six-section segmented HPGe detector crystal (Right) [1].

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THE SPECIFIC FEATURES OF PHOTODISINTEGRATION OF ^{58,60}Ni

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The reliability of experimental cross sections of partial photoneutron reactions (γ, 1*n*) and (γ, 2*n*) for ^{58,60}Ni obtained using both bremsstrahlung [1–4] and quasimonoenergetic annihilation photons [5] were analyzed using the objective physical criteria. The ratios of partial reaction cross sections to that of neutron yield reaction F_i = σ(γ, *in*)/σ(γ, *xn*) = σ(γ, *in*)/[σ (γ, 1*n* + 2σ(γ, 2*n*)] were used. In the cases of (γ, 1*n*) and (γ, 2*n*) reactions reliable data ratios F_i^{exp} must have values not higher than 1.00 and 0.50 [3] and near the values F_i^{theor} calculated in the combined photonuclear reaction model (CPNRM) [6]. It was obtained that data under discussion [1–4] do not satisfy those criteria. The new reliable cross sections of partial reactions for both ^{58,60}Ni were evaluated using data [5] and experimental-theoretical method [7]: σ^{eval}(γ, *in*) = F_i^{theor} σ^{exp}(γ, *xn*). It was found that the noticeable differences between experimental and evaluated cross sections are because of definite shortcomings of the neutron multiplicity sorting method used [5]. The main reason is that generally the σ^{exp}(γ, 2*n*) in reality in a large extent is the σ(γ, 1*n*1*p*). The point is that in the case of ^{58}Ni the threshold B_{1n1p} of the (γ, 1*n*1*p*) reaction is 2.9 MeV smaller in comparison with B_{2n} and the value of σ(γ, 1*n*1*p*) is ~20 times larger in comparison with σ(γ, 2*n*). In the case of ^{60}Ni the correspondent deviations are somewhat less but also very large. The role of (γ, 1*n*1*p*) reaction in the cases of relatively light nuclei is very specific. The sharing of investigated nucleus excitation energy between neutron and proton in the (γ, 1*n*1*p*) reaction is (at least could be) similar to that between two neutrons in the reaction (γ, 2*n*) and because of that energies of neutrons from both partial reactions could be near. But outgoing neutron from the reaction (γ, 1*n*1*p*) has multiplicity equal to 1 but both neutrons from the reaction (γ, 2*n*) have multiplicity equal to 2. Therefore, the reaction (γ, 2*n*) cross sections for both ^{58,60}Ni were obtained [5] with significant systematic uncertainties and must not be recommended for using in research and applications.

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PARTIAL PHOTONUCLEAR REACTION CROSS SECTIONS OBTAINED USING BREMSSTRAHLUNG

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Cross sections of partial reactions, primarily (γ, 1*n*) and (γ, 2*n*), are widely used in both scientific researches and applications. There are two main methods for obtaining those in various experiments. The majority of σ(γ, 1*n*) and σ(γ, 2*n*) for was obtained using quasimonoenergetic annihilation photons [1, 2] in Livermore (USA) and Saclay (France). The method of photoneutron multiplicity sorting using measured neutron energy was used for direct measurement the cross sections σ(γ, 1*n*) and σ(γ, 2*n*). For 19 nuclei from ^{51}V to ^{209}Bi investigated in both laboratories significant systematic disagreements were found [3, 4]. Using the objective physical criteria of data reliability, it was shown that in general partial reaction cross sections obtained using the method of neutron multiplicity sorting are not reliable because the presence of significant systematic uncertainties from the unreliable (erroneous) identification of multiplicity of detected neutron [5]. The most important criteria are that positive ratios F_i^{exp} = σ(γ, *in*)/σ(γ, *xn*) = σ(γ, *in*)/[σ(γ, 1*n*)+2σ(γ, 2*n*)] for reliable data in the cases of (γ, 1*n*) and (γ, 2*n*) reactions must have values not higher than 1.00 and 0.50 and near the values F_i^{theor} calculated in the combined photonuclear reaction model

(CPNRM). Data on partial reaction cross sections were obtained also using bremsstrahlung. The neutron yield cross sections σ(γ, *xn*) = σ(γ, 1*n*)+2σ(γ, 2*n*) were measured directly and used for determination of σ(γ, 2*n*) using the corrections based on the nuclear reaction statistical theory. After that σ(γ, 1*n*) was obtained using the correspondent subtraction procedure σ(γ, 1*n*) = σ(γ, *xn*) – 2σ(γ, 2*n*). The reliability of partial reaction cross sections σ(γ, 1*n*) and σ(γ, 2*n*) for nuclei ^{59}Co, ^{58,60}Ni, ^{90}Zr, ^{112,114,119}Sn, ^{127}I, ^{165}Ho, ^{166}Er, ^{181}Ta was investigated using the criteria mentioned above. It was found that generally those cross sections are not reliable because of many physically forbidden negative values or values for which $F_2^{exp} > 0.50$. This is the results of some shortcomings in GDR statistical theory description of competition between particle reactions.

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TO YIELD STUDIES FOR THE REACTIONS ^{13}C (γ, *p*), ^{14}N (γ, 2*p*), ^{14}N (γ, 2*n*) WITH (^{12}B, ^{12}N)- ACTIVITY MEASUREMENTS BY ΔE- DETECTOR TELESCOPES AT THE PULSED ELECTRON ACCELERATOR

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Studies of yields for photonuclear reactions with production of ^{12}B ($T_{1/2}$ = 20.2 ms) and ^{12}N ($T_{1/2}$ = 11.0 ms) are interesting both for development of models of nuclear reactions with nuclei-products near the boundaries of stability to nucleon-emission, and for detection of hidden explosives and drugs (see, e.g., [1]) with (^{12}B and ^{12}N)- activity registration. In [2, 3], there were considered features of emission of gamma- quanta, electrons and positrons from targets at decays of produced in them (^{12}B and ^{12}N)- nuclei.

In [4] for the reactions ^{13}C (γ, *p*), ^{14}N (γ, 2*p*), ^{14}N (γ, 2*n*), there was given analysis of known experimental and model-calculated data (including our own ones calculated by means of the widely used models of nuclear reactions). It was shown that new yield measurements are necessary for these reactions because estimated discrepancies of data are on the level of 1–2 orders of magnitude. In [5], there were briefly considered variants of such measurements with detecting (^{12}B and ^{12}N)- activities by scintillation gamma- spectrometers or telescopes of thin Δ*E*- counters. The first variant with NaI- spectrometers was considered in [6].

In the present work we considered measuring of (^{12}B and ^{12}N)- activities at the pulsed electron accelerator based on registration of emitted from the target electrons or positrons by rather thin telescopic plastic counters with usage of the controlled PMT power supply dividers for all these scintillation counters [7].

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PHOTONUCLEAR REACTIONS: SOME POSSIBILITIES FOR METHODOLOGICAL IMPROVEMENT

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Cross sections for photonuclear reactions in the energy range of giant dipole resonance have often been measured. One of the most commonly used experimental methods was the activation of a selected material in a high-energy bremsstrahlung beam. Considering that there is still a need for reliable results of cross-sectional measurements of photonuclear reactions, this work will refer to some results aimed at improving the methodology itself.

Insufficiently precise knowledge of the energy spectrum and intensity of the high energy photon beams has lead to the use of comparators, i.e. materials of well known activation properties. With a known geometry of bremsstrahlung production, it is possible to obtain a reliable energy distribution of the emitted photon radiation using some simulation routine. In this case, the photon beam can be calibrated by measuring the dose. By the activation of the gold (for which the cross section for (γ, *n*) reaction is well known) and dosimetry measurements, calibration of photon beams of Microtron 25, in the energy interval from 5 MeV to 25 MeV was performed. Dosimetry measurements were done using calibrated ionization chamber intended for dosimetry control of photon beams of therapeutic linear accelerators.

Reconstruction of cross-sections from photoactivation measurements has so far been performed using different numerical procedures. In reactor physics, powerful computer algorisms have been developed to solve similar problems – to estimate the shape of the energy differential cross section based on neutron activation measurements. It has been shown [1] that a couple of such software packages can be successfully used in photoactiovation measurements, in the energy range up to 10 MeV. In this work, a step further was done and mentioned software codes were tested on the example of gold activation at energies up to 25 MeV.

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PHOTONEUTRON CROSS SECTIONS OF COBALT

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From measurements of gamma ray activities, induced by irradiating ^{59}Co with 55 MeV bremsstrahlung, the yields of the reactions (γ, *n*), (γ, 2*n*), (γ, 3*n*), and (γ, 2*pn*) were determined. Absolute yields were obtained by reference to cross section data for the Cu(γ, *n*) process. The isomeric yield ratio (Y_m/Y_g) of ^{58}Co, which was measured at this energy, is 1.255 ± 0.004. This value is in a good agreement with previous experimental data, such as 1.33 ± 0.09 at the maximum beam energy equel 54 MeV [1].

The flux-weighted average cross-sections for the (γ, *n*), (γ, 2*n*) reactions of ^{59}Co are 18.53 ± 0.03, 6.99 ± 0.04 mb, respectively. They were compared with the flux-weighted average cross-sections obtained from other experimental data, based on mono-energetic and bremsstrahlung data, and theoretical predictions. These results of current experiment are lower then results, obtained by Alvarez [2] for (γ, *n*) reaction, and higher for (γ, 2*n*) reaction, which are 22.6 mb and 6.19 mb respectively.

The theoretically simulated ^{59}Co(γ, *n*)^{58}Co, ^{59}Co(γ, 2*n*)^{57}Co reaction average cross-sections based on TALYS show a general agreement with experimental data (18.58 mb and 6.69 mb respectively).

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THE INVESTIGATION IN NON-STATISTICAL MECHANISMS OF PHOTONUCLEAR EMISSION OF CHARGED PARTICLES ON MOLYBDENUM

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It is generally accepted that photonuclear reactions caused by photons occur in two stages in region of giant dipole resonance (GDR): the excitation of the nucleus as a system and its decay according to statistical laws. Neutron emission is the most well studied decay channel. Its output has a much greater magnitude than other reactions: (γ, 2*n*), (γ, *p*), etc. In addition, the direct registration of reaction products doesn't allow to attribute nucleons to specific channel reliably if thresholds of several reactions are exceeded. Thus, the photonuclear reactions with the emission of charged particles are studied poorly. However, they point out the domination of non-statistical decay mechanisms in GDR region. For example, the collective model overestimates the yields of reactions with the neutron emission and significantly underestimates the reactions with the proton emission in nuclei with $A > 90$. The isospin splitting of GDR effect is the reason for this.

We've investigated the photonuclear reactions on molybdenum isotopes for bremsstrahlung with 20, 40 and 55 MeV in this research. (γ, *p*), (γ, *pn*), (γ, *p*2*n*), (γ, α) and (γ, α*n*) are studied. 20 MeV bremsstrahlung allows to distinguish the dominant reaction. 40 and 55 MeV bremsstrahlung enable to follow cross sections changes.

The values calculated in TALYS, is equal 1.95 and much smaller than the observed ones. We've tested method of isospin splitting consideration for (γ, *p*)-reactions and it has provided us with the values which are close to experiments.

The statistical model also gives a strong yield underestimation for the reactions with the emission of α-particles, for which the Coulomb barrier is essential in its framework. The observed yield can be explained by the contribution of semi-direct reactions occurring on time scales of 10^{-21} s when the barrier does not have enough time to form and inhibit (γ, α). Our results show the connections between yields and nuclear shell completeness. If the residual nucleus has the magic number of neutrons ($N = 50$ in our case) then yield is much higher for such a reaction.

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INVESTIGATION OF (γ, αxn) REACTIONS ON ^{93}Nb

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The study of the photon interactions with atomic nuclei remains a topical experimental and theoretical task at the present time. Despite the accumulated scientific base, there is no unified theory describing the emission of charged particles for a wide range of nuclei. The main reason is the paucity of experimental data on the emission of charged particles. In addition, such studies are of great practical importance. Research of reactions with charged particle emission makes it possible to develop alternative channels for the radioactive isotopes' production for nuclear medicine, industry, and etc.

We have studied reactions with the emission of alpha particles using the induced activity method by 20 and 40 MeV bremsstrahlung beams on natural niobium targets weighing 2.1 g. The induced activity was measured in a low-background laboratory by a Canberra semiconductor spectrometer with an energy resolution of 2 keV on the 1332 keV ^{60}Co gamma line. The $^{87,88}Y$ weighted average yields were measured for 40 MeV bremsstrahlung quanta and ^{88}Y weighted average yield was measured for 20 MeV bremsstrahlung quanta for the first time. The following weighted average yields were obtained for E^{bd} = 40 MeV: $Y(^{88}Y) = 242 \pm 15$ μb and $Y(^{87}Y) = 176 \pm 15$ μb; for E^{bd} = 20 MeV: $Y(^{88}\mathrm{Y})$ = 970 ± 90 μb.

The dominance of semi-direct processes is stated according to the simulation results within the TALYS 1.96 program code.

STUDY OF REACTIONS WITH THE α-PARTICLE EMISSION AT E^{max} = 20 MeV ON NATURAL ZIRCONIUM TARGETS

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Data of the cross sections and population yields of high-spin isomeric states in reactions with the emission of charged particles makes it possible to obtain various information both on the structure of excited levels in the continuous and discrete excitation regions and on the nuclear reaction mechanisms. Therefore, the present work aim is to study the ^{87,91,92}Sr yields in reactions with bremsstrahlung quanta for energies in the region of the giant dipole resonance on zirconium isotopes.

The study of weighted average yields was carried out by the activation method by 20 MeV bremsstrahlung gamma quanta on targets of natural metallic zirconium.

The spectra of irradiated targets were measured using Ortec and Canberra gamma spectrometers with a 15–40% detection efficiency compared to a 3'×3" NaI(Tl) detector. The energy resolution of the spectrometers was 1.8–2.0 keV at the 1332 keV ^{60}Co gamma line.

Gamma transitions from the ^{87m}Sr and ^{91,92}Sr decays are reliably identified in the studied spectra. The weighted average yields of ^{87m}Sr and ^{92}Sr occupation in the (γ, α)-reaction, as well as ^{91}Sr in the (γ, α*n*) reaction, were studied for the first time on natural zirconium for 20 MeV bremsstrahlung gamma quanta. The following weighted average yields were obtained: for ^{87m}Sr (I^{π}=1/2^{-}) $Y = 6.9 \pm 0.7$ μb, for ^{91}Sr $Y = 14 \pm 3$ μb, for ^{92}Sr $Y = 5.5 \pm 0.6$ μb.

The dominance of non-statistical processes is stated according to the simulation results within the TALYS 1.96 program code.

STUDY OF RADIONUCLIDE YIELD IN PHOTONUCLEAR REACTIONS ON NATURAL IRON

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The study of the atomic nuclei photodisintegration is one of the important tasks of fundamental nuclear physics, since a quantitative comparison of such important branches of giant resonance decay as (γ, n) and (γ, p) channels has not yet been carried out. This is due to the limited measurements of photoproton cross sections. Data of the radionuclide yields on iron atoms are also important for the development of photoactivation analysis of various origin structural materials.

We have studied the weighted average yield of the (γ, *p*) reaction for ^{57}Fe upon irradiation of natural composition iron targets. The targets were irradiated with 20 MeV bremsstrahlung quanta. Irradiated targets were measured by an Ortec semiconductor spectrometer with a high purity germanium detector. The 847 keV γ-line from the ^{56}Mn decay was reliably distinguished in the spectra, as well as by the half-life measurement method. As a result, the weighted average output $Y(\gamma, p)=5.1 \pm 0.6$ mbn was obtained. However, calculations of this output using the Talys 1.96 code results $Y_{T} = 1.1$ mbn. This value indicates a large role of non-statistical processes. We also considered the mechanism of semidirect reactions, taking into account the isospin splitting of the resonance, and we obtained the value $Y_{I} = 1.5$ mbn.

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STUDY OF (γ, *p*)-REACTIONS ON NICKEL ISOTOPES

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The study of photonuclear reactions on nickel isotopes is of great fundamental and applied importance. The study of (γ, *n*)- and (γ, *p*)-reactions on nickel isotopes makes it possible to study the nature of direct, semi-direct, and statistical processes in such nuclei region.

We have carried out activation studies of weighted average yields of (γ, *p*)-reactions for ^{58,62}Ni with the 20 MeV bremsstrahlung beam on natural nickel targets. The spectra of irradiated targets were measured using a Canberra semiconductor spectrometer with an energy resolution of 0.75 keV at the 122 keV γ-line and 1.7 keV at the 1378 keV γ-line.

The ^{57,61}Co activities were reliably identified in the studied spectra. Moreover, the ^{61}Co activity was reliably detected using the 909 keV γ-line, which made it possible to minimize the error in measuring the gamma spectra of "thick" targets. As a result, the following values of the weighted average yields of (γ, *p*)-reactions were obtained: for ^{57}Co $Y = 15.1 \pm 0.7$ mb, for ^{61}Co $Y = 1.61 \pm 0.16$ mb.

Based on the simulation results within the TALYS 1.96 program code, the following values were obtained: for ^{57}Co $Y = 6.5$ mb, for ^{61}Co $Y = 0.44$ mb.

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APPLICATION OF UNFOLDING METHOD FOR OBTAINING NUCLEAR DATA

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The unfolding method is a well-known technique used in nuclear physics. This method is usually used to unfold the neutron spectrum based on a measurement of neutron activities in various energy ranges and known cross sections for reactions of interest. But it has also found application in various fields of nuclear physics. The basis of this method is that the activity measured in an experiment, when the activity is induced by nuclear reaction, is proportional to the product od the cross section for the reaction and the flux of the projectile particles. Then, combining the measurements of activities with the well-known values of one of the spectrum involved, the other one can be determined from the set of initial assumptions about the spectrum (default), which can be a theoretical calculation or any other available source. This spectrum is then unfolded in order to better describe the experimentally obtained results.

This allows for various usage of the unfolding methods within the field of nuclear physics, which will be presented here. It can be used to approximate the presence of neutrons at the place of the HPGe detector based on the activities of activated Ge isotopes after the interaction of the neutrons with the nuclei of the detector. By using the theoretical spectrum for the neutron flux from cosmic rays at ground level, this spectrum can be unfolded to better describe the actual neutron spectrum at the position of HPGe detector [1]. In the case of photo-nuclear reactions, if the photon flux is well known, based on the measured activities, it is possible to test various theoretical values of cross section by inserting them as a default functions and comparing the unfolded spectrum with the theoretical spectrum [2]. In case of photo-nuclear reaction where the cross section is well known, it can be used to determine the photon flux, by using the theoretical bremsstrahlung spectrum as a default function.

In this work, we will present previously done work and possible future applications of the unfolding method in the field of nuclear physics.

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DIRECT REACTIONS AND SYNTHESIS OF COLD HEAVY NUCLEI

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The cross-section of the superheavy element's yields produced in collision of heavy ions is extremely small. One of the main reasons for this smallness comes from the fact that the compound nucleus produced in this collision possesses the excitation energy which substantially exceeds its fission barrier and therefore practically immediately performs fission into the two fragments. Moreover, even the meager amount of the surviving superheavy elements immediately starts neutron evaporation and leaves the region of the most stable superheavy isotopes.

To minimize the influence of these processes one might use direct reactions of alpha-particle knock on by the incident ion and heavy fragment stripping of this ion. In these reactions a major part of the projectile is transferred to the target and forms a superheavy nucleus while alpha particle might carry away the major part (sometimes practically all) of the system's excitation energy. Very fast alpha-particles created in these processes were first observed by the FNLR experimental group at JINR back in 1980s (see refs. in [1]) practically simultaneously with the theoretical explanation of their results in terms of heavy particle stripping or knock-on reactions (see e.g. [2]). It was pointed that registration of alpha-particles with energy close to the kinematical two-body limit $E^{(2)}_{\alpha,\mathrm{lab}}$ meant that the new heavy nuclei with *Z* equal to the sum of the target Z_T and projectile Z_P charges minus 2 was created in the observed reaction.

These experiments are renewed now on the U-400 accelerator at FNLR. The use of the new high resolution magnetic analyzer and detector system allows to measure light particles at the high-energy end of the spectrum whose yield is about $10^{-6} - 10^{-8}$ of the yield at maximum. The experiments are performed with the different sets of the projectiles and the targets. Practically for all those sets alphas were observed close to the two-body limiting energies $E^{(2)}_{\alpha,\mathrm{lab}}$. However, in the case of the possible nucleus production with $Z_f = (Z_P + Z_T) \geq 99$ alpha-particles with energies exceeding $E^{(2)}_{\alpha,\mathrm{lab}}$ were observed. A possibility is considered that this indicates a new type of the direct process which might be named “direct fission”. If the binary nuclear system created in the peripherical collision of the projectile and the target closely resembles the excited heavy nucleus in the process of fission into two asymmetric fission projects, then the emitted alpha-particle might also carry a part of the *Q*-energy produced in fission.

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A NOVEL APPROACH FOR TAKING INTO ACCOUNT THE ZERO-POINT OSCILLATIONS IN CALCULATING HEAVY-ION FUSION CROSS-SECTIONS

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It had been shown [1] that accounting for the zero-point oscillations (ZPO) of the shape of colliding complex nuclei results in increasing substantially the calculated sub-barrier capture (fusion) cross-sections. Calculations in [1] was made in a simplified way with a schematic nucleus-nucleus potential.

In the present work we develop an advanced method for taking into account the ZPO of quadrupole mode for both collision partners. Within this method we evaluate the sub-barrier capture cross-sections for several reactions and compare the results with the experimental data. In our novel approach, the nucleus-nucleus bare potential results from the semi-microscopic double-folding model with M3Y-Paris nucleon-nucleon forces [2, 3]. For this aim, we generalize the earlier published code [4]. In this generalization, we heavily rely on [5].

The nucleon densities come from the Hartree–Fock–Bogoliubov calculations [6]. For each collision partner, about 10 quadrupole deformations are accounted for with the appropriate probabilities. The transmission coefficients are evaluated by means of the WKB approximation below the barrier and using the single parabolic barrier approximation above the barrier.

Neglecting the ZPO typically results in the theoretical sub-barrier cross-sections to be below the data whereas accounting for the quadrupole ZPO often improves the situation.

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COUPLED CHANNEL METHOD WITH ASYMPTOTIC COUPLING FOR HEAVY ION NUCLEAR REACTIONS

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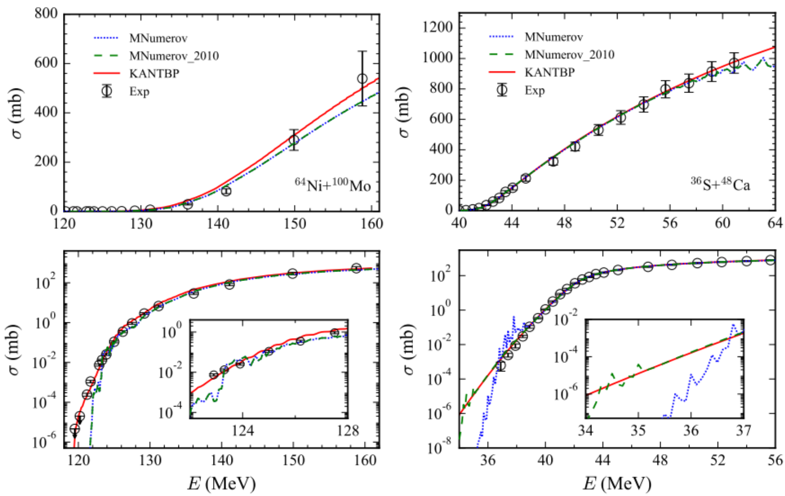
We have applied the new version of coupled channel method with asymptotic coupling of the exit channels to the computation fusion cross sections and the astrophysical S-factor of sub-barrier and above-barrier reactions to study the deep sub-barrier fusion hindrance phenomenon in [1, 2]. It applied also to study fusion reaction ^{40}Ca + ^{208}Pb, leading to the formation of the transfermium nucleus ^{248}No [3]. The results obtained using modified KANTBP 3.1 code [4] and the modified Numerov method in the CCFULL code [5] were compared. For example, see fusion cross sections ^{64}Ni + ^{100}Mo and ^{36}S + ^{48}Ca in figures.



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THEORETICAL STUDY OF THE REACTIONS LEADING TO PRODUCTION OF NEW SUPERHEAVY NUCLEI

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The major goals of modern superheavy element physics are the production of superheavy elements with Z = 119, 120 and the synthesis of neutron-enriched isotopes, thereby advancing to the center of the “island of stability” (the neutron shell with $N = 184$).

In this talk, a multidimensional dynamical model of nucleus-nucleus collisions based on the Langevin equations [1, 2] has been used for analysis of reactions of ^{48}Ca ions with actinide target nuclei. The cross sections of capture and fusion as well as the cross sections of evaporation residues for two combinations of colliding nuclei ^{48}Ca + ^{244}Pu and ^{48}Ca + ^{248}Cm have been studied. The possibilities of obtaining new neutron-enriched isotopes of superheavy elements in pxn channels have been analyzed.

The analysis of the competition of quasi-fission and fusion-fission processes in the reactions leading to the formation of 119 and 120 elements has been done in the framework of the dynamical model.

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DIFFUSENESS OF NUCLEON DENSITY DISTRIBUTION AND DOUBLE-FOLDING NUCLEUS-NUCLEUS POTENTIAL

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Description of the internuclear interaction is the one of the most important tasks in analysis of various nuclear reactions. In particular, the position and height of the barrier determined by Coulomb and nuclear interactions should be estimated in order to evaluate general properties of fusion of heavy nuclei.

The calculations of fusion barriers are carried out within the double-folding approach assuming the diabatic regime of collisions of heavy ions with $Z, N > 9$. Nucleon density distributions are required to calculate the double-folding potential [1, 2]. Thus, radial parameters of nucleon densities given in the Fermi-distribution form are approximated on the basis of *rms* charge radii [3]. According to experimental data [4], diffuseness parameters of nucleon distributions are not clearly correlated with *Z, N, A* of corresponding nucleus and have significant uncertainties. Therefore, the diffuseness values were fitted to reproduce the Bass barriers [5] for spherical nuclei (fig. 1). Potential barriers obtained in such a way can be used as estimation of fusion barriers in heavy ion reactions.

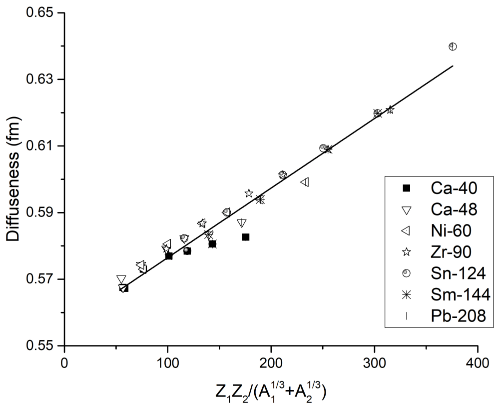

Fig. 1. Fit of the duffuseness values obtained from comparison with the Bass barrier.

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RELATIVE PROBABILITY OF HIGH-SPIN ISOMERIC STATES POPULATION IN (α, *n*)-REACTIONS

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Experiments which were performed by use of the alpha-particle beam of SINP MSU cyclotron are the subject of the present talk. Results of the investigations of the relative yield of high-spin and low-spin isomers in reactions ^{86}Sr (α,n)^{89}Zr, ^{112}Sn(α,n)^{115}Te, ^{134}Ba (α, *n*)^{137}Ce in the energy range of the alpha particles 15–31 MeV based on off-beam measurements of induced activity of members of the isomeric pair are presented.

Uniquely large isomeric cross-section ratios for the first and the second reactions are obtained. The features of the third reaction, which are promising for its application in fundamental research, are revealed. The first of the reactions can also be used as an injection reaction for generating beams of high-spin isomers.

Quality of the description of such reactions by popular computer codes is analyzed and some problems of these codes are detected.

FRAGMENTATION OF NUCLEI UNDER RADIATION ACTION OF VARIOUS TYPE

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The study of the mechanisms of formation and decay of an excited nucleus is important for describing the characteristics of fragments of a nuclear reaction [1]. The applied significance of this problem lies in the use of various types of radiation in experiments to determine the radiation effects in the electronics. The single event effects on onboard electronics can occur not only from direct medium ionization by primary ions, but also from the effect of charged fragments of the nuclear reactions on the sensitive volumes of electronic circuit assemblies [2].

We study the influence of the primary particle of ionizing radiation on the mechanism of relaxation of the excited nucleus, as well as on the distribution of heavy secondary ions with the nuclear charge $Z > 2$ during the passage of protons, gamma rays and relativistic electrons through silicon. The interaction cross section and secondary ion energy distribution at the moment of decay of an excited nucleus were calculated using the GEANT4 [3] and TALYS [4] programs. A new analytical approximation for secondary heavy ion distribution in terms of linear energy transfer is proposed.

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THE MSU SINP CDFE IN THE NUCLEAR REACTION DATA CENTRES NETWORK

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About 50 years ago international community started the job in compilation, computer processing and dissemination of nuclear data essential to the development and application of nuclear sciences and technologies. The scope of the IAEA Network of Nuclear Reaction Data Centres (NRDC) includes nuclear data for both various applications, as well as for basic nuclear science. The important preparative and communication activities between 14 nuclear data centres from Austria, China, France, Hungary, India, Japan, Korea, France, Russia, Ukraine, USA are organized under the auspices o the IAEA. Each of the centres provides coverage for different geographical zones and/or specific types of nuclear data, thus together providing a complete service for users worldwide. The three of Russia centres participate now – Center of Nuclear Physics Data (CNPD), All Russian Scientific Research Institute of Experimental Physics, Sarov; Russian Nuclear Data Center (CJD), Institute of Physics and Power Engineering, Obninsk; Centre for Photonuclear Experiments Data (Centr Dannykh Fotoyadernykh Eksperimentov, CDFE), Moscow State University Skobeltsyn Institute of Nuclear Physics, Moscow. The NRDC Network coordinated by the IAEA Nuclear Data Section successfully collaborates in the maintenance and development of the digital EXFOR library, the most comprehensive nuclear reaction data collection [1–3]. More than 20000 experimental studies of neutron, charged-particle, and photon induced reaction data are accumulated [4]. In addition to the EXFOR library many other nuclear databases (DB) convenient for using in scientific research and educational processes are available through Internet.

The MSU SINP CDFE is responsible for providing photonuclear data for various organizations in Russia, primarily scientific and educational institutes and organization of Russian Academy of Science. All data are organized as relational DB on the CDFE Web-site (http://cdfe.sinp.msu.ru) [5] with powerful and flexible Search Engines. That gives to one the possibility for effective surfing the data needed for new nuclear reaction and nuclear structure physics researches.

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2. USA National Nuclear Data Center Database "Nuclear reaction experimental data EXFOR", http://www.nndc.bnl.gov/exfor/exfor00.htm.
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CHARGE EXCHANGE PROCESSES IN CARBON IONS FRAGMENTATION AT 300 MeV/NUCLEON: A COMPARISON WITH MODELS OF ION-ION INTERACTIONS

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The study of ion-ion interactions at high energies is one of the main directions of modern nuclear physics. A significant number of Monte Carlo models have been developed in this direction, that require both experimental verification and improvement of their basic approaches. Also, the processes of nucleon charge exchange in ion fragmentation are poorly studied. There are only a few experiments performed in energy range 1–2 GeV/nucleon and only for isobaric transitions [1, 2].

The experimental data were obtained at the FRAGM facility of the ITEP−TWAC heavy-ion complex for ^{12}C fragmentation at 300 MeV/nucleon on a beryllium target [3, 4]. Fragments were detected at an angle equal to 3.5^0 with respect to the incident ion beam. The fragmentation of carbon ions leads to the production of three long-lived isotopes as a result of single nucleon charge exchange: ^{11}Be (7 neutrons), ^{12}B (7 neutrons), ^{12}N (7 protons). Isotopes ^{11}Be and ^{12}B were found and their momentum spectra were measured. The predictions of four Monte Carlo models of ion-ion interactions (BC, INCL, LAQGSM, and QMD) were tested if they can describe the experimental momentum spectra of the fragments. The binary cascade (BC) model gives the best description.

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MEASUREMENT OF THE NEUTRON YIELD FROM ^{13}C(α, n_0)^{16}O REACTION

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The ^{13}C(α, *n*)^{16}O reaction is important for some application including neutrino measurements, nuclear astrophysics and nuclear power industry. The measurement of the total neutron yields (TNY) from this reaction has a high priority [1] because this data are used for normalization and testing the experimental data and the cross-section evaluations. The existing sets of experimental data on TNY were measured with uncertainty >10% due to the uncertainty of the ^{13}C content in natural graphite.

The goal of the work is the independent check and normalization of the ^{13}C(α, n_0)^{16}O reaction cross-section data measured in 2021 [2]. The differential spectra of neutrons and the total neutron yields from the ^{13}C(α, n_0)^{16}O reaction were measured in the energy range 3–6.5 MeV using the thick carbon target enriched in ^{13}C. The time-of-flight method was used to determine the neutron energy and to separate the neutrons corresponding to ground state of the residual nucleus. The ^{13}C enrichment and the elemental composition of the target were determined using the ion beam analysis methods. The obtained TNY values were compared with ones calculated based on the ENDF/B-VIII.0 evaluation.

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NUCLEI IDENTIFICATION BY MULTIPLE ENERGY LOSSES IN DETECTORS OF THE PAMELA SPECTROMETER

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PAMELA magnetic spectrometer [1] includes a set of detectors, each of which measures the energy losses of charged particles along its trajectory. In total, it is possible to obtain up to 6 values of energy loss in detectors of the time-of-flight system, up to 12 values in the track system, and up to 43 values in the calorimeter. This information combined with rigidity and velocity measurements can be used for effective identification of particles.

We propose two algorithms for identification of nuclei with atomic numbers 1–26 (from protons up to iron): the first algorithm is based on maximum likelihood estimation method, and the second is based on machine learning. For both algorithms we performed Monte-Carlo simulation of particles interaction in detectors of PAMELA with Geant4 software [2].

The first algorithm consists of the following steps.

1. Fit the energy loss distributions in simulation for each detector depending on particle type and magnetic rigidity R by a 2-parametric family of distributions $f(x;\mu,\sigma)$.

2. Approximation of the relation between parameters (μ,σ) and particle rigidity by some functions $\hat{\mu}(x)$ and $\hat{\sigma}(x)$. As a result, we obtain a set of functions $\hat{\mu}_{ij}(x)$ and $\hat{\sigma}_{ij}(x)$ for each nucleus number (charge) i and detector number j.

3. After that, we can apply an algorithm to the experimental data. For each nucleus type calculate a likelihood function (where R – is magnetic rigidity):

$$L_i(R) = \sum_{j=1}^{N} \ln f\left(R; \hat{\mu}_{ij}(R), \hat{\sigma}_{ij}(R)\right)$$

The result of an identification algorithm is a nucleus n, which minimizes $L_i(R)$:

$$\hat{n} = \operatorname{argmin}_i L_i(R).$$

The second method is based on machine learning using the gradient boosting method, which is currently one of the reference methods of classical learning [3]. The magnetic rigidity and energy releases along the trajectory are used as features.

We present the results of each of the above methods separately, as well as in comparison with each other.

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THE CROSS-SECTION OF NUCLEAR-TUNGSTEN INTERACTIONS OBTAINED WITH MEASUREMENTS OF COSMIC RAYS BY PAMELA

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The aim of this work is to study the cross-section of the inelastic interactions of nuclei with tungsten based on the data of PAMELA space experiment [1]. This instrument is a magnetic spectrometer designed to study fluxes of charged particles in cosmic rays, which was launched into the near-Earth orbit aboard the Resurs-DK1 satellite; data collection continued from 2006–2016. PAMELA includes a set of detectors which helps to identify the particles including their magnitude and sign of charge, rigidity, velocity, mass and energy.

So, we can select from the PAMELA data a necessary component of cosmic rays with known particles and their energy coming at a known angle. At the same time, another detector - a coordinate-sensitive calorimeter with a tungsten absorber plays a role of target for these particles. This looks like an experiment in particle physics on accelerators with formation of a beam of particles and observation of its interaction in target. Thus, it becomes possible to study the characteristics of nuclear-nuclear interactions with a large number of different nuclei in a beam according to chemical composition of cosmic rays in a wide energy range from hundreds of MeV to ~TeV.

A similar method is used in ground-based observations of ultrahigh-energy cosmic rays; however, in this work, we use the previously proposed method relies on a much larger amount of information about cosmic ray particles due to the precision nature of the PAMELA measurements [2].

In the report, we present the experimental cross sections for the interaction of nuclei from protons to carbon with tungsten nuclei obtained by the described method. Obtained results compared with the cross-sections reconstructed from the simulation data coming from Geant4 software package [3], with measurements at accelerators and existing theoretical models.

Results can be used to improve our knowledges about nuclear forces and expand the standard Geant4 hadronic models and other numerical packages describing the interaction of particles with matter.

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MEASUREMENT OF THE REACTIONS WITH LIGHT NUCLEI BY AMBER EXPERIMENT AT CERN

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The recently approved NA66/AMBER experiment (Apparatus for Meson and Baryon Experimental Research) at the CERN Super Proton Synchrotron pursues a broad research program [1]. An essential part of the program is a measurement of the antiproton production cross section in proton-helium collisions, which will provide much needed input for the searches of Dark Matter. This, as well as other proposed experimental studies to address the various aspects of the so-called Emergence of Hadron Mass mechanism: the proton and mesons charge radii, the mesonic parton momentum distributions, will be discussed.

1. COMPASS++/AMBER: Proposal for Measurements at the M2 beam line of the CERN SPS Phase-1: 2022-2024, CERN-SPSC-2019-022; http://cds.cern.ch/record/2676885.

SOLAR NEUTRINOS CAPTURE BY MOLYBDENUM 98 AND 100 NUCLEI

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In calculating the cross section for neutrinos interaction with atomic nuclei $\sigma(E_\nu)$, it is necessary to calculate the structure of the charge-exchange strength function $S(E)$ of nucleus, which has a resonant character. The work presents calculations of the solar neutrinos capture cross-section $\sigma(E_\nu)$ by ^{98,100}Mo nuclei. In calculations the experimental data on strength function $S(E)$, received in charge-exchange reactions (p, n) [1] for ^{98}Mo and (^{3}He, t) [2, 3] for ^{100}Mo was used. Calculations of the charge-exchange strength function $S(E)$ for these nuclei were performed as part of the self-consistent theory of finite Fermi-systems. The resonance structure of the strength function $S(E)$ was analyzed and Gamow–Teller (GTR) [4], analog (AR) [5] and pigmy resonances (PR) [6] were distinguished. The effect of the resonant structure $S(E)$ on the calculated solar neutrino capture cross section $\sigma(E_\nu)$ and solar neutrino capture rate R (number of absorbed neutrinos per unit of time) was studied. It was shown that the contribution of GTR and PR to $\sigma(E_\nu)$ and R values for ^{98}Mo is significant ~ 40%, but for ^{100}Mo this contribution is small due to the influence of low-energy solar neutrinos, which are orders of magnitude larger. It was noted that the capture of solar neutrinos by the ^{100}Mo nucleus is the background process in the double beta decay study of this nucleus.

This work was supported in part by a grant from the Department of Neutrino Processes and an internal grant from the National Research Center "Kurchatov Institute" (No. 2767 dated 28.10.2021).

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CROSS SECTION OF NEUTRINO ABSORPTION BY ^{82}Se NUCLEI

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Selenium-82 is a perspective isotope for neutrino investigations. Recently in experiments, produced with the help of NEMO-3 detector [1], which is composed of a tracker and a calorimeter, capable to reconstruct the full topology of ββ processes and measurements, performed at CUPID-0 setup [2], based on Zn^{82}Se scintillating crystals, operated as cryogenic bolometers, nuclear mechanism of ^{82}Se 2ν2β-decay have been examined. It was shown, that contribution of the single lowest excited 1^+-level of intermediate nucleus ^{82}Br dominates in the transition amplitude. It should be noted that for ^{82}Se the quantum numbers of intermediate nucleus ^{82}Br ground state are 5^-, so transition via this state is strongly suppressed. Contribution of excited 1^+-states to 2ν2β-transition amplitude was considered in [3].

The lowest excited 1^+-level of ^{82}Br, E_x = 75 keV, and corresponding

Gamow–Teller strength have been determined in a high-resolution ^{82}Se(^{3}He, *t*) ^{82}Br charge-exchange experiment [4]. Low value of threshold for neutrino absorption reaction together with considerable magnitude of transition strength to 75 keV (1^+) state make ^{82}Se to be interesting object both for solar neutrino detection and for measurements, aimed at investigation of new physics in calibration experiments.

The cross sections of absorption by ^{82}Se nucleus of neutrinos, produced by artificial sources ^{51}Cr, ^{37}Ar, ^{65}Zn are calculated. The parameters of experimental setup on the base ^{82}Se for searching of new types of neutrino are discussed.

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STUDY OF THE MECHANISMS OF HADRON-NUCLEAR INTERACTIONS ON THE POSITIVE BEAM LINE 18 OF U-70 ACCELERATOR

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The aim of the project is to study the mechanisms of hadron-nuclear interactions at the Hyperon experimental setup located on beam line 18 of the U-70 accelerator complex, Protvino. It is proposed to upgrade the setup so that to be able to study additionally the excited states of secondary nuclei by means of precision nuclear gamma-ray spectroscopy in dependence on the specific type of interaction of hadrons with target nuclei. Of particular interest is the newly discovered d*(2370) dibarionic state formed both in vacuum and in the composition of light nuclei, where it can presumably replace deuteron clusters. Precision gamma-ray spectroscopy makes it possible to differentiate these cases. Further detailed study of these phenomena is necessary. It opens up a new direction in nuclear physics at the junction with the particle physics of intermediate energies.

The project will be carried out on the basis of the existing Hyperon-M experimental setup of NRC "Kurchatov Institute" – IHEP. The main detector of the setup is the cherenkov lead glass photon spectrometer LGD2 used for detection of energetic photons in the forward hemisphere of reaction $\pi^+ A \to M^0{}_{\to k\gamma} A'$. To fulfill the tasks of the new project, it is proposed to upgrade the setup with the Charged Particle Veto (CPV) and Gamma Nuclear Transition (GNT) detectors. The CPV detector is a system of segmented scintillation counters dedicated for detection of the secondary charged particles in a solid angle close to 4π. For detection of the scintillation light the SiPM type photodetector will be used. The GNT detector is dedicated for precision measurement of photon energies in nuclear gamma-transitions of secondary nuclei formed as a result of the interaction of beam particles with target nuclei. The energy spectrum of these photons lies in the range from 0.25–MeV.

After the gradual modernization of the setup to the Hyperon+ level, it is planned to expose the setup on the positive beam line with the momentum of 7 GeV/*c* for several nuclear targets (Li, Be, B, C, O) and obtain experimental data for a detailed analysis of $2\pi^0$ systems formed, among other things, as a result of the decay of $d^*(2370) \rightarrow > d + 2\pi^0$ both in vacuum and inside the target nucleus.

DEUTERON BEAM VECTOR POLARIZATION MEASUREMENT USING PROTON-PROTON QUASIELASTIC SCATTERING AT THE ENERGIES FROM 200 TO 650 MEV/NUCLEON

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The deuteron beam vector polarization was obtained at the Nuclotron Internal Target Station using quasielastic proton-proton scattering on the polyethylene target. The selection of useful events was performed using the time and amplitude information from scintillation counters. The asymmetry on hydrogen was obtained by the subtraction of the carbon background. The values of vector polarization were obtained at the beam energies of 200, 500, 550, and 650 MeV/nucleon. The obtained values are compared with the data obtained in the deuteron-proton elastic scattering at the beam energy of 135 MeV/nucleon.

CONSTRUCTION MANAGEMENT INFORMATION SYSTEM AT JINR

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Earlier this year the commissioning of an all-around Construction Management information System (CMIS) was completed as a joint effort of two JINR Laboratories (LHEP and LIT). The system is particularly useful for the fine-grained control and continuous feedback of the production of complex multipart objects like the detectors subsystems composing the Multi-Purpose Detector of the NICA facility at LHEP. The structure and functionalities of CMIS at JINR are based on a previous system developed by Kybernetika s.r.o.(Slovak Republic) for the upgrade of the Inner Tracking System of the ALICE experiment at CERN and was reconfigured to be transferred and deployed on the available computational platform of JINR in a joint effort by specialists from Kybernetika and JINR's LIT and LHEP. The system is composed of a web user interface and a collection of web-accessible API functions that are connected to an Oracle database. The CMIS may hold several projects at the same time and for each of them it allows to control several aspects of the production process including (but is not limited to) the human resources, the project organization and planning, as well as the current status and tests results history of every component of the detector consenting for the direct interfacing of the assembly and testing hardware/software to the construction database, so that information ranging from the current location of a component in-transit to/from an assembly site down to the final position of a single chip inside the detector may be tracked down and recorded.

Currently, the CMIS is meant to be used to follow the production of silicon tracker detectors at the STS department of the LHEP at JINR but since it is centrally hosted at LIT it might be also used by other hardware production projects at JINR (or outside) whose complexity would make it very hard to fulfilling its quality and timing requirements otherwise.

INVESTIGATION OF FISSION MODES OF ^{248}Cf AND ^{254,256}Fm FORMED IN THE REACTIONS WITH HEAVY IONS

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The role of closed proton and neutron shells in the fission of ^{248}Cf* and ^{254,256}Fm* nuclei at excitation energies from 40 to 56 MeV was studied. Earlier, multimodal fission of the light ^{233}Pa* [1] as well as the heavy ^{260}No* [2] actinide nuclei was observed. Moreover, for these nuclei the manifestation of the super-asymmetric fission mode was found. To check the presence of the fission modes in the central region of actinide nuclei the mass-energy distributions of fragments formed in the ^{16}O + ^{232}Th and ^{16,18}O + ^{238}U reactions at energies near the Coulomb barrier have been measured. The experiments were carried out at the U-400 and U-400M accelerators at the Flerov Laboratory of Nuclear Reactions using the double-arm time-of-flight CORSET spectrometer [3]. An increase in the mass yields in the asymmetric region caused by the shell effects was observed. To describe the mass and energy distributions of the fission fragments a multimodal analysis was performed.

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STUDY OF EXCITATION FUNCTIONS FOR TRANSFER REACTIONS ^{197}Au(^{3}He, *d*)^{198}Hg AND ^{197}Au(^{3}He, *t*)^{197}Hg WITH ^{3}He BEAMS AT ENERGY UP TO 30 MeV

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In charge-exchange reactions, only charges of atomic nuclei change, while the total number of nucleons is preserved. Charge-exchange reactions are a particular case of transfer reactions. Charge-exchange reactions (^{3}He, *t*) as well as reactions (*n*, *p*) play a special role. These reactions lead to excitation of isobar-analogue and other single-particle states in the residual nucleus.

The integral cross sections for such reactions can reach the values of 100 mb at the energy of the beam of bombarding particles near the Coulomb barrier and up to 10 MeV/nucleon [1].

The excitation functions for the reactions ^{45}Sc(^{3}He, *t*)^{45}Ti, ^{194}Pt(^{3}He, *t*)^{194}Au, and ^{197}Au(^{3}He, *t*)^{197}Hg were measured in [1]. It was shown that charge-exchange reactions belong to the class of peripheral reactions [2].

At the U-120M cyclotron of the Institute of Nuclear Physics in Řež, Czech Republic, experiments were carried out to measure emission of deuterons and tritons at different angles in the reactions ^{197}Au(^{3}He, *d*)^{198}Hg and ^{197}Au(^{3}He, *t*)^{197}Hg. The measurements showed that the energy and angular distributions of deuterons and tritons are sensitive to the impact parameter of the colliding nuclei and to the transferred angular momentum. The angular distributions of emitted deuterons for the reaction ^{197}Au(^{3}He, *t*)^{197}Hg have a maximum at the grazing angle for this reaction (68° in the laboratory system).

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STUDY OF MULTINUCLEON TRANSFERS IN REACTIONS WITH ^{48}Ca IONS ON Au, U TARGETS AT AN ENERGY OF 280 MeV

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Recently, there has been increased interest in experimental studies on the production of new isotopes in multinucleon transfer reactions [1, 2]. Reactions on 48Ca ion beams are successfully used for the synthesis of new nuclei in a wide range of masses and charges. In particular, it is of interest to obtain new isotopes with the number of neutrons $N = 126$ in the reaction channels of multinucleon transfers [3]. To estimate the cross sections for the formation of nuclei in these reactions, we conducted an experiment on their detection. In the experiment, nuclei with masses greater than the target mass values were measured.

The experiment was carried out on a ^{48}Ca (5,8 MeV/nucleon) ion beam using ^{197}Au (6 μm thick) and ^{238}U (1 μm thick) targets. Specially prepared targets were irradiated on a beam of accelerated ions, on a cyclotron U-400 at the FLNR JINR. The activation method was used to identify the nuclei formed in the reactions. Measurement of induced activity (gamma and alpha) was carried out in the "off-line" mode.

In the reaction of ^{48}Ca+Au, neutron pickup channels for 1n and 3n were measured. The cross sections of these channels were σ(+ 1*n*) – 150 mb and σ(+ 3*n*) – 0.5 mb, respectively. The GRAZING [4] code used to analyze the obtained values gives a good agreement with the experimental results.

In the ^{48}Ca + Au reaction induced alpha activity of ^{206}Po nuclei was observed, which corresponds to the transmission channel (+ 5*p* + 9*n*) from the projectile nucleus to the target nucleus.

The ^{48}Ca+U reaction products were measured using an alpha spectrometer. Among the products, the nuclei ^{228}Th, ^{239}Am, ^{255}Fm were identified by the measured half-lives and characteristic energies of alpha particles. These products correspond to the following channels ^{238}U(–2*p*, –8*n*) → ^{228}Th, ^{238}U(+3*p*, –2n) → ^{239}Am, ^{238}U(+8*p*, +9*n*) → ^{255}Fm. The value of the section of these channels σ(^{228}Th) ~ 55 μb, σ(^{239}Am) ~ 1.2 μb, σ(^{255}Fm) ~ 2.2 μb.

Thus, the cross section data show that such reactions are suitable for obtaining nuclei of multinucleon transfers. Further analysis of the obtained data is underway.

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RADIATIVE CAPTURE IN THE ^{4}He + ^{2}H SYSTEM IN THE FRAMEWORK OF A MICROSCOPIC APPROACH

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The ^{4}He + ^{2}H system is of great importance for nuclear astrophysics because the radiative capture proceeding in this system is responsible for production of the ^{6}Li nuclei during the primordial nucleosynthesis. In this work, the ^{4}He + ^{2}H radiative capture reaction is considered from the microscopic viewpoint within a developed approach [1, 2] based on clustering aspects of nuclear structure and dynamics and formalism of expansions over the oscillator basis. The cross section of the reaction in terms of the astrophysical *S* factor is calculated. The low-energy dependence of the total astrophysical *S* factor serves as a source of information useful for the so-called second “lithium puzzle”. A comparison of the obtained results with experimental data is performed.

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MUON CAPTURE ON THE DEUTERON. THE MUSUN EXPERIMENT

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This article present the result of the MuSun experiment, precise measurement of muon capture rate by deuteron (L_d). The rate of the reaction μd (F = 1/2) → $\nu_\mu + n + n$ is measured with precision 1%. That accuracy makes it possible to fix the low-energy constant (LEC) in an effective EFT field theory in a model-independent way. After that this makes it possible to reliably calculate the cross sections of weak reactions in two−nucleon processes, for example, such as pp synthesis going to the sun $p + p \to d + e + \nu_e$ or neutrino scattering on deuteron $\nu_e + d \to p + p + e^-$.

The experiment performed on a muon beam of the Swiss Meson Factory (Paule Scherrer Institute, PSI). The experimental technique is based on measuring the rate of muon loss in deuterium by registration Michel electrons. The basis of the setup was a time-projection chamber (TPC), an active target filled with deuterium. Decay electrons were detected with a geometric efficiency of 70% by two external cylindrical proportional chambers and scintillation counters. The measurements were carried out at a deuterium temperature of 31 K and a pressure of 5 bar. For additional isotopic purification of deuterium, a cryogenic separation was used, which allows to reduce the concentration by protium to of level 10^{-4}. In this case, the correction of L_d associated with the *pd* synthesis is less than 1 Hz. To reduce the amount of heavy elements in deuterium, a cryogenic circulating purification system was developed. This allow to reduce the presence of impurities in deuterium to $0.5 \cdot 10^{-9}$. Measurement of such a low concentration of impurities was carried out by chromatographic method with cryogenic concentration. In order to reliably determine the L_d correction associated with muon capture on impurities, which is 99% nitrogen, an additional experiment was carried out on a muon beam with the addition of $2 \cdot 10^{-6}$ nitrogen. As a result, the muon transfer rate to nitrogen $L_{dN} = 2.2(1) \cdot 10^{11}$ Hz was measured and corresponding correction to L_d was determined as 1.5 Hz.

At the end of MuSun experiment $1.2 \cdot 10^{10}$ useful events were collected, events with the muon stopping in the sensitive area of the TPC with registration of the decay electron. The statistical error of the measurement is 4 Hz. The main systematic correction to the μd capture rate connects with muon losses in the dd fusion reaction $\mu dd \to {}^3\text{He}\mu + n$. It is reliably calculated as 8.0(1)Hz.

PRELIMINARY DATA OF THE EXPERIMENT ON THE STUDY OF PROTON-PROTON CORRELATIONS IN THE $d + {}^1\text{H} \rightarrow p + p + n$ REACTION

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A value of a neutron-neutron scattering length was obtained in different experiments. It can be observed that there is a spread in values of a neutron-neutron scattering length a_{nn}. In [1] it was suggested that such spread may be explained by influence of 3*N*-forces. It can be assumed that *pp*-scattering length and energy of ${}^1S_0$ virtual state extracted in the $d + {}^1\text{H} \rightarrow n + p + p$ reaction will be influenced by 3*N*-forces and will differ from the value obtained in the experiment with two protons in a final state. To test the assumption, in INR RAS the study of the $d + {}^1\text{H} \rightarrow n + p + p$ reaction is carried out.

In current work a processing of data from several measurements to study the $d + {}^1\text{H} \rightarrow n + p + p$ reaction with registration of protons from the breakup of a *pp*-system and a recoil neutron is discussed. The proton energy spectrum was obtained in these measurements. A comparison of obtained experimental spectrum with the simulated ones that correspond to different values of virtual *pp*-state energy was carried out. As the comparison result the estimation of possible value of proton-proton energy state was done.

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EXPERIMENTS TO SEARCH FOR SINGLET DEUTERON AND PROBLEM OF THE DINEUTRON

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The possibility of the existence of quasi-stationary state of a neutron and a proton in the ${}^1S_0$ state with a mass slightly less than the sum of the masses of the neutron and proton is discussed in a number of works. This work discusses the manifestations of this level in electromagnetic interactions – radiative capture $np \rightarrow d\gamma$ and scattering of gamma quanta by deuterons. The problem of the existence of the singlet deuteron is connected with the question of the existence of the dineutron. Literature data on this problem are presented.

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DATA ON THE *np*-SCATTERING LENGTH FROM THE *nd*-BREAKUP REACTION AT LOW ENERGIES

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A kinematically complete experiment to determine the *np*-scattering length in the $n + d \rightarrow (np) + n$ reaction on the neutron beam of the RADEX channel of the INR RAS was carried out. In the experiment a recoil neutron as well as a neutron from the breakup of the *np* system was registered. The primary neutron energy and the proton energy from the breakup of the np system was reconstructed from the known emission angles and energies of two neutrons and the fact that a breakup proton was detected in an active deuterated target. The experiment was carried out at low neutron energies 8–13 MeV. The value of the *np*-scattering length was obtained by a comparison of the experimental dependence of the *nd*-breakup reaction yield on the relative energy of the *np* pair with the simulation results. The obtained value of the *np*-scattering length differs significantly from the value obtained in direct *np*-scattering and can be associated with a significant influence of 3*N*-forces.

STUDIES OF EXCITED STATES OF ^{9}Be IN THE REGION OF 11–13 MeV EXCITATION

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The angular distributions for the 11.28 MeV, 11.82 MeV and 13.79 MeV states are obtained from the experiment on the scattering of alpha particles with energies of 30 and 90 MeV on ^{9}Be. The analysis of the obtained data was carried out using the DWBA model, which made it possible to determine the values of the spin-parity of the states under study. Determining the value of the spin-parities made it possible to assign these levels to the corresponding bands in the ^{9}Be nucleus.

A SYSTEMATIC STUDY OF EXCITATION FUNCTIONS IN ALPHA PARTICLE INDUCED REACTIONS AT MODERATE EXCITATIONS: A COMPARATIVE STUDY OF PRE-EQUILIBRIUM EMISSION MODEL CODES

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Excitation functions (EFs) of α-particle induced reactions in the intermediate energy region are of increasing importance for a wide variety of applications e.g., medical radioisotope production, radiation and shielding effects in space and technology development of an accelerator driven system for transmutation of nuclear waste or for energy production [1, 2]. In addition to above mentioned facts the information on the excitation function of residual nuclei is also important for verification of different nuclear models used to explain the reaction mechanism, optimize the production yield, and estimation of the impurities of radioisotopes simultaneously produced. In the frame of a systematic study of excitation functions for production of medically relevant radioisotopes by charged particle induced reactions on rare earths, the ^{165}Ho(α, 2n)^{167}Tm reaction and the ^{165}Ho(α, n)^{168}Tm, ^{165}Ho(α, 3n)^{166}Tm, ^{165}Ho(α, 4n)^{165}Tm side reactions were measured up to 40 MeV employing well established stacked foil activation technique followed by offline HPGe gamma-ray spectroscopy. The measured results were compared to the earlier measurements available in literature. The analysis of measured excitation functions has also been performed using Monte-Carlo nuclear reaction simulation code COMPLET [3], ALICE-91 [4], and TALYS 1.9 [5]. The prime interest of the present work is to perform a quantitative comparison of earlier reported experimental data with those obtained with theoretical model codes, to study the quality/predictability of the model codes and they fit the excitation functions of the experimental values more specially for the medically relevant radioisotope ^{165}Tm.

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CROSS-SECTION MEASUREMENT FOR THE ^{7}Li(p,p'γ)^{7}Li AND ^{7}Li(p,α)^{4}He REACTION

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Reliable data on the ^{7}Li(p, α)^{4}He and on ^{7}Li(p, p'γ)^{7}Li reactions cross section are important for many applications, including fusion and accelerator neutron sources with a lithium target. The existing cross-section datasets in the literature are unfortunately inadequate and discrepant in many cases. Measurements of the reactions cross section were carried out at the accelerator-based neutron source at the Budker Institute of Nuclear Physics (Novosibirsk, Russia) using a NaI, HPGe γ-ray and α-spectrometers. The ^{7}Li(p, p'γ)^{7}Li reaction cross section and 478 keV photon yield from a thick lithium target at proton energies 0.65–2.225 MeV have been measured with high accuracy. The ^{7}Li(p, α^{4}He reaction cross section is determined for proton energies 0.6–2 MeV. The experimental data are compared to the data from literature, when available.

Plans to measure the ^{11}B(p, α)αα neutronless fusion reaction cross section.

The report will describe the neutron source VITA, present and discuss the results obtained, and declare plans.

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DIFFERENTIAL CROSS-SECTIONS FOR ELASTIC BACKSCATTERING OF ALPHA PARTICLES BY CARBON

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Differential cross-sections for ^{12}C(α, α_0)^{12}C scattering have been measured at the 150° and 170° angles for alpha beam energies ranging from 3.5–6.5 MeV. At alpha beam energies greater than ~2.2 MeV the ^{12}C(α, α_0)^{12}C cross-section is non-Rutherford. For ion beam analysis of carbon, enhanced cross-sections at elevated energies provide increased sensitivity and separation of the partial spectrum of carbon against the background of heavier elements. To accurately determine the carbon content requires the use of precise cross sections at the energy and backscattering angle of interest. Since apparent discrepancies between different sets of available experimental data result in significant uncertainties in the evaluated $^{12}C(\alpha, \alpha_0)^{12}C$ cross-sections [1] new measurements were undertaken followed by a revision of the current evaluation [2].

Measurements were carried out at the 3 MV tandem accelerator of IPPE with an energy step of 5–10 keV. A polished pyrolylitic graphite bulk target of a natural isotopic abundance was used in the experiment in order to avoid problems with carbon build up. The backscattering cross-sections were obtained from the measured spectra by fitting in a narrow energy window near the high energy edge of the spectrum, the cross-section being a free parameter. Fitting was performed by the COBYLA method [3] using the OLE automation technique provided by the SIMNRA-7 program [4]. The obtained results were incorporated in the data set for the cross-section evaluation performed in the framework of the R-matrix theory.

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PRELIMINARY DATA OF THE EXPERIMENT TO DETERMINE THE CLUSTER STRUCTURE OF THE EXCITED STATES OF THE ^{6}Li

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A test experiment to determine the cluster structure of the excited states of the ^{6}Li nucleus in the $n + {}^6$Li reaction with registration of charged particles and neutrons in coincidence was carried out on the RADEX neutron channel of INR RAS. Charged particles were registered by a telescope of silicon ΔE-E detectors at an angle of 50º in a small vacuum scattering chamber with a mounted $^6Li_2CO_3$ target [1]. Neutrons were registered by three scintillation detectors at an angle of 80º on the other side of the beam axis. Preliminary data on the energy spectra of neutrons and charged particles have been obtained. The obtained data make it possible to estimate the beam time required to obtain statistically reliable data for studying the cluster structure of highly excited states of the ^{6}Li nucleus.

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LOW ENERGY INCOMPLETE FUSION REACTIONS: PROBING OF ENTRANCE CHANEEL EFFECTS

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During last couple of years, the probability of incomplete fusion in heavy ion induced reactions for both strongly bound and loosely bound projectiles has been observed at energies as low as 4–5 MeV/A [1–4]. The HI induced reactions are important in basic research for the fundamental understanding of reaction mechanism and to test the validity of various parameters existing in available nuclear reaction models [5–7]. The importance of measured cross-section data has been found in applied research, more particularly, in reactor technology for nuclear energy generation and waste management. Although the dynamics of the multiplicity of processes like complete fusion (CF), incomplete fusion (ICF), and pre-compound (PCN) emission in heavy ion (HI) interactions at low projectile energies depend on various entrance channel parameters, moreover the projectile energy and angular momentum of the compound nucleus systems are some of the key parameters, which play significant role in the characterization of such processes in HI reactions. The entrance channel mass asymmetry, alpha Q-value, neutron thickness, coulomb factor (ZpZt) and target deformation are some important entrance channel parameters, that affects the probability of incomplete fusion in heavy ion reactions. In the present work an attempt has been made to have an exclusive study on aforementioned entrance channel parameters on ^{12}C, ^{13}C, ^{16}O, ^{18} O and ^{14}N induced reactions with various target systems. It is observed that proper account of these entrance channel parameters is very much essential to conclusively explain the incomplete fusion reactions.

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MEASUREMENT OF FISSION CROSS SECTION AND ANISOTROPY OF ANGULAR DISTRIBYTIONS OF FISSION FRAGMENTS FROM NEUTRON-INDUCED FISSION OF ^{236}U IN INTERMEDIATE ENERGY RANGE 1-200 MEV

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The neutron-induced fission cross sections of ^{236}U and ^{235}U (used as a standard) have been measured simultaneously in the energy range 1–200 MeV at the neutron time-of-flight spectrometer GNEIS based on the 1 GeV proton synchrocyclotron of the NRC KI – PNPI (Gatchina) used as pulsed neutron source [1]. The fission fragments from neutron-induced fission of investigated nuclei were registered by two position sensitivemulti-wire proportional counters which allowed measuring not only the ^{236}U to ^{235}U fission cross section ratio but also the angular distributions of fission fragment at the same time.

The description of the original experimental set-up is presented, as well as the some principal details of experimental data processing. The anisotropy of fission fragments W(0º)/W(90º) deduced from the experimental data on angular distributions for ^{236}Uare presented. A special attention is devoted to the neutron energy range above 20 MeV where the present data have been obtained for the first time in spite of the ever-growing interest to this field stimulated by the development of new nuclear technologies. This report presents the experimental part of the work, while the theoretical analysis of the data obtained are given in other report presented at this Conference. This work is a part of large program devoted to the investigations of neutron-induced fission at intermediate energies [2–5].

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ANISOTROPY IN PRE-FISSION AND (n, $n'\gamma$) NEUTRON SPECTRA OF ^{238}U + n

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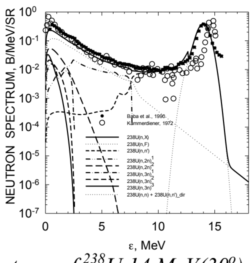
Strong anisotropic component was observed in ^{239}Pu(n, F) prompt fission neutron spectra (PFNS) at E_n ~12-20 MeV and correlated with pre-fission (n, xnf) neutrons [1]. We interpreted the trend of the ratios of the temperatures of PFNS for forward and backward neutron emission [2]. Similar peculiarities would be observed in ^{238}U(n, F) PFNS since measured neutron emission spectra are strongly anisotropic at ^{238}U excitations E^* = 1–6 MeV. That is due to pre-equilibrium/semi-direct emission of the 1st neutron, its spectrum is tuned to reproduce (n, F), (n, xn) reaction cross sections and extensive data on n-emission spectra. Direct excitation of g.s. band levels J^π = 0^+, 2^+, 4^+, 6^+, 8^+ is calculated with rigid rotator model. Direct excitation of members of the K^π = 0^+, 2^+ and first octupole band K^π = 0^- at E^* <1.2 MeV is calculated with soft-deformable rotator model [3]. The angular dependence approximation as

$$d\sigma^1_{nnx}/d\varepsilon \approx d\sigma^1_{nnx}(\theta)/d\varepsilon + \sqrt{\frac{\varepsilon}{E_n}}\cdot\frac{\omega(\theta)}{E_n-\varepsilon}$$

reproduces ^{238}U + nn-emission data [4, 5]. The low-energy tail of 1st neutron spectrum is pronounced in (n, xnf) spectra, the major anisotropy would be in (n, $n\gamma$) spectra. The exclusive spectra of $(n, nf)^1$, $(n, 2nf)^2$ and $(n, 2n)^1$ [6, 7] are also angle-dependent.

The partial neutron spectra for the forward neutron emission at angle of ~30° see on fig. 1. The angular dependence of (n, xnf) neutron spectra influences the observed prompt fission neutron spectra and its average energies, The ratio of its $\langle E\rangle$ for forward and backward emission of ^{238}U(n,xnf)-neutrons is compared with measured data [1] for ^{239}Pu on fig. 2. $\langle E\rangle$ depend on the averaging range.



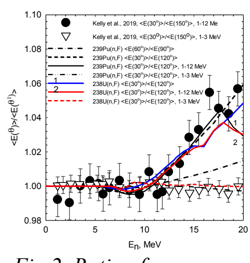


Fig. 1. n-emission spectrum of ^{238}U,14 MeV(30°) *Fig.2. Ratio of mean energies at 30°/150°*

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PRE-FISSION $(n, 2nf)^{1,2}$ NEUTRONS IN ^{235}U(*n*, *f*), ^{239}Pu(*n*, *f*)

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Pre-fission (*n*, *xnf*) neutrons influence the observed prompt fission neutron spectra (PFNS), TKE, average number of prompt fission neutrons, (*n*, *F*) and (n, *xn*) reaction cross sections. Though (*n*, *xnf*) in PFNS of ^{235}U(*n*, *F*) [1, 2] and ^{239}Pu(*n*, *F*) [1] were first observed around E_n ~ 14–14.7 MeV, it is still a subject of controversy [3,4,5]. Measured data base [5–8] support the revealed in 2000–2010 influence of fissility of nuclides ^{236}U and ^{240}Pu on the PFNS shape [3, 4] and study the correlation of PFNS shapes at thermal neutron energy [4, 9] and E_n < 20 MeV.

The PFNS shapes at E_n >5 MeV are correlated with composite and residual nuclide fissilities in ^{235}U(*n*, *xnf*) and ^{239}Pu(*n*, *xnf*) reactions. Calculated exclusive $(n, n\gamma)^1$, $(n, 2n)^{1,2}$, $(n, 3n)^{1,2,3}$ and $(n, xnf)^{1,..,x}$ pre-fission neutrons spectra [3, 4, 9, 10] predict that the contribution of $(\mathrm{n,2nf})^{1,2}$ spectra is much larger for ^{235}U(*n*, *F*) than for ^{239}Pu(*n*, *F*) at E_n ~14.7 MeV (Fig.1). The data of [5–8] support the predicted relatively low contribution of $(n, 2nf)^{1,2}$ neutrons in ^{239}Pu(*n*, *F*). The Fig. 1, 2 demonstrates partials of PFNS for ^{239}Pu(*n*, *F*) and ^{235}U(*n*, *F*)) reactions. They correlate with contribution of (*n*, *xnf*) fission chances to the (*n*, *F*) reaction. The model parameters renormalization for new measured TKE values influences mostly the neutrons emitted by fission fragments emerging in first chance fission reaction.

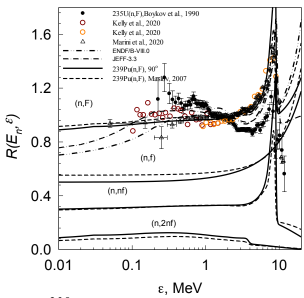
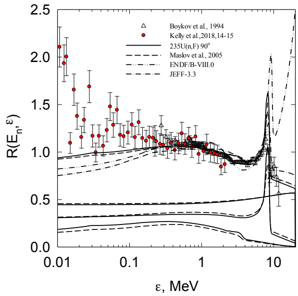


Fig. 1 PFNS of ^{239}Pu(n, F) at14-15 MeV



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EFFECT OF DOUBLE SPIN-ORBIT PARAMETERS ON FUSION BARRIER OF PROLATE-PROLATE DEFORMED NUCLEI

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Relativistic mean-field model (RMF) and Skyrme–Hartree fock (SHF) approach with effective energy functionals are applied to describe the bulk properties of nuclei. However, SHF model with standard parametrization fails to address the charge isotope shifts in the vicinity of major shell closures [1], which on the other hand is well described by the RMF model calculations [2]. This contrariety is related to the peculiarity of the spin-orbit (S-O) interaction potential (V_J) and hence corresponding modifications are required in SHF functional. In view of this, a simple generalization of the Skyrme functional is considered with a larger flexibility within the spin-orbit term by means of an additional coefficient W_0' term along with W_0. Subsequently, six parameterizations of the Skyrme functional such as SkI*x* (x = 1–5) [3] and SAM*i* [4] are obtained. In the present work, out of six forces, four different parameter sets are chosen such as SAM*i* (W_0 = 137; W_0' = 42), SkI4 (W_0 = 183.09; W_0' = –180.35), SkI3 (W_0 = 94.25; W_0' = 0) and SkI2 (W_0 = 60.301; W_0' = 60.301) and their effect in terms of double spin-orbit strength is examined in the fusion dynamics of ^{90}Zr + $^{90-96}$Zr reactions. The explicit dependence of deformation effect is incorporated by taking prolate-prolate target-projectile combinations. The study is carried out within the framework of Skyrme energy density formalism (SEDF) [5] by calculating the change in fusion barrier height ($\Delta V_B = V_{B\,(\text{with } VJ)} - V_{B\,(\text{without } VJ)}$) of considered reactions. It is observed that independent of the reaction channel, maximum decrease in the fusion barrier height is obtained with SAM*i* force (having greater influence of S-O term) followed by SkI4, SkI3 and minimum with SkI2 Skyrme force. Moreover, the effect of target deformation is such that the value of ΔV_B is maximum for ^{90}Zr + ^{96}Zr reaction having strong deformation dependence (β_{2P} = 0.035; β_{2T} = 0.217) and minimum for weakly deformed combination i.e., for ^{90}Zr+^{90}Zr channel (β_{2P} = 0.035; β_{2T} = 0.035). This means that the double spin-orbit parameters of the spin-orbit strength along with deformations of interacting nuclei significantly affect the fusion barrier height of considered reactions. In further study the relative influence of these Skyrme forces will be analysed on fusion excitation functions and the results will be presented during the conference.

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DETERMINATION OF ASYMPTOTIC NORMALIZATION COEFFICIENTS FOR THE CHANNEL ^{16}O→α+^{12}C. EXCITED STATE ^{16}O(0$^+$; 6.05 MeV)

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Asymptotic normalization coefficients (ANC) determine the asymptotic behavior of nuclear wave functions in binary channels at distances between fragments exceeding the radius of nuclear interaction (see the recent review paper [1] and references therein). ANCs are of particular importance for nuclear astrophysics. First of all, it should be noted that they determine the overall normalization of cross sections of peripheral radiative capture reactions at astrophysical energies [2]. ANCs should be included in the number of important nuclear characteristics along with such quantities as binding energies, probabilities of electromagnetic transitions, etc.

In the present work, we treat the ANC *C* for the virtual decay ^{16}O(0$^+$; 6.05 MeV)→α+^{12}C(g.s.), the known values of which are characterized by a large spread: (0,29-1.65)·10^3 fm$^{-1/2}$. The ANC *C* is found by analytic continuation in energy of the α-^{12}C s-wave scattering amplitude, known from the phase-shift analysis of experimental data [3] to the pole corresponding to the ^{16}O excited 0$^+$ bound state and lying in the unphysical region of negative energies. To determine *C*, two different methods of analytic continuation were used. In the first method, the scattering data are approximated by the sum of Chebyshev polynomials in energy in the physical region and then extrapolated to the pole. The best way of extrapolation is chosen on the basis of the exactly solvable model. Within the second approach, the ANC *C* is found by solving the Schrödinger equation for the two-body α-^{12}C potential, the parameters of which are selected from the requirement of the best description of the phase-shift analysis data at a fixed experimental binding energy of ^{16}O(0+; 6.05 MeV) in the α+^{12}C channel. The values of the ANC *C* obtained within these two methods lie in the interval (0.94–1.14)·10^3 fm$^{-1/2}$.

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SOLITON SOLUTIONS OF HYDRODYNAMIC EQUATIONS IN DESCRIBING COLLISIONS AND OSCILLATIONS OF ATOMIC NUCLEI

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In the present work, the hydrodynamic approach is used and the distribution function of particles in complex systems is found. Within the framework of our approach, we have found an analytical solution of the equations of hydrodynamics in the soliton approximation for the collision of layers in the one-dimensional and two-dimensional cases. The prospects of the hydrodynamic approach in physics and the importance of taking into account nonequilibrium processes are noted. The compression stage, the expansion stage, and the freeze-out stage are considered within the framework of a single formula for layers with energies on the order of ten MeV per nucleon. Such a reduction of solutions of hydrodynamic equations to soliton solutions has not been considered before.

The introduction of dispersion into the effective forces and into the pressure does not violate the concept of the formation of a hot spot. The introduction of additional dimensions does not violate this representation. Usually the solution of this system of non-linear partial differential equations is found numerically on a computer. Here we develop an approach to the approximate analytical solution of these equations, both in the case of weak nonlinearity, by reducing them to the Korteweg-de Vries equations, and in the case of large-amplitude perturbations, using soliton-like solutions. Our generalization to the two-dimensional case leads to the idea of the formation of a rarefied bubble region at the stage of expansion. And the approach itself is of independent interest and can be used in other areas of physics when calculating the nonlinear dynamics of oscillations of complex systems. In our works [1–4], it was shown that the local thermodynamic equilibrium in the process of collisions of heavy ions is not established immediately. For this purpose, in this work, we use the result of solving the kinetic equation to find the nucleon distribution function, which at low energies leads to the equations of nonequilibrium long-range hydrodynamics [1]. The non-equilibrium approach to hydrodynamic equations makes it possible to describe experimental data better than the equation of state corresponding to traditional hydrodynamics, which assumes the establishment of local thermodynamic equilibrium.

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HIDDEN VARIABLES IN ANGULAR CORRELATIONSOF FISSION PRODUCTS

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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.

A comparative analysis of experiments [1, 2] on studying the (n, f), on one hand, and (n, n), on the other hand, angular correlations in fission is carried out, based on the model proposed by muonic conversion in fragments of prompt fission of ^{238}U with negative muons. Their fundamental difference is shown in the sense of the information that can be inferred from them. To show this explicitly, and for the purpose of testing the experimental method, I propose an experimental check of the empirical relation between the alignment and polarization parameters, respectively:

$$A_{\mathrm{nJ}} = 2\, A_{\mathrm{nf}}.$$

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 [3].

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DIFFRACTION PROCESSES IN ^{12}C ELASTIC SCATTERING BY MEDIUM NUCLEI

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The study of multicluster structures of a nucleus is an urgent task due to the fact that the influence of cluster states, both excited and ground, rather strongly affects the properties of the nuclei under study. In the framework of the diffraction theory and under the assumption of complete absorption inside the interaction sphere, in this work, the authors obtained expansions of the total amplitudes of the angular distributions of the differential cross sections for elastic scattering of ^{12}C on nuclei up to ^{40}Ca. The study of such diffraction processes using the method [1] makes it possible to reveal the partial scattering amplitudes and their contribution to the total amplitude, which characterize the multicluster structure of the nucleus. For a comprehensive analysis of the multicluster structure of nuclei, the authors of [2] proposed an experimental method for the direct detection of cluster structures in the nucleus. The available world experimental data are described within the framework of the method. This method showed itself well in the study of alpha-cluster 4*n* nuclei. However, for 4*n* ± 1 nuclei, a third component was added to the total amplitude [1]. This modification of the method made it possible to describe a larger range of light atomic nuclei. Until now, only incident alpha particles have been analyzed. In [3], the authors performed an analysis of the angular distributions of the differential cross sections of elastically scattered ^{16}O on 4n nuclei, which fairly well described the experimental data up to ^{40}Ca.

In this work, the authors chose 12-C as the incident particles. As a result, an analysis of the differential cross sections of elastic diffraction scattering of ^{12}C on medium nuclei at energies from tens to hundreds of MeV was performed using a modified method of angular distributions. From a systematic analysis of the previous and results of this work, it was obtained and shown that clusters with characteristic radii of 1 fm and 0.5 fm are mainly detected.

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SOME REGULARITIES IN THE FORWARD ANGLE YIELDS OF ISOTOPES WITH 4 ≤ Z ≤20 IN THE REACTION OF ^{40}Ar(40·A MeV) WITH ^{9}Be

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Systematic study of forward-angle inclusive yields of nuclei with atomic numbers 4< Z <20 produced in nucleus-nucleus collisions of the ^{40}Ar projectile on the ^{9}Be target in the Fermi energy domain (40·A MeV) was carried out. The reaction products were measured by using the double achromatic fragment-separator COMBAS [1, 2] in the spectrometry mode at FLNR, JINR (Dubna). The inclusive velocity, isotopic and element distributions were obtained. There is no unique mechanism to explain the total set of the results obtained from the experiment. Two main contributions of dissipative low energy reaction mechanisms and of fragmentation mode were observed. The simple exponential approximation realized by the Q_{gg} – systematics satisfactorily describes the total yield of the isotopes produced in stripping nucleon reactions with large negative Q_{gg} values especially for neutron-rich isotopes. The Q_{gg} – systematic can be used to predict correctly the yields of unknown drip-line nuclei. The production rates of neutron-rich isotopes of elements with 4 < Z < 20 were determined.

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PHYSICAL FEATURES OF THE VVER-1200 REACTOR CORE REFLECTOR MODEL IN SERPENT CODE

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Reactor codes (BIPR, DYN3D [1], etc.) based on solving the neutron transport equation in the diffusion approximation are widely used to analyze stationary and transient processes in the reactor core. To perform such type of calculation it is necessary to create a XS library - a set of macroscopic cross sections and constants. It is usually calculated using spectral codes such as deterministic (HELIOS, TVS-M, etc.) or Monte Carlo (Tripoli, Serpent [2], etc.).

When modeling the whole reactor core, the question is about the boundary conditions at the outer boundary of the fuel part. In VVER-type reactor, the environment of the fuel part (baffle and other internal elements) plays the role of a reflector for thermal neutrons, in which there is no neutron source.

To calculate and create a XS library of sections for the reflector, a model of ¼ reactor core was created (Fig. 1), which allows correctly take into account the full spectrum of neutrons created in the fuel part of the core and interacting with a two-layered reflector (R1-R2).

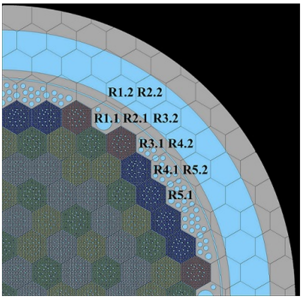

Fig. 1. Model of radial reflector.

In this paper, a model of a radial reflector for VVER-1200 reactor is proposed for calculating and preparing a XS library using Serpent Monte Carlo code for DYN3D diffusion code, taking into account physical features at the reactor core outer boundary.

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SPECTROSCOPIC AMPLITUDES FOR POLE MECHANISMS IN ^{16}O(α, α)^{16}O(3$^-$) AND ^{15}N(α, *t*)^{16}O(3$^-$)REACTIONS

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The direct mechanisms of proton stripping in ^{15}N(α, *t*)^{16}O(3$^-$) reaction and ^{12}C(J_C) cluster transfer (with summation over all states allowed by the selection rules) for both reactions are illustrated by pole diagrams (fig.).

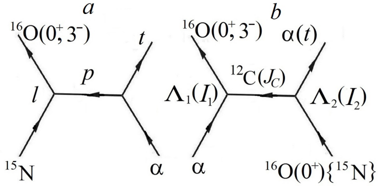

Fig. Pole mechanisms diagrams to ^{16}O(0$^+$)(α, α′)^{16}O(3$^-$) and ^{15}N(α, t)^{16}O(3$^-$) reactions: a – stripping, b – exchange of ^{12}C(J_C)

decay vertices	l	s	j	SA
$\alpha \to t + p$	0	1/2	1/2	1.4
$^{16}O(3^-) \to p + {}^{15}N$	2	1/2	5/2	–0.2
	J_C	Λ_1	I_1	SA
$^{16}O(3^-) \to {}^{12}C + \alpha$	0	3	3	0.2
	2	1	1	0.2
		3	3	0.5
	4	1	1	0.1
		3	3	0.4
		5	3	0.6
$^{16}O(0^+) \to {}^{12}C + \alpha$	L_C	Λ_2	I_2	SA
	0	0	0	0.6
	2	2	2	1.1
	4	4	4	1.6
$^{15}N(1/2^-) \to {}^{12}C + t$	0	1	1/2	0.7
	2	1	3/2	1.7
		3	5/2	1.1
	4	3	7/2	2.8

According to [1, 2], we calculated spectroscopic amplitudes (SA) at all decay vertices of diagrams in Figs. in shell model for pure $\left|1p\right\rangle$ and mixed $\left|1p^{-1}d\right\rangle$ configurations. Comparison of our SA with those obtained in the [3] for the decay ^{16}O(0$^+$) → ^{12}C(2$^+$) + α in the tetrahedron model shows agreement with an accuracy of 10–15%.

The performed theoretical calculation of the reaction cross sections with the found SA values gives good agreement with the experiment.

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TEST EXPERIMENT TO DETERMINE THE TIME DISTRIBUTION OF THE BACKGROUND BETWEEN MMF ACCELERATOR PULSES ON THE RADEX CHANNEL

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To determine the possibility of studying various cluster structures (for example, [1]) in light nuclei on the RADEX neutron channel of the MMF INR RAS accelerator, it is necessary to carry out a study to measure the background between accelerator pulses (the level, composition and time distribution of it). For example, when searching for the cluster structure of α-4*n*-α and ^{8}Be-4*n* in the highly-excited state of ^{12}Be*, it is necessary to detect charged particles from the β-decay of ^{12}Be* during its formation in the n + ^{13}C reaction in the intervals between pulses of cascade neutrons [2]. This will be possible with a certain background level and its time distribution.

The first experiments of this kind were carried out on the RADEX MMF channel at several pulse durations and frequencies from 1 to 50 Hz. Between the pulses of the accelerator, the spectra and time distribution of gamma quanta, neutrons, and β-particles were measured. The first measurement results are presented.

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SUBJECTIVE METHOD OF DETERMINING THE VELOCITY OF A HEAVY ION

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The report discusses a new method and algorithm for solving the problem of determining the velocity of a heavy ion using a semiconductor detector (PIN diode) [1, 2], using the mathematical formalism of subjective modeling (MFSM) [3, 4], which allows to mathematically formulate both a subjective model of the object under study and a subjective mathematical model of its measurements and their subjective interpretation.

In experimental practice, the ion velocity is measured by ``time-of-flight''.

To measure the time-of-flight, it is necessary to obtain the timestamps "start" and "stop" corresponding to the moments of the beginning and end of the ion movement along the flight path. Time pick-off detectors are used to obtain timestamps. The "stop" timestamp is often obtained from a semiconductor detector, for example, from a so-called PIN diode. When an ion hits the diode, a signal (voltage pulse) appears at the output of the diode, which can be represented as the sum of the actual voltage pulse caused by the recorded ion and additive probabilistic noise. The physics of the interaction of a heavy ion with a semiconductor is such that the waveform first represents a slowly growing function, the graph of which is *unknown*, then comes out to an almost linear dependence (the length of this section is also *unknown*). It is required to determine the moment of time when the ion hits the detector ("absolute time reference") - i.e., the actual beginning of the signal, despite the fact that the initial part of the pulse leading edge lies inside the area with a high noise level.

To solve the problem of determining the velocity of a heavy ion, an algorithm based on the mathematical formalism of subjective modeling has been developed and implemented, which allows to restore the unknown shape of the pulse leading edge by a smoothing spline with the following special condition: the initial part of the spline (on the left) is given by the parabola equation, and the vertex of this parabola should lie on the averaged noise line, since in the absence of noise the leading edge begins to grow from the zero line. To determine the optimal smoothing factor of the spline, subjective optimality criterion [4] was used. Correctness of new time pick-off algorithm was tested in experiment at the accelerator in the Laboratory of Nuclear Reactions of the Joint Institute for Nuclear Research (Dubna).

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^{6}Li(d, α)^{4}He REACTION CROSS SECTION EVALUATION IN 0–20 MeV DEUTERON ENERGY RANGE

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New evaluation of ^{6}Li(d, α)^{4}He reaction integral cross sections (fig.1) was performed at our SaBa library [1]. Our data obtained from measured differential cross-sections [2, 3] at 3.75–8 MeV deuteron energy were used for evaluation. Astrophysical S-factor evaluated value at zero deuteron energy was (24370 ± 269) MeV·mb.

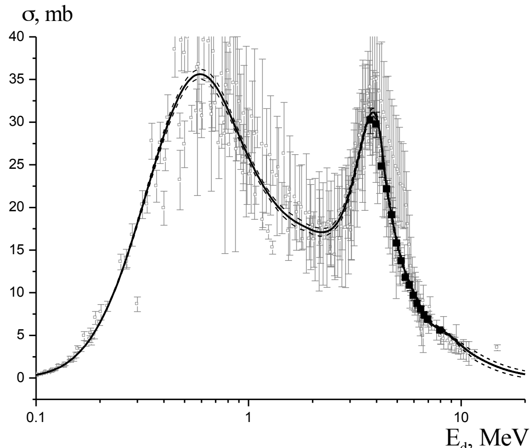

Fig. 1 Experimental and evaluated values of ^{6}Li(d, α)^{4}He reaction cross sections; white dots – data from literature, black dots – our data, solid and dash curves – evaluated curve and its errors.

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ON THE WIDTH OF γ-LINE AND THE PHOTON STRUCTURE

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The reason to turn once again to the question of the natural width Γ_γ of the γ-radiation line of nuclei is provided by the discovery of an increase in the half-life $T_{1/2}$ for nuclear isomers in a metal matrix (see ref. [1] and references therein). For nuclei in such a matrix, a decrease in the width Γ_γ can be expected, since, according to generally accepted concepts, $\Gamma_\gamma \propto \hbar / T_{1/2}$ for the emission of photons in a nuclear transition from an excited state E^* of a half-life $T_{1/2}$ to the ground state.

However, even in early Mössbauer experiments with the ^{57m}Fe isomer, a decrease in Γ_γ was observed with an increase in the age of the E^* level (see, e.g., ref. [2]), which could be interpreted as a result of a decrease in the level width with its age. But such an interpretation is not allowed by the experiment [3] with the ^{181m}Ta isomer ($T_{1/2} \approx 6$ μs), in which broadening of the 6.2 keV γ-line was observed due only to the shading of the absorber from the emitter by a mechanical chopper, which opened their mutual visibility for a time of 1 μs without referencing by the time the isomer was formed. Hence it follows that the width Γ_γ is determined not by the value of $T_{1/2}$, but only by the time T_γ, which in the Mössbaur experiments the absorber nucleus sees the emitter before the emission of an energy quantum. Of course, if there are no restrictions on the measurement time of the width Γ_γ, then the average value T_γ is proportional to $T_{1/2}$.

Then, taking into account that the energy of the γ-transition is emitted in less than 1 ns – this can be seen, for example, from the duration of the γ-signal in the scintillator, we can assume the following photon structure. Immediately after the formation of the excited state E^*, the nucleus begins to emit an electromagnetic wave of frequency ω that does not carry energy – abbreviated as a 0-wave. The duration of this 0-wave determines the width Γ_γ. The energy quantum $\hbar\omega$ is emitted at the end of the 0-wave. The energy $\hbar\omega$ may not be emitted at all if the state E^* decays via another channel, and then the 0-wave will exist on its own, without an energy quantum. A possible source of the 0-wave is the virtual transitions from the E^* level to the ground state and back before the emission of an energy quantum.

The 0-wave with a quantum $\hbar\omega$ "on its tail" resembles a pilot wave introduced by De Broglie to explain the wave-particle duality of electrons. It is interesting to study effect of 0-waves on absorber nuclei, for example, to search for the modulation of the Γ_γ value via an additional resonance irradiation of the absorber in Mössbaur experiments.

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DESCRIPTION OF *P*-EVEN *T*-ODD ASYMMETRIES IN NUCLEAR FISSION REACTIONS WITH THE EMISSION OF LIGHT PARTICLES IN THE FRAMEWORK OF THE QUANTUM APPROACH

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The *P*-even *T*-odd asymmetries were investigated in the framework of the quantum mechanical approach [1–2]. The differential cross sections for fission reactions of non-oriented target nuclei by cold polarized neutrons n with a polarization vector $\boldsymbol{\sigma}_n$ emitting light particles p (α-particles. evaporative neutrons and γ-quanta) can be represented [1] by expression

$$d\sigma_{nf,p}(\theta)/d\Omega = d\sigma^{\{0\}}_{nf,p}(\theta)/d\Omega + d\sigma^{\{1\}}_{nf,p}(\theta)/d\Omega, \quad (1)$$

where the first term corresponds to the case of unpolarized neutrons ($\boldsymbol{\sigma}_n$=0) and has the form $d\sigma^{\{0\}}_{nf,p}(\theta)/d\Omega = \sigma^{\{0\}}_{nf,p} P^{\{0\}}_p(\theta)$, and $P^{\{0\}}_p(\theta)$ is the angular distribution of light particles *p*. The second term in (1) corresponds to *P*-even *T*-odd components of the analyzed cross sections linearly depends on the vector $\boldsymbol{\sigma}_n$ and is expressed [1] in terms of the sum of triple and quintuple correlators $\left(d\sigma^{\{1\}}_{nf,p}(\theta)/d\Omega\right)_{3(5)} = \left(d\sigma^{\{1\}}_{nf,p}(\theta)/d\Omega\right)_{ev(odd)}$, which are even and odd, respectively, under the transformation $\theta \to \pi - \theta$. The experimental values of these correlators can be related to the values $\left(\beta^{\exp}_{nf,p}(\theta)\right)_{3(5)} = \left(d\sigma^{\{1\}\exp}_{nf,p}(\theta)/d\Omega\right)_{3(5)} \Big/ \sigma^{\{0\}}_{nf,p}$ that are expressed by

$$\left(\beta^{\exp}_{nf,p}(\theta)\right)_{3(5)} = \left(D^{\exp}_{nf,p}(\theta) P^{\{0\}}_p(\theta)\right)_{ev(odd)} \quad (2)$$

through the values of the asymmetry coefficients $D^{\exp}_{nf,p}(\theta)$ found in [3, 4]. For the theoretical description of the quantities $\left(\beta^{\exp}_{nf,p}(\theta)\right)_{3(5)}$, one can use definition

$$\left(\beta_{nf,p}(\theta)\right)_{3(5)} = \Delta_{p,3(5)}\, d\left(P^{\{0\}}_p(\theta)\right)_{ev(odd)} \Big/ d\theta. \quad (3)$$

This definition takes into account [1, 2] the influence of the Coriolis interaction of the total spin of a compound fissile system (CFS) rotating around an axis perpendicular to its symmetry axis on the angular distributions of fission fragments and particles. Since the rotation angles $\Delta_{p,3(5)}$ in the quantum approach take into account interference effects [2], it is natural to use the maximum likelihood method to determine them. The values $\left(\beta_{nf,p}(\theta)\right)_5$ for *p* particles calculated by (3) turned out to be in satisfactory agreement with the corresponding values

$\left(\beta_{nf,p}^{\exp}(\theta)\right)_5$ for positive angles $\Delta_{p,5}$ in the case of ^{235}U, ^{239}Pu и ^{241}Pu nuclei and negative values of these angles for the ^{233}U nucleus. It can be shown that the quantities $\left(\beta_{nf,p}(\theta)\right)_5$ for evaporative neutrons and γ-quanta contain only five-fold (odd asymmetry), since $\left(\beta_{nf,n'(\gamma)}(\theta)\right)_3$ is equal to zero. In result, the angular distributions $P_{n'(\gamma)}^{\{0\}}(\theta)$ in (3) depend on $\cos^2(\theta)$. The values $\left(\beta_{nf,\alpha}(\theta)\right)_3$, calculated by (3), are turned out to be in satisfactory agreement with the corresponding values $\left(\beta_{nf,\alpha}^{\exp}(\theta)\right)_3$ for the ^{235}U, ^{239}Pu и ^{241}Pu nuclei. In the case of the ^{233}U nucleus, a agreement is achieved by introducing into (3) an additional term $\left(\tilde{\beta}_{nf,\alpha}^{0}\right)_3$, which is independent of the angle θ. The appearance of this term can be associated with the influence of the rotation of the compound fissile system around its symmetry axis [2], due to the violation of the axial symmetry of the compound fissile system, caused by its collective transverse vibrations.

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USING A ΔE(SI)-E(CSI(TL)) TELESCOPE TO IDENTIFY LIGHT CHARGED PARTICLES

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In this work the analog, digital and combination (analog-digital) electronic readout methods of pulse analysis of Δ*E*-*E* telescope detectors were studied. The Δ*E*-*E* telescope, consisting of thin Si-detector (H = 100 um) as a Δ*E* detector and CsI(Tl) scintillator (H = 20 mm) activated with Tl 0.7% as an *E* detector was used. The analog method of pulse analysis was carried out by using a dual spectroscopic amplifier Ortec-855 at the different integration times (τ = 0.5÷3.0 us) and a VME module of the analog-to-digital converter Mesytec MADC-32. The digital method of pulse analysis was carried out using a pulse processor Mesytec MDPP-16 CsI.

In the report the electronic block schemes and two dimensional Δ*E*×*E* spectra obtained by the above mentioned methods were presented. The main attention was focused on the dynamic range of the detected particle identification.

The ^{1,2,3}H, ^{4}He light charged particles with high positive Q_{gg} value of the ^{6}Li + ^{9}Be reaction together with ^{6,7}Li isotopes were registered by $\Delta E \times E$ telescope at the broad energy range. It was shown that the combined and digital electronic readout methods of pulse analysis give the most effective particle identification at low-energy and high-energy ranges, respectively.

The measurements were carried out with ^{6}Li beam at E = 10 MeV/nucleon of the U400 cyclotron at the FLNR JINR.

A METHOD OF GAMMA-SPECTRUM PROCESSING BASED ON EXPONENTIAL SMOOTHING

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This paper proposes a new method to smooth out the spectral lines. Calibration samples supplied with the gamma spectrometer containing radioactive isotopes Eu^{152}, Co^{60} and Na^{22}were used as test objects. The position, width and area of the peaks obtained as a result of spectrometry characterize the energy and intensity of gamma radiation. As is known, these peaks are superimposed on a continuous spectrum of energy resulting from secondary effects and background radiation [1].

The smoothing procedure was performed using interpolation by the system of uniform shifts of the Gaussian function [2]:

$$\varphi_k(x) = \exp\left(-\frac{(x-k)^2}{2\sigma^2}\right), \ k \in Z.$$

Since the standard interpolation procedure becomes highly unstable with increasing variance [3], regularization was applied. Results of the simulation indicate that the proposed method for filtering spectral lines does not introduce distortions into the original signal. On the other hand, the representation of spectral lines as a linear combination of Gaussian function shifts provides an additional opportunity for analytical calculations with a given signal during subsequent more detailed processing.

It is not necessary to pick the form of the peaks because they are represented as a sum of several shifts of the Gauss function with various amplitudes. As a result, a more versatile peak detection system has been obtained that does not require serious changes from one type of signal to another. A feature of the proposed method is that the peak areas for the original and smoothed signal may differ by around 10%, but with a significant change in the variance σ of the regularization parameter ε the area changes are small, which ensures the calculation robustness.

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NEUTRON SCATTERING ANALYS BY LIGHT NUCLEI USED COUPLED CHANNEL OPTICAL MODEL

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When fast neutrons are scattered by nuclei with dynamic and static deformation, collective states are excited in a direct process or through the decay of highly excited resonant compound states. This creates a correlation of the widths and densities of the resonances of the compound nucleus and a dynamic coupling of the reaction channels. Such a process for medium and heavy nuclei is described by vibrational or rotational variants of the coupled-channel method of the optical model (CCOM), which takes into account the collective motions of nucleons [1]. At present, an optical-model analysis of the scattering of nucleons by light nuclei, which have a cluster structure and collective states, is used [2, 3].

We have calculated the cross sections of fast neutron scattering on even-even nuclei of 1p shell used by rotational variants of CCOM. Nuclei with an unfilled 1p-shell are deformed and have a non-uniform nucleon distribution density. They can manifest themselves as Borromean nuclei with many-particle decay channels. The cross sections of elastic and inelastic scattering of neutrons by even isotopes of helium, beryllium, carbon, and oxygen with the excitation of rotational states of these nuclei were calculated. The calculation results of inelastic scattering cross sections up to an energy of about 10 MeV are analyzed.

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DETERMINATION OF THE ASYMPTOTIC NORMALIZATION COEFFICIENTS FOR ^{7}Li +p → ^{8}Be FROM THE PERIPHERAL DIRECT CAPTURE ^{7}Li(p, γ)^{8}Be REACTION AND THE ASTROPHYSICAL S FACTOR AT LOW ENERGIES

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The reaction ^{7}Li(p, γ)^{8}Be is part of the pp-chain in the Sun, leading to the formation of ^{8}Be. In the present work, the analysis of the experimental astrophysical S factors $S^{\exp}(E)$ for the nuclear-astrophysical ^{7}Li(p, γ)^{8}Be reaction in the off-resonance energy region measured in [1] are performed within the modified two body potential approach [2], and assuming that, in this energy region (E ≤ 200 keV) radiative proton capture by ^{7}Li nucleus is direct.

The method involves two additional conditions that verify the peripheral character of the direct radiative capture reaction ^{7}Li(p, γ)^{8}Be in the off-resonance energy region: 1) $R(E,b) = const$ for arbitrary variation of the single particle asymptotic normalization coefficient b for each fixed experimental value of the energy E; 2) the ratio $C^2_{p^7Li} = S^{exp}(E)/R(E,b)$ must not depend neither from b and nor from the energy E for each experimental point of the energy (E = 98.3, 147.6 and 198.3 keV), where $R(E,b) = S^{(sp)}(E)/b^2$, $S^{(sp)}(E)$ is a single-particle astrophysical S factor. Fulfillment of the conditions above, it allows to determine "experimental" values of ANCs $C^2_{p^7Li}\left[=\left(C^{exp}_{p^7Li}\right)^2\right]$ for ground and first excited states of ^{8}Be with their uncertainty. The obtained values of ANCs $\left(C^{exp}_{p^7Li}\right)^2$ can be used in the expression $S(E) = \left(C^{exp}_{p^7Li}\right)^2 R(E,b)$ for obtaining the extrapolated values of $S(E)$ and its uncertainties within the energy range E < 98.3 keV, including E = 0.

Variation of values of the parameters of the Woods–Saxon potential r_0 and a is done in the wide range (1.1≤ r_0 ≤1.4 fm, 0.59≤ a ≤0.72 fm) and it is shown that the reaction is strongly peripheral. As a result, the new values of ANCs $\left(C^{exp}_{p^7Li}\right)^2$ with their uncertainties for ^{7}Li + p → ^{8}Be were obtained. The obtained values of ANCs are used for calculation of the astrophysical S factor of the radiative resonance capture ^{7}Li(p, γ)^{8}Be reaction within the modified R-matrix method [3].

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DETERMINATION OF A HEAVY ION VELOCITY BASED ON THE MATHEMATICAL FORMALISM OF SUBJECTIVE MODELING

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The report discusses a new method and algorithm for solving the problem of determining the velocity of a heavy ion using a semiconductor detector (PIN diode) [1, 2], using the mathematical formalism of subjective modeling (MFSM) [3, 4], which allows to mathematically formulate both a subjective model of the object under study and a subjective mathematical model of its measurements and their subjective interpretation.

In experimental practice, the ion velocity is measured by ``time-of-flight''. To measure the time-of-flight, it is necessary to obtain the timestamps “start” and “stop” corresponding to the moments of the beginning and end of the ion movement along the flight path. The “stop” timestamp is often obtained from a so-called PIN diode. A signal (voltage pulse) appears at the output of the diode, can be represented as the sum of the actual voltage pulse caused by the recorded ion and additive probabilistic noise. The physics of the interaction of a heavy ion with a semiconductor is such that the waveform first represents a slowly growing function, the graph of which is *unknown*, then comes out to an almost linear dependence (the length of this section is also *unknown*). It is required to determine the moment of time when the ion hits the detector (“absolute time reference”) - despite the fact that the initial part of the pulse leading edge lies inside the area with a high noise level.

To solve the problem of determining the velocity of a heavy ion, an algorithm based on the mathematical formalism of subjective modeling has been developed and implemented, which allows to restore the unknown shape of the pulse leading edge by a smoothing spline with the following special condition: the initial part of the spline (on the left) is given by the parabola equation, and the vertex of this parabola should lie on the averaged noise line, since in the absence of noise the leading edge begins to grow from the zero line. To determine the optimal smoothing factor of the spline, subjective optimality criterion [4] was used. Correctness of new time pick-off algorithm was tested in experiment at the accelerator in the Laboratory of Nuclear Reactions of the Joint Institute for Nuclear Research (Dubna).

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MODERNIZATION OF CORSET SETUP TO MEASURE CHARGE DISTRIBUTIONS OF FISSION FRAGMENTS USING BRAGG IONIZATION CHAMBER

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Because fission is the result of competition between electrostatic and nuclear forces, information about the distribution of charge is critical to understanding the dynamics of a fissioning nucleus, as well as refining the parameters of fission process models needed for their developing. In this regard, the measurement of the charges of fission fragments is a crucially important task, therefore, various methods have been developed for measuring charges based on the Bethe-Bloch theory [1], which relates the specific energy loss to the charge number *Z*. One of these methods is the determination of the charge by the Brag peak [2], which is widely used both in nuclear physics experiments and applied research [3–7].

A system for measuring the charge distributions of fission fragments using an axial Bragg ionization chamber (BIC) has been developed. The design of the chamber makes it possible to change the distance between the cathode and the anode, which, in turn, along with a change in the pressure of the working gas, makes it possible to register a wider range of charge distributions depending on the task. The development of a technique for extracting information about the charge number from the signals of the BIC will significantly expand the range of tasks of the CORSET time-of-flight spectrometer [8]. In addition to measuring the mass-energy distributions, the charge distributions of fission fragments will be measured. The upgraded setup has the ability to smoothly change the angles of the Bragg ionization chamber, which allows one to measure the charge distributions of fragments emitted at different angles relative to the beam. This work presents test measurements.

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DESCRIPTION OF CHARGE-EXCHANGE REACTIONS IN TIME-DEPENDENT 2D MODEL

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The experimental data on the charge-exchange reactions ^{45}Sc(^{3}He,t)^{45}Ti, ^{194}Pt(^{3}He, *t*)^{194}Au [1, 2] requires development of microscopic models of such processes. The microscopic approach based on the time-dependent Schrödinger equation for the wave function of the independent nucleons [3] does not take into account proton-neutron interaction and correlations. Simultaneous transfer of a proton from the projectile nucleus to the target nucleus and transfer of a neutron in the backward direction is studied using quantum two-body two-dimensional (2D) time-dependent model [4].

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SIMPLE METHOD FOR OBTAINING MASS DISTRIBUTIONS OF FISSION FRAGMENTS

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An experimental method is presented for simply obtaining the mass distributions of fission fragments.

A feature of this method is the simultaneous use of two detectors for time-of-flight measurements, one of which is considered as a start detector and the other as a stop detector. The relevant quantity in the described method is the difference in the time of flight of two coinciding fission fragments ΔT (used earlier, for example, in Refs [1, 2]). It is shown, that the distribution form ΔT obtained for two additional fragments is completely identical to their mass distribution.

The paper presents the time-of-flight difference spectra of fragments of spontaneous fission ^{252}Cf and induced fission of target nuclei ^{238}U and ^{nat}W, measured by detectors located on both sides of the target. Experiments on U and W fission were carried out on a proton beam with an energy of Ep = 1 GeV at the PNPI synchrocyclotron.

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STUDY EXCITATION OF ISOMERIC STATES IN (γ, *n*), (*n*, 2*n*) AND (*n*, γ) REACTIONS ON ^{108,110}Pd

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This work presents work results of investigation of the isomeric yield ratios of the ^{110}Pd(γ, *n*)^{109m,g}Pd, ^{110}Pd(*n*, 2*n*)^{109m,g}Pd and ^{108}Pd(*n*, γ)^{109m,g}Pd reactions. The isomeric yield ratios were measured by the induced radioactivity method. Samples of natural Pd (Palladium metal foils) have been irradiated in the bremsstrahlung beam in the energy range of 10–35 MeV with energy step of 1 MeV. For 14 MeV neutron irradiation, we used the NG-150 neutron generator. For the (*n*, γ) reaction, experiments were carried out at the ВВЗ-СМ research reactor of the Institute of Nuclear Physics of the Academy of Sciences of the Republic of Uzbekistan.

The gamma spectra reactions products were measured with a spectroscopic system consisting of HPGe detector CANBERRA with energy resolution of 1.8 keV at 1332 keV gamma ray of ^{60}Co, amplifier 2022 and multichannel analyzer 8192 connected to computer for data processing. The filling of the isomeric and ground levels was identified according to their γ lines. The values of isomeric ratios for the reactions (γ, *n*), (*n*, 2*n*) and (*n*, γ) are respectively: 0.063±0.003 (at $E_{\gamma max}$ = 30 MeV); 0.43 ± 0.03 (at E_n = 14.1 MeV) and 9.1±0.8. Using the isomer yield ratio and the total cross section of the (γ, *n*) reaction on ^{110}Pd [1] received the cross sections of $(\gamma, n)^m$ and $(\gamma, n)^g$ reactions. The cross section isomeric ratios at $E_\gamma = E_m$ are estimated.

The isomeric cross-section ratios were determined in the case of the reaction (n, 2n). In order to obtain the absolute values of the cross sections for the ground state and for the isomeric state, use was made of methods based comparing the yields of the reaction under study and the monitoring reaction. The reaction ^{27}Al(*n*, α)^{24}Na ($T_{1/2}$ = 15 h, E_γ = 1368 keV). For reaction ^{197}Au(*n*, γ) was used as a monitor reaction

The experimental results have been discussed, compared with those of other authors as well as considered by the statistical model. Theoretical values of the isomeric yield ratios have been calculated by using code TALYS-1.6.

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STUDY OF THE EXCITATION OF ISOMERIC STATES IN (γ, *n*), (*n*, 2*n*) AND (*n*, γ) REACTIONS ON ^{198,200}Hg NUCLEI

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The isomeric ratios in reactions of the (γ, *n*), (*n*, 2*n*) and (*n*, γ) types on ^{180,200}Hg nuclei in the energy range of 10–35 MeV have been studied by the method of induced activity. Samples of mercury oxide (HgO) have been irradiated in the bremsstrahlung beam of the betatron of the National University of Uzbekistan in the energy range of 10–35 MeV with an energy step of 1 MeV. For 14 MeV neutron irradiation we used the NG-150 [1] neutron generator of the Institute of Nuclear Physics. For the (*n*, γ) reaction, experiments were carried out at the BB3-CM research reactor of the Institute of Nuclear Physics of the Academy of Sciences of the Republic of Uzbekistan.

The induced γ-activity of the targets was measured on a Canberra γ -ray spectrometer, consisting of an HPGe germanium detector (with a relative efficiency of 15%, a resolution for the ^{60}Co 1332 keV line – 1.8 keV), a DSA – 1000 digital analyzer, and a personal computer with the Genie software package.

The experimental results have been discussed, compared with those of other authors as well as considered by the statistical model. Theoretical values of the isomeric yield ratios have been calculated by using code TALYS-1.6 [2].

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HYDROGEN ISOTOPES PRODUCTION UNDER π^-- MESON ABSORPTIONIN SILICON “LIVE” TAGET

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The results of the analysis of the outputs *p, d, t* formed under the absorption of stopped π⁻-mesons by silicon nuclei are presented. The measurements were performed using a "live" target – Si detector (analog of the ^{28}Si target). For the ^{28}Si nucleus, the spectrum of primary protons was obtained from the absorption act on the *np* pair when both particles (*n* and *p*) are not distorted by secondary interactions. It is shown that the data on proton yield do not contradict the assumption that the ratio of widths of elementary pion absorption processes on n*p* and *pp* pairs ($R' = 3.5$) is constant. "Direct", without excitation, mechanisms of formation of deuterons and tritons on silicon were found, and their yields were estimated at a level ≥ 30%. This result makes it possible to test models of the formation of complex particles associated with the excitation of nuclei.

COMPUTER SIMULATION OF PFN DETECTOR

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PFN emission of ^{235}U(*n*, *f*) reaction are under investigation in JINR for last 20 year. The recent achievements in experimental apparatus simulation are the subject of this presentation. The object of simulation is prompt fission neutron (PFN) detector used for resonance neutron induced fission of U-235. The neutron source was IREN facility and double ionization chamber (DIC) with Frisch grids was used for fission fragment spectroscopy. The PFN detector was multi detector system consisted of 32 BC501 scintillation liquid filled modules from the Sionix (Netherlands) company. Detectors were located on the sphere surface with 50 cm radius. Double Frisch gridded ionization chamber, used as fission spectrometer at the same time generated trigger signal for PFN registration apparatus. For each fission event the following simulated information was recorded: correlated fission fragments time mark, emission angle in respect to the selected coordinate frames along with the pulse heights and shapes of neutron detector signals. Multiple neutron scattering and the cross-talks were taken into account in order to evaluate contribution of those effects in the final results.

Section 3. Intermediate and high energies, heavy ion collisions

ENERGY DEPENDENCE OF TRIANGULAR FLOW FOR IDENTIFIED HADRONS IN Au+Au COLLISIONS AT $\sqrt{s_{NN}}$ = 14.5 – 62.4 GeV FROM THE STAR EXPERIMENT

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Heavy-ion collisions create matter which is characterized by high temperature and energy density, called Quark-Gluon Plasma (QGP). One of the methods for studying the transport properties and equation of state of the created matter is the measurement of azimuthal anisotropy of particles using the Fourier expansion of the azimuthal angle with respect to the event plane. The second order Fourier coefficient υ_2 is called elliptic flow and is sensitive to the pressure gradients arising in the region of overlapping nuclei. The third order coefficient υ_3 (triangular flow) is sensitive to the fluctuations of nucleons in the initial state of colliding nuclei and therefore υ_3 weakly depends on the collision centrality. Theoretical studies show that υ_3 is more sensitive to viscous effects than υ_2, making triangular flow an ideal harmonic for studying the viscosity.

This work is devoted to the study of triangular flow in a wide energy range of Au+Au collisions from the STAR experiment at RHIC ($ $\sqrt{s_{NN}}$= 14.5, 19.6, 27, 39, 62.4 GeV). New measurements of triangular flow will be presented as a function of particle transverse momenta (p_T) and collision energy. Physics implications will be discussed.

GLOBAL POLARIZATION OF Λ AND Ξ HYPERONS IN Au+Au COLLISIONS IN THE STAR EXPERIMENT

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Global polarization of Λ hyperons appearing in non-central heavyion collisions was measured by the STAR experiment at RHIC for Au+Au collisions with √sNN = 3–200 GeV and at the LHC for Pb+Pb collisions with √sNN = 2.76 and 5.02 TeV. Global polarization reflects the vortical structure of quark-gluon matter at its initial evolution stage. Global polarization of multistrange hyperons, such as Ξ, can provide new information for hydrodynamic description of the system and its vorticity nature. In this talk, we will report results of Ξ and Λ global polarization measurement for Au+Au collisions at √sNN = 19.6, 27, and 54.4 GeV.

PION FEMTOSCOPY IN Au+Au COLLISIONS AT $\sqrt{s_{NN}} =$ 3 GeV IN THE STAR EXPERIMENT

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There is a method that allows directly measuring the spatio-temporal extent of the region where hadrons are emitted and the parameters of the nuclear-nuclear interaction, called femtoscopic correlation [1]. In heavy-ion collisions, femtoscopy is an important tool for studying the geometric and dynamic characteristics of the emission region.

Two-particle momentum correlations of identical particles in nuclear-nuclear collisions make it possible to extract femtoscopic parameters (radii of emission region, R, and correlation strength, λ) [2]. Reaction dynamic is reflected in the femtoscopic radii dependence on pair transverse momentum, k_T.

This work is devoted to the study of two-particle momentum correlations of identical pions produced in collisions of gold nuclei in the STAR experiment at the RHIC at $\sqrt{s_{NN}} = 3$ GeV. The extracted three-dimensional femtoscopic radii (R_{out}, R_{side}, R_{long}) are measured as a function of collision centrality and transverse momentum of the pairs.

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FEMTOSCOPIC PROBES IN COLLISIONS OF SMALL AND LARGE SYSTEMS FROM STAR

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One of the goals of ion-ion collision studies is to understand mechanism of particle production and reveal the properties of particle-emitting source. A quark-gluon matter, produced in collisions of relativistic heavy ions at high energies ($\sqrt{s_{NN}} \geq 62.4$ GeV), undergoes a rapid transition to the hadronic matter known as crossover [1]. At lower collision energies it is expected that the phase transition will be of the first order [2] that also implies an existence of the critical point [3]. The change of phase transition type may be imprinted on the spatial and temporal properties of the particle-emitting source. The correlation femtoscopy method, based on the measurement of two-particle momentum correlations arising due to the quantum statistical correlations, is designed to access space-time extents of the fireball [4]. In addition to the large collision systems, it is also important to obtain the information about the particle production mechanism in small collision systems.

In this talk, we report the results of the two-particle femtoscopic correlations measured in collisions of small and large systems (including p+Au and Au+Au) from the STAR experiment at RHIC. The physics implications will be discussed.

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STUDY OF NCQ SCALING OF ELLIPTIC AND TRIANGULAR FLOW FOR IDENTIFIED HADRONS IN Au+Au COLLISIONS AT $\sqrt{s_{NN}} = 11.4 - 200$ GeV

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A main purpose of Beam Energy Scan experiments is to study the properties of the Quark-Gluon-Matter (QGM) forming in the collisions of two nuclei. Anisotropic flow of produced particles is one of the important observables sensitive to the transport properties of the QGM created in relativistic heavy-ion collisions. Anisotropic flow of identified particles measured in Au + Au collisions at top RHIC energy $\sqrt{s_{NN}} = 200$ GeV exhibits a remarkable NCQ scaling with number of constituent quarks and transverse kinetic energy.

In this work, we report on the calculations of elliptic (v2) and triangular (v3) flow of identified charged hadrons produced in Au + Au collisions at 11.5−200 GeV from several state of the art models and provide the direct comparison with published results from RHIC BES experiments. Further insights about the mechanism of NCQ scaling of anisotropic flow will be discussed.

DIRECT PHOTON AND NEUTRAL MESON PRODUCTION RESULTS FROM ALICE EXPERIMENT

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The ALICE experiment at the LHC is dedicated to the study of the hot and dense medium produced in heavy-ion collisions, the so-called quark-gluon plasma (QGP). Neutral meson spectra and direct photon spectra at high p_T impose constraints on parton distribution functions in protons and nuclei, and provide information about the transport properties of the QGP. The temperature of the hot fireball created in a heavy-ion collision can be studied via the measurement of low-p_T direct photons.

Photons are reconstructed in ALICE with two complementary methods, using the electromagnetic calorimeters or via the reconstruction of e^+e^- pairs from conversions in the ALICE detector material using the central tracking system. This approach provides reliable cross checks of results and allows to reduce the statistical and systematic uncertainties of the measurements. In addition, the fraction of direct photons to inclusive photons can be measured with virtual photons (dielectrons) at low p_T with different systematic uncertainties.

We report recent results from ALICE on the direct photon and neutral meson measurements in pp, p-Pb, and Pb-Pb collisions and compare them to model calculations.

PRODUCTION OF Σ^0 HYPERON AND SEARCH OF Σ^0-HYPERNUCLEI AT LHC WITH ALICE

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The first measurements of the transverse momentum (p_T) spectra, integrated yields and mean p_T of Σ^0 and anti-Σ^0 hyperons in *pp* collisions at $\sqrt{s}$

=7 TeV at the LHC are presented. The Σ^0(anti-Σ^0) signal is reconstructed via its electromagnetic decay channel Λ (anti-Λ)γ. The Λ (anti-Λ) baryon is reconstructed via its decay into $p + \pi^-$ (anti-$p + \pi^+$), while the photon is detected by exploiting the unique capability of the ALICE detector to measure low-energy photons via conversion into e+e− pairs in the detector material.

The yield of Σ^0 is compared to that of the Λ baryon, which has the same quark content but different isospin. These data contribute to the understanding of hadron production mechanisms and provide a reference for constraining QCD-inspired models and tuning Monte Carlo event generators such as PYTHIA.

In addition, the feasibility of a search for a bound state of proton, neutron and Σ^0 (Σ^0-hypernuclei ${}^{3}_{\Sigma^0}$H) is presented, based on the luminosities foreseen for the LHC Runs 3 and 4.

SEARCHES FOR NEW PHYSICS WITH ULTRA-PERIPHERAL COLLISIONS AT THE LHC

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Ultra-peripheral collisions of heavy ions (UPCs) give a unique opportunity for studies of two-photon interactions in an environment with suppressed hadronic processes and enhanced electromagnetic interactions. Specifically, studies of light-by-light scattering process (LbyL) can provide a new insight on axion-like particles (ALPs) production, which emerge in a number of Standard Model extensions and are proposed as dark matter candidates. LbyL was measured by the ATLAS and CMS collaborations in the mass region above 5 GeV/c^2, and there is a possibility for the new ALICE 3 experiment to cover the low mass region, that could possibly explain muon *g*–*2* discrepancy observed at the Fermilab.

Precise measurements of the anomalous magnetic moments of leptons can be used to probe effects of physics beyond the Standard Model (BSM), such as production of supersymmetric particles or composite nature of leptons. Sensitivity to BSM physics of the anomalous magnetic moment of the τ-lepton is predicted to be ~280 times higher than that of the muon, but the short lifetime makes it impossible to use conventional measurement methods. UPCs are proposed as an alternative tool, as cross sections of τ production are sensitive to the anomalous magnetic moment.

In this contribution, the prospects of LbyL measurements, ALP searches and tau *g*–*2* studies with ultra-peripheral collisions at the LHC will be discussed.

PROBING THE HOT QCD MATTER VIA QUARKONIA AT THE NEXT-GENERATION HEAVY-ION EXPERIMENT AT LHC

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Quarkonia represent one of the most valuable probes of the deconfined quark-gluon hot medium since the very first experimental studies with ultrarelativistic heavy-ion collisions. A significant step forward in characterizing the QCD matter via systematic studies of quarkonia production will be performed by the next-generation heavy-ion experiment ALICE 3 [1], a successor of the ongoing ALICE experiment at the Large Hadron Collider. The new advanced detector of ALICE 3 will allow for exploring production of S- and P-state quarkonia at high statistics at low and moderate transverse momenta range. Performance of the ALICE 3 for quarkonia measurements and requirements for the detectors will be discussed in the talk.

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PERFORMANCE OF THE PRECISE ELECTROMAGNETIC CALORIMETER ALICE/PHOS AND UPGRADE PLANS

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The photon spectrometer (PHOS) of the ALICE experiment is a high-granularity $PbWO_4$ crystal calorimeter with avalanche photodiode (APD) readout. Its primary physics goal is the measurement of direct photon and neutral meson spectra and correlations in pp, p-A and A-A collisions. PHOS participated in LHC Run 1 (2009-2013) and Run 2 (2015-2018), during which a large amount of physical data were collected in pp, p-Pb and Pb-Pb collisions.

The choice of active material with small Molière radius allows PHOS to operate in a high-multiplicity environment and to reconstruct neutral pions by two-photon decays up to very high transverse momenta ~60 GeV/c. In order to increase the light yield of the crystals and reduce electronic noise, PHOS is cooled down and kept at a constant temperature of -25^{o} C. This resulted in excellent energy and position resolutions. Dedicated L0 and L1 triggers were used to increase collected integrated luminosity during data taking.

We will present an overview of the PHOS performance during Runs 1 and

2 and plans for an upgrade for LHC Run 4 and beyond with the aim of improving the time and energy resolution and extending the dynamic range down to low energies. This goal can be achieved by upgrading the photodetectors from APD to multi-pixel photon counters (MPPC), upgrading the front-end electronics and the detector mechanics. The expected improvements of the time and energy resolutions will be presented and the resulting reduction of systematic uncertainties of ongoing analysis and new possibilities will be discussed.

FIRST MEASUREMENT OF THE FORWARD RAPIDITY GAP DISTRIBUTION IN PROTON-LEAD COLLISIONS AT LHC ENERGY $\sqrt{s_{NN}} = 8.16$ TeV WITH THE CMS EXPERIMENT

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For the first time at LHC energies, we present the forward rapidity gap spectra from proton-lead (pPb) collisions for both pomeron-lead and pomeron-proton topologies. The analysis is performed over 10.4 units of pseudorapidity. The center-of-mass energy is 8.16 TeV per nucleon-nucleon pair, i.e., almost 300 times higher than previous measurements of diffractive production in proton-nucleus collisions. For the pomeron-lead topology, the EPOS - LHC predictions are a factor of two below the unfolded data, but the model does give a reasonable description of the spectrum's shape. For the pomeron-proton topology, the EPOS-LHC, QGSJET II, and HIJING generator predictions are all at least a factor of five below the data. This effect can be explained by a significant contribution of ultra-peripheral photoproduction events mimicking the signature of diffractive processes. The obtained data may be of significant help in understanding the high energy limit of QCD and modeling cosmic ray air showers.

SEARCHES FOR NEW PHYSICS IN THE DILEPTON CHANNEL WITH THE CMS DETECTOR AT THE LHC

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Search for physics beyond the standard model using resonant and nonresonant models in dilepton channel has been performed using Run 2 data with integrated luminosity 140 fb^{-1} in proton-proton collisions at $\sqrt{s}$=13 TeV with the CMS experiment at the LHC.

A good agreement with the predictions of the standard model is found, no significant deviations are observed.

Limits on the parameters of the considered models are reported.

SEARCHES FOR LONG-LIVED PARTICLES IN CMS EXPERIMENT

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Many models beyond the standard model predict new particles with long lifetimes, such that the position of their decay is measurably displaced from their production vertex. We present recent results of searches for long-lived particles obtained using data recorded by the CMS experiment at the LHC

MODEL STUDY OF THE ENERGY DEPENDENCE OF THE CORRELATION BETWEEN ANISOTROPIC FLOW AND THE MEAN TRANSVERSE MOMENTUM IN Au+Au COLLISIONS

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One of the key goals of the heavy-ion programs is to study the transport properties of the quark-gluon plasma (QGP) forming in the collisions of two nuclei, such as the specific shear viscosity η/s as a function of temperature T and baryon chemical potential μ_B. The precise extraction of such parameters may present a certain difficulties. To strengthen the constraints for $\eta/s(T, \mu_B)$ the modified Pearson correlation coefficient $\rho(v_2^2,[p_T])$ between the average transverse momentum $[p_T]$ and square of the elliptic flow coefficient v_2^2 might be employed.

In this work, sensitivity of the correlation coefficient $\rho(v_2^2,[p_T])$ to the attenuation effects of the specific shear viscosity and the initial-state geometry of the collisions is studied using the UrQMD+vHLLE hybrid model to simulate Au+Au collisions. Measurements of the correlation between v_2^2 and $[p_T]$ could aid precision extraction of $\eta/s(T, \mu_B)$ from the experimental data available at RHIC.

GEANT4 FTF MODEL DESCRIPTION OF THE NA61/SHINE COLLABORATION DATA ON STRANGE PARTICLE PRODUCTION IN PP-INTERACTIONS

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Geant4 is the well-known package for simulation of particle penetration in matter which is used in many high energy experiments. There is FTF (Fritiof) model in Geant4. The FTF model is responsible for simulations of elementary interactions. We compare the FTF model results on inclusive distributions of Λ, K0s, Ξ-, anti-Ξ+ and K*(892)0 produced in pp interactions at Plab=158 GeV/c recently measured by the NA61/SHINE collaboration. It is found that for a good description of the K*(892)0 mesons it is needed to set up the ratio of pseudo-scalar to vector meson probability as 0.4/0.6 in a production. A description of the Ξ- and anti-Ξ+ hyperons requires a special treatment of fragmentation of anti-diquark – diquark strings with low masses, and an additional tunning of quark and diquark fragmentation functions. With all of these, we reproduce Λ and K0s spectra well. It is the best model description of the strange particle production in the literature. The collaboration could not be able to describe its data using the EPOS 1.99 model.

DETERMINATION OF NEUTRAL PION PRODUCTION IN AG+AG COLLISIONS AT 1.23 A GEV BEAM ENERGY AT THE HADES EXPERIMENT

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The High Acceptance DiElectron Spectrometer (HADES) is a fixed target experiment which explores the properties of hadronic matter in collisions of pions, protons and nuclei at beam energies 1–2 A GeV. It operates at the SIS18 accelerator in GSI, Darmstadt. Due to the newly built electromagnetic calorimeter ECal the HADES has a possibility to measure yield of the neutral pions via $\pi^0 \rightarrow \gamma\gamma$ decay. These measurements play an important role in reducing the systematic uncertainties in study of dilepton spectra.

The analized data were collected in Ag + Ag collisions at the beam energy 1.23 A GeV. The events with centrality 0-30 % were chosen for the analysis. The procedure of π^0 yield determination and its uncertainty is discussed in this talk. This analysis includes calibration of the ECal detector, acceptance and efficiency corrections and extrapolation of the spectra.

STUDY OF CHARGED SPECTATORS MULTIPLICITY DISTRIBUTIONS IN NUCLEUS-NUCLEUS REACTIONS AT THE HADES EXPERIMENTS

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Multiplicity distributions of charged spectators with $Z = 1, 2, 3$ measured at the HADES experiments in reactions Ag+Ag at 1.58 AGeV and Au+Au at 1.23 AGeV will be presented. The experimental data have been obtained by Forward multichannel scintillation detector, Forward Wall (FWall). The multiplicity distributions of charged fragments for different centrality classes have been compared with simulated ones obtained in the SHIELD and DCM-QGSM-SMM models.

TEST OF FULL PSD READOUT CHAIN AT THE mCBM

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The forward hadron calorimeter (PSD – Projectile Spectator Detector will be used at the Compressed Baryonic Matter (CBM) experiment at FAIR to measure the nucleus-nucleus collision centrality and orientation of the reaction plane. The PSD is a sampling lead/scintillator with modular transverse structure and longitudinal segmentation. The PSD has 46 modules with 10 longitudinal sections in each module. Light readout from each section is provided by Hamamatsu MPPC installed at the rare side of modules.

The PSD FEE and readout system is based on the ADC FPGA board, which was originally designed for ECAL at PANDA. This board employs two Kintex-7 FPGAs, which are processing the incoming data from ADCs with 14-bit resolution and 125MHz digitization rate for 32 channels per one FPGA. Due to high radiation doses and neutron fluences expected at the CBM, PSD readout electronics will be placed in the radiation protected room. Boards with photodetectors (MPPCs) will be placed on the back plane of the PSD without preamplifiers and will be connected with 60 m coaxial cable with readout electronics placed outside of the cave.

The developed data acquisition system registers signals from 2.5 mV to 1.5 V, which provides coverage of the dynamic range x500 when adjusting the voltage corresponding to photodetectors for temperature correction of their gain. Direct digitization of low amplitude signals without the use of active electronics on the detector side is a new approach for the detector's readout system in nuclear physics, which makes it possible to realize the maximum possible dynamic range of the detector.

The full chain of the FEE and readout electronics of one PSD module - "mini PSD" (mPSD) has been assembled at mCBM. The readout has been integrated into mCBM trigger-less data acquisition system. Details of the PSD readout electronics, signal processing and transmission within the common synchronized mCBM data transport system will be shown.

UPGRADE OF PROJECTILE SPECTATOR DETECTOR AT NA61/SHINE EXPERIMENT

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Projectile Spectator Detector (PSD) is a sampling hadron calorimeter used in the NA61/SHINE experiment to provide measurement of collision centrality and event plane reconstruction independently from tracking detectors. The PSD consists of modules with longitudinal segmentation based on lead/scintillator layers with the sampling ratio 4:1. Light from scintillator plates is collected with WLS fibers and each six consecutive scintillator plates are read out by one Hamamatsu MPPC placed at the end of the module. A fast analog signal from PSD modules allows to select events with required centrality on-line at the trigger level. Performance of the PSD will be shown for the measurements at the energy range 13–150 AGeV.

New physics program of NA61/SHINE experiments beyond 2020 includes open charm measurements. Current beam rate has to be increased by an order of magnitude. This requires PSD upgrade to survive in new high radiation conditions and to have faster photodetectors and read-out electronics. Instead of the present PSD, it is proposed to use two forward calorimeters. The first one is modified current PSD with constructed beam hole in the center and the second one is a new calorimeter with small transverse sizes placed downstream. Details of the PSD upgrade including simulation results of radiation conditions as well as results of the performance studies for new calorimeter system will be presented.

MCDST: A UNIFIED STORAGE FORMAT FOR HEAVY ION COLLISION SIMULATED DATA

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Each Monte Carlo generator used for heavy-ion collision simulations has a specific output form of simulated events. This fact complicates data storage and prevents standardization of processing data generated considering different models.

The McDst format is implemented to work around this. The format allows to store and smoothly read simulated data, that obtained from different generators, for analysis performance. To take advantage of the McDst unified approach a set of convertors for popular MC generators output formats is also implemented. Discussed programming solution is developed in C++ using ROOT libraries.

In this talk, the architecture of the McDst format is presented. A quick start guide to ease simulated data processing is also provided.

ELLIPTIC FLOW FOR π^0 MESONS IN ASYMMETRIC Cu+Au COLLISION SYSTEM AT $\sqrt{S_{NN}} = 200\ GeV$

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Quark-gluon plasma (QGP) is a state of nuclear matter, where quarks and gluons are deconfined [1]. It can be formed in laboratory conditions in collisions of heavy ions at high energies [2]. Elliptic flow (v_2), which reflects azimuthal anisotropy of hadron production in heavy ion collisions, is one of the main observables characterizing properties of QGP [3]. The study of the elliptic flow in relativistic heavy ion collisions (Cu+Cu and Au+Au) leads to the assumption that the QGP behaves as a nearly inviscid fluid [4]. The measurements of the v_2 in Cu+Au asymmetric collision system allow to determine the dependence of the elliptic flow for light hadrons on the initial geometry of the system [5]. Since π^0 meson consists of the first-generation quarks (u, d), its production is well-measurable up to high values of p_T. Thus, the measurement of π^0 meson v_2 in Cu+Au collisions is considered as an effective tool to study QGP's properties.

In symmetric collision systems such as Cu+Cu and Au+Au the scaling of elliptic flow values v_2 for π^0 mesons with the participant nucleon eccentricity (ε_2) and with the third root of the number of participant nucleons ($N_{part}^{1/3}$) in all centrality classes was observed [6]. Such scaling could be interpreted in the frame of relativistic hydrodynamic model, considering QGP formation [7]. The observation of $\varepsilon_2 N_{part}^{1/3}$ scaling in asymmetric Cu+Au collision system could lead to a conclusion that $v_2/(\varepsilon_2 N_{part}^{1/3})$ values for π^0 mesons do not depend on the initial geometry of the system. Current report presents the study of the elliptic flow for π^0 mesons in asymmetric Cu+Au collisions at $\sqrt{s_{NN}} = 200$ GeV versus transverse momentum and centrality of the collision.

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FEMTOSCOPIC ANALYSIS OF IDENTICAL CHARGED KAONS IN Pb–Pb COLLISIONS AT 5.02 TeV WITH ALICE

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Femtoscopy is an important tool for studying space–time properties of the emission sources created in heavy-ion collisions such as spatial sizes, evolution duration, collective flow effects, etc. The importance of kaon femtoscopy is to check different model scenarios that work equally well for pions. In this contribution, we present the results of femtoscopic analysis of identical charged-kaon correlations in Pb–Pb collisions at 5.02 TeV. The results of one- and three-dimensional analyses show that the kaon femtoscopic radii are smaller for more peripheral collisions and decrease with increasing of transverse momentum. According to hydrokinetic models, it might be explained by the radial expansion of the emission source. Comparison between the obtained three-dimensional radii and the integrated Hydro Kinetic Model calculations for two particularization temperatures obtained from two different Equations of State has been performed. The one-dimensional radii are compared with the same results for other colliding systems, Pb–Pb at 2.76 TeV, p–Pb at 5.02 TeV and pp at 7 TeV, as a function of event multiplicity to check whether they have the common trend or not. Another important result of this analysis is the extraction of the maximal emission times for kaons in a wide centrality range (from 0 to 90%).

HADRONIC RESONANCE PRODUCTION WITH ALICE AT THE LHC

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The study of resonance production is important in proton-proton, proton-nucleus, and heavy-ion collisions. In heavy-ion collisions, since the lifetimes of short-lived resonances are comparable with the lifetime of the late hadronic phase, regeneration and rescattering effects become important and resonance yield ratios to those of longer lived particles can be used to estimate the time interval between the chemical and kinetic freeze-out. The measurements in pp and p-Pb collisions constitute a reference for nuclear collisions and provide information for tuning event generators inspired by Quantum Chromodynamics.

In this talk, recent results on short-lived hadronic resonances obtained with ALICE at LHC energies are presented. The presented results include system-size and collision-energy evolution of transverse momentum spectra, yields and the ratios of resonance yields to those of longer lived particles, and nuclear modification factors. The results will be compared with model predictions and measurements at lower energies.

DIPHOTON PRODUCTION RATE WITH THE EFFECT OF CHEMICAL POTENTIAL IN RELATIVISTIC HEAVY-ION COLLISIONS

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We investigate the production of diphotons from the hot and dense matter of quark-gluon plasma. The emission of diphotons is one of the most important electromagnetic signatures from quark-gluon plasma, experiments on which are still in progress at Large Hadron Collider (LHC) and Relativistic Heavy-Ion Collider (RHIC) [1,2]. For the same purpose, we employ a quasi-particle model containing quarks and gluons. Instead of the earlier used dynamical quark mass, we take into account the parameterization factors in temperature-dependent quark mass which rises due to the interaction of these quarks in extremely hot and dense state of quark-gluon plasma [3,4]. In addition, a finite chemical potential is considered in our phenomenological model. We show the diphoton emission mass spectra in QGP and compare it with the diphoton production from hadronic gas at high temperatures and finite chemical potential. Our results contribute to further understanding of diphotons which is useful in the study of quark-gluon plasma and heavy-ion collision experiments at LHC and RHIC.

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A SPECIFIC HEAT OF NUCLEAR MEDIUM PROBED BY K_S^0 MESONS PRODUCED IN AU+AU COLLISIONS AT RHIC

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The data [1] on spectra of K_S^0 mesons measured by the STAR Collaboration in Au+Au collisions at various centralities characterized by different multiplicity densities of negative particles were analyzed in the z-scaling approach [2,3]. The transverse momentum distributions obtained in the BES-I program at RHIC were accumulated in seven centrality classes from the most central 0-5% to peripheral 60-80% collisions in the rapidity range $|y|<0.5$. These data and the earlier STAR data at $\sqrt{s_{NN}}$ = 62, 130 and 200 GeV allow us a detail study of the energy and centrality dependence of K_S^0-meson production in a wide range of $\sqrt{s_{NN}}$ =7.7–200 GeV.

The scaling function $\psi(z)$ was constructed and the self-similarity of K_S^0-meson production was confirmed. It was found that the model parameter c_{AuAu} interpreted as a specific heat of produced medium depends on collision energy. The scaling behavior is consistent with an abrupt decrease of c_{AuAu} from the value of 0.16 at $\sqrt{s_{NN}}$ =7.7 and 11.5 GeV to about 0.09 at the top RHIC energy. At $\sqrt{s_{NN}}$=39 GeV, a kink in the significant drop of this parameter is observed, as well as an indication of its flattening at higher $\sqrt{s_{NN}}$. The non-trivial dependence of c_{AuAu} on the collision energy obtained from the z-scaling of K_S^0-meson production shows that the strange probe is much more sensitive to properties of nuclear medium than a non-identified negative hadron [3]. The irregularities in the behavior of the specific heat parameter c_{AuAu} could indicate existence of a phase transition in nuclear matter.

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FRACTAL ANALISIS OF Au+Au MONTE CARLO EVENTS AT 200 GEV/c

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Results of fractal analysis of Au+Au events at the energy of $\sqrt{s_{NN}}$ = 200 GeV/c by the method of the equation systems of power coverings (SePaC) [1] are presented. A Multi-Phase Transport (AMPT) model [2,3] to generate events in relativistic heavy ion collisions was used. In Event-by-Event analysis a distribution on the transverse momentum p_T of negatively charged particles produced in the pseudo-rapidity interval $|\eta| <0.5$ in the events with different centrality from 0-5% to 30-40% was studied.

The fractal data set includes 1823 events obtained by independent [4], dependent [5], and combined [6] partition. Fractal events differ in multiplicity (from 8 to 1024), the base of formation P_F (from 3 to 8), and the type of structures. The criteria characterizing the similarity of structures at different levels and reducing the portion of background events (mixed data, events with Gaussian, exponential, and uniform distributions) [7] were used.

Comparison of the Monte Carlo fractals, random events and AMPT events was performed. It was found that the multiplicity distribution for the sets of random events coincides with the distribution obtained using the AMPT generator. Distribution of fractal events with different multiplicity on the dimension D_F was obtained and their structure is discussed. The results of applying the selection criteria for various types of events are presented.

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VORTICITY AND HELICITY FIELDS IN HEAVY-ION COLLISIONS AND HYPERON POLARIZATION

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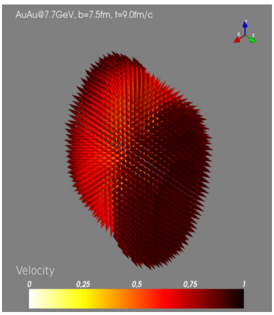
The experimentally observed significant polarization of Λ and anti-Λ particle in heavy-in collisions [1] lead to speculations that rapidly rotating swirls are of nuclear matter are created [2]. We use the transport model PHSD to simulate the Au+Au and Pb+Pb collisions at NICA energies and perform the fluidization procedure determining density, temperature, and velocity fields created at different stages of the collisions. Vorticity and hydrodynamic helicity fields are calculated and visualized in dynamics. The velocity field is illustrated on the left panel in Fig.1. It looks dominantly as the Hubble-like profiles expanding in transverse and longitudinal directions (approximate cylindrical symmetry). The small vorticity field looks like a small perturbation on top of the longitudinal and transverse flows. The vorticity field is shown on the right panel of Fig.1. We see that two vortex (asymmetrical) rings moving in the opposite direction along the z-axes are formed. The PHSD model is proved to describe successfully hyperon yields in the broad range of collision energies of our interest. Therefore, we can calculate the polarization of (anti-)hyperons on a dynamic freeze-out surface. The experimental polarization of Λ is well reproduced. However, the anti-Λ polarization is underestimated.



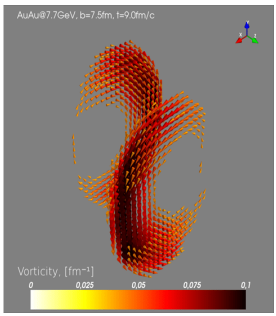


Fig. 1. Velocity and vorticity fields calculated within PHSD model for Au+Au collisions at $\sqrt{s_{NN}} = 7.7 GeV$ *for impact parameter* $b = 7.5 fm$ *at the time moment* $t = 9.0\ fm/c$*.*

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DIJET EVENTS WITH LARGE RAPIDITY SEPARATION IN PROTON-PROTON COLLISIONS AT √s = 2.76 TeV WITH CMS DETECTOR

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The new search for Balitsky-Fa-din-Kuraev-Lipatov (BFKL) evolution effects is performed at the Large Hadron Collider by the Compact Muon Solenoid experiment. The cross sections for inclusive and Mueller-Navelet dijet production are measured as a function of the rapidity separation between the jets in proton-proton collisions at $\sqrt{s}$ = 2.76 TeV for jets with transverse momentum pT > 35 GeV and rapidity |y| < 4.7. Various dijet production cross section ratios are also measured. A veto on additional jets with pT > 20GeV is introduced to improve the sensitivity to the BFKL evolution. The measurement is compared with the predictions of various Monte Carlo models based on leading-order and next-to-leading-order calculations including the Dokshitzer-Gribov-Lipatov-Altarelli-Parisi leading-logarithm (LL) parton shower as well as the LL BFKL resummation.

THE ROLE OF PARTON DISTRIBUTION FUNCTIONS IN THE ϕ MESON PRODUCTION IN RELATIVISTIC ION COLLISIONS

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Lattice gauge QCD calculations predict phase transition from hadronic matter to deconfined state of quarks and gluons - quark-gluon plasma (QGP) - at a high temperature and energy density [1]. Minimal conditions of the QCD phase transition and QGP matter formation are studied in relativistic small-system collisions [2]. One of the ways to investigate QGP properties in experiment is to measure the peculiarities of particles production [2]. Due to its characteristics, the vector ϕ meson is considered as a good probe of the partonic matter formed in relativistic ion collisions [3].

The cross section of particle production in hard processes in the leading order QCD at the nucleon level is determined using nuclear parton distribution functions (nPDFs) [4-6]. These functions characterize the probability of a parton to have a certain fraction of the nucleon momentum inside the ion at any scale of the square of the momentum transfer in the interaction. The distributions are extracted from comprehensive global analysis of hard scattering data from variety of fix-target and collider experiments in framework of pQCD. The implementing of various sets of nPDF parameterizations [4-6] may help to interpret the experimental results on particle production.

This report presents the comparison of ϕ meson production in p+Al, p+Au, d+Au, and ^{3}He+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV at midrapidity ($|\eta| < 0.35$), measured at PHENIX [1], to PYTHIA/Angantyr, PYTHIA+EPPS16, and PYTHIA+nCTEQ15 nPDFs calculations. Model calculations are consistent with experimental data within uncertainties. However, at intermediate transverse momentum range, PYTHIA/Angantyr, PYTHIA+EPPS16, and PYTHIA+nCTEQ15 calculations do not predict the ordering of ϕ meson production with the collision system size, observed in the experiment. Therefore, ϕ meson production in p/d/^{3}He+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV might be driven by mechanisms additional to nPDF.

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MULTIPLICITY DISTRIBUTIONS AND COMBINANTS IN MULTI-POMERON EXCHANGE MODEL

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In the framework of the multi-pomeron exchange model (MPEM) with string fusion [1,2] we study the multiplicity distributions of charged particles and their combinants in pp collisions at LHC energies and compare the results with the data obtained by ALICE [3] and CMS [4] collaborations at CERN. We use the standard distribution in number of cut pomerons in pp collisions [5]. In this model, each cut pomeron corresponds to the formation of a pair of quark-gluon strings. An increase in the multiplicity density with initial energy in pp collisions is explained by an increase in the mean number of cut pomerons and a growth of the average multiplicity from a single string. The last effectively takes into account the string fusion processes.

We show that the initial version of the MPEM with the Poisson distribution of particles from a single pomeron can not explain the experimental data.

We replace the Poisson distribution by a Gaussian distribution with the scaled variance $\omega > 1$, corresponding to the NBD at high multiplicities. We found that the value of ω increases with the width of observation window in pseudorapidity. This is in correspondence with the result obtained in [6-8] that the $\omega - 1$ is proportional to the width of the observation window and the integrated two-particle correlation function of a single source (string). As a result we obtain a satisfactory description of the ALICE and CMS experimental data on the multiplicity distribution of charged particles in pp collisions for observation windows of various width in energy range from 0.9–7 TeV.

Using the calculated multiplicity distribution we also found their combinants. We see that these quantities really are very sensitive to the form of the multiplicity distribution spectra, as it was pointed out in [9]. Even minor deviations of the ALICE and CMS data, within the error, lead to considerable changes in combinants. However, our results of calculating combinants in the framework of the MPEM manage to reproduce the general behavior of combinants with their number, in particular, their oscillations. The research was supported by St. Petersburg State University (project No. 93025435).

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NUCLEON RESONANCE CONTRIBUTIONS INTO INCLUSIVE ELECTRON SCATTERING

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Experiments with the CLAS detector at Jefferson Lab provided the dominant part of available in the world information on exclusive meson electroproduction in the resonance excitation region. Analyses of these results allow us to obtain electrocoupling of most excited states of the nucleon in mass range up to 1.75 GeV and at photon virtuality Q^2 from photon point and up to 5 GeV^2 [1]. It made possible, for the first time, evaluate the resonant contribution into inclusive electron scattering observables from experimental results on nucleon resonance electrocouplings [2,3].

The approach and the computational tool developed for evaluation of the resonant contribution into inclusive electron scattering observables will be presented in the talk. We use a relativistic Breit-Wigner ansatz to estimate the resonant contributions to the inclusive electron scattering unpolarized cross sections and to the unpolarized structure functions F_1 and F_2. In extraction of F_1 and F_2 structure functions from the data, the experimental results on the longitudinal over transverse cross section ratio R_{LT} available from the Hall A/C measurements [2,4] was used.

The results obtained offer new opportunities for insight into unpolarized parton distribution function (PDF) in the ground state of the nucleon at large values of partial parton momentum x within the resonance excitation region and for exploration of quark-hadron duality. Further extension of this effort in 12 GeV era at Jefferson Lab will allow us to obtain the resonant contributions into inclusive electron scattering within Q^2 range up to 10 GeV^2, offering a unique information on PDF evolution in the resonance region at the distances where the transition from quark-gluon confinement to perturbative QCD regime of strong interaction is expected.

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*N*π ELECTROPRODUCTION IN THE RESONANCE REGION IN 12 GeV ERA

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Studies of single pion electroproduction off protons is the major source of information on the spectrum and structure of nucleon resonances (N^*) located in the mass range of $W < 2.0$ GeV which decay preferentially to the Nπ final states [1]. Experimental data from CLAS on the exclusive $p\pi^0$, $n\pi^+$ electroproduction channels already provided unique information on N^* electroexcitation amplitudes at photon virtualities $Q^2 < 5.0$ GeV^2 [2]. The analysis of the electroexcitation amplitudes of $\Delta(1232)3/2^+$, $N(1440)1/2^+$, and $\Delta(1600)3/2^+$ resonances within the framework of Dyson-Schwinger equation approach (DSE) demonstrated the possibility of gaining insight into emergence of hadron mass (EHM) [3].

The new CLAS12 [3] detector is only available in the world facility capable of extending the knowledge on N^* electroexcitation amplitudes in the mass range up to $W < 3.0$ GeV and at still almost unexplored range of highest Q^2 ever achieved up to 10 GeV^2. The first results on $\pi^0 p$ electroproduction studies with the CLAS12 detector will be presented in the talk. The expected results on unpolarized differential cross sections as well as on beam spin asymmetries will provide the important information needed for extraction of the transition helicity amplitudes for most prominent in $\pi^0 p$ channel excited states of the nucleon at $Q^2 < 10$ GeV^2. Analysis of these results within DSE will allow us to map out momentum dependence of dressed quark mass within the essential range of distances where the dominant part of hadron mass is expected to be generated shedding light on one of the most challenging and still open problem of the Standard Model on emergence of hadron mass and quark gluon confinement from QCD.

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FIRST RESULTS FROM CLAS12 ON $\pi^+\pi^- p$ ELECTROPRODUCTION IN FULLY EXCLUSIVE KINEMATIC

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Studies of the excited nucleon state spectrum and structure offer unique insight into the dynamics of strong interaction in the regime of large QCD running coupling, i.e. the regime of strong QCD.[1] The experimental program at Hall B in Jefferson Laboratory with the CLAS detector using electron and photon beams has provided the first and only available in the world results on electroexcitation amplitudes ($\gamma v p N^*$ electrocouplings) for the most resonances in the mass range up to 1.8 GeV and photon virtuality up to Q^2<5.0 GeV^2. Experiments with the CLAS12 detector will extend our knowledge on the N^* spectra, in particular, in the mass range above 2.0 GeV. Studies of $\pi^+\pi^- p$ electroproduction represent an important part of these efforts. The first results of studying this complex electroproduction channel will be outlined in the talk.

The analysis of the 6.5 GeV data set obtained by Run Group-K (RG-K) will be presented. The $\pi^+\pi^- p$ channel's event selection has been performed in accordance with the RG-K's general procedures. Using Monte Carlo simulation several further selections on different kinematic variables have been developed which allowed to observe resonance structures in the missing mass distributions.

The expected results will allow us to explore the spectrum of high-lying resonances contributing to the $\pi^+\pi^- p$ electroproduction including the search for predicted in quark models but still not observed in experiments so-called "missing" resonances and the new expected states of hadron matter, so-called hybrid baryons with glue as an active structural component.

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STUDIES OF DOUBLE PION ELECTROPRODUCTION WITH CLAS12 IN KINEMATICS WITH MISSING HADRON

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Exclusive $N\pi$ and $\pi^+\pi^-p$ electroproduction channels currently represent the major source of information on nucleon resonance ($N*$) electroexcitation amplitudes. Experiments with CLAS detector on exploration of $\pi^+\pi^-p$ electroproduction at Jefferson lab with decisive contribution from Moscow State University group provided information on electroexcitation amplitudes of most excited states of the nucleon in the mass range up to 1.8 GeV. These results offer a unique insight into many facets of strong interaction in non-perturbative regime which underlie the generation of different resonances with different structural features as the bound systems of quarks and gluons. [1,2]. Further extension of the efforts on exploration of $\pi^+\pi^-p$ electroproduction with the new CLAS12 detector in the 12 GeV era of experiments at JLab will be presented in the talk. CLAS12 takes data using electron beams with energies up to 11 GeV which allows to probe the structure of nucleon resonances at highest photon virtualities (Q^2) ever achieved up to 10 GeV^2. The event selection of the $ep \rightarrow e'p'\pi^+\pi^-$ channel measured in CLAS12 for the kinematics where one final hadron is missing will be presented. The plan for extraction of $\pi^+\pi^-p$ differential cross sections will be outlined.

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EVALUATION OF KΛ AND KΣ^0 ELECTROPRODUCTION CROSS SECTIONS FROM THE CLAS DATA

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The method and computational tool will be presented for the evaluation of KΛ and KΣ^0 electroproduction cross sections from the experimental results on exclusive structure functions $\frac{d\sigma_T}{d\Omega}$, $\frac{d\sigma_L}{d\Omega}$, $\frac{d\sigma_{LT}}{d\Omega}$, $\frac{d\sigma_{TT}}{d\Omega}$ available from the measurements with the CLAS detector [2,3] with numerical results stored in the CLAS physics database [1]. The tool is capable to predict differential KΛ and KΣ^0 cross sections within the kinematic area of the invariant mass of the final hadrons W < 2.6 GeV and at photon virtualities 0 GeV^2 < Q^2 < 5.0 GeV^2 from interpolated/extrapolated exclusive structure functions $\frac{d\sigma_T}{d\Omega}$, $\frac{d\sigma_L}{d\Omega}$, $\frac{d\sigma_{LT}}{d\Omega}$, $\frac{d\sigma_{TT}}{d\Omega}$. For reliable interpolation of $\frac{d\sigma_{TT}}{d\Omega}$ structure function at low Q^2, the photoproduction data on beam spin asymmetry Σ [4] were used. The developed approach provides evaluation of differential electroproduction cross section within mentioned above kinematics area entirely from the experimental data without any bias from reaction model assumptions. We implement several techniques for interpolation of the exclusive structure functions over kinematic variables W, Q^2, and the final kaon emission angle in the CM frame cos(θ). In addition, various extrapolation procedures were implemented in the kinematic area where the experimental data are still not available or insufficient. Comparison with available data confirmed credible evaluation of KΛ and KΣ^0 differential cross sections. The developed approach will be used for extraction of $\frac{d\sigma_{LT'}}{d\Omega}$ structure function from the first results on KΛ and KΣ^0 beam spin asymmetry data measured with the recently put in operation CLAS12 detector at Jefferson Lab. The studies of KΛ and KΣ^0 electroproduction channels will open the new avenue in exploration of the nucleon resonance structure in the experiments of 12 GeV era at Jefferson Lab in collaboration with Physics Department and Skobeltsyn Nuclear Physics Institute at Lomonosov Moscow State University.

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THE COMPUTATIONAL TOOL FOR EVALUATION OF NП ELECTROPRODUCTION CROSS SECTIONS

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The measurements of exclusive π^+n and π^op electroproduction with the CLAS detector in Hall B at Jlab provided the dominant part of the world data on observables of these channels [1,2] stored in the CLAS Physics Data Base [3]. The data on exclusive *N*π and $\pi^+\pi^- p$ electroproduction are the major source of the information on nucleon resonance (*N**) electroexcitation amplitudes. They offer insight into the Nπ structure and strong QCD dynamics which underlie the nucleon resonance generation from quarks and gluons [1,2,4]. The approach for evaluation of the four-fold Nπ differential cross sections from unpolarized, transverse-transverse, longitudinal-transverse exclusive structure functions will be presented in the talk. The special procedures were developed for extraction of the mentioned above structure functions from experimental data. These structure functions were interpolated within entire Np electroproduction phase space covered in the measurements with CLAS offering evaluation of *Np* electroproduction cross section entirely from the experimental data without any bias from reaction models. Comparison with the available data on *Np* electroproduction demonstrated credibility of approaches developed for cross section evaluation. For the first time, reliable estimates of *N*π electroproduction observables have become available within a broad kinematics area of the invariant masses of the final hadron system of $W < 1.7$ GeV and the photon virtuality range $Q^2 < 5.0$ GeV^2. The estimated *N*π cross sections and exclusive structure functions are of particular importance for the studies of the *N** structure. Future extension of these estimates toward higher *W* covering DIS region are important for exploration of the ground nucleon structure in 3-dimesions from the results on the chiral-odd generalized parton distributions constrained by the data of deeply virtual *N*π electroproduction. The extracted structure functions and the computer code for on-line evaluation of *Np* electroproduction cross sections are available on the website [5] for the access worldwide.

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COMMISSIONING OF THE FORWARD DETECTORS TO MEASURE SPECTATORS IN NUCLEUS-NUCLEUS REACTIONS AT THE BM@N

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The BM@N (Baryonic Matter at Nuclotron) is a fixed target experiment at the NICA-Nuclotron (JINR, Dubna, Russia) accelerator complex designed to study the properties of the dense nuclear matter produced in the nucleus-nucleus collisions. Several forward detectors have been developed and constructed at the INR RAS. These detectors are the Forward Hadron Calorimeter (FHCal), the Scintillation Wall (ScWall) and the Beam Hodoscopes (BH).

The FHCal is a lead/scintillator sampling hadron calorimeter with modular design and longitudinal module segmentation. The calorimeter has a hole in the center for the passage of the beam particles that did not interact with the target through the calorimeter. The ScWall consists of scintillator tiles and is designed to detect the charged fragments from nucleus-nucleus reactions. The BHs are designed for detection of heaviest nuclear fragments and non-interacting beam ions. They will be installed on the entrance of the FHCal and will cover the beam hole of the calorimeter. The BHs consist of optically isolated scintillator or quarz bars with light collection from both ends. All forward detectors have light detection performed by silicon photomultipliers. Signals are amplified and digitized with fast sampling ADCs.

The status of development and construction of the forward detectors for the BM@N experiment will be presented. Performance of the forward detectors and their calibration during the Short Range Correlations (SRC) run period at the BM@N will be discussed.

APPLICATION OF THE MC-GLAUBER APPROACH FOR CENTRALITY DETERMINATION IN HEAVY-ION COLLISIONS WITH THE BM@N EXPERIMENT

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Centrality is an important concept in the study of strongly interacting matter created in a heavy-ion collision whose evolution depends on its initial geometry. In the case of Baryonic Matter at Nuclotron (BM@N), which is a fixed-target experiment, collision can be characterized by the measured multiplicity or energy of produced particles at midrapidity or spectator fragments in the forward rapidity region.

We will present the application of the MC-Glauber approach for centrality determination in heavy-ion collisions with the BM@N experiment. The multiplicity of charged hadrons is measured in BM@N using a combination of Silicon Tracking System (STS) and Gaseous Electron Multiplier (GEM) detectors and connected to collision geometry parameters using the Monte-Carlo Glauber model. We will discuss the applicability of the standard Monte-Carlo Glauber approach for medium-sized nuclei collisions with low multiplicity, which is typical for the BM@N.

DEVELOPMENT OF EVENT RECONSTRUCTION METHODS IN THE HEAVY-ION PROGRAM OF THE BM@N EXPERIMENT

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The BM@N (Baryonic Matter at the Nuclotron) is the first experiment on the **NICA** accelerator complex under construction at **JINR** (Dubna, Russia). The main purpose of the experiment is to study the interaction of relativistic heavy ions with fixed targets.

Technical runs of the experiment took place in 2017-2018. The first physical run on the **Xe** beam and **CsI** target is planned for the Autumn 2022. At the moment there is an active phase of preparation for the experimental run. The report presents methods under development for reconstruction of particle trajectories and event vertices in conditions of high multiplicity of primary tracks. Methods for rejecting false hits are presented.

HIGH-PERFORMANCE OPTIMIZATION OF THE SOFTWARE FOR EXPERIMENTAL DATA DECODING IN BM@N NICA EXPERIMENT

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In the BM@N (Baryon Matter at Nuclotron) experiment at NICA accelerator complex in Joint institute for Nuclear Research (Dubna, Russia) study of collisions of isospin symmetric nuclei with fixed targets is performed [1]. Efficient software environment plays key role in the BM@N experimental program. The BmnRoot software package is used for both simulation and event reconstruction of simulated and experimental data. Special attention is to the BmnRoot performance optimization [2]. The present report is devoted to performance optimization of the experimental data decoding module of the BmnRoot software package. Most time-consuming hotspots of the decoder have been localized. Vectorization of these hotspots improved performance of most time-consuming decoder functions by 1.25-2 times. As a consequence, total time of execution is improved by 15-20%. Quality assurance demonstrated correctness of optimization.

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A METHOD OF CALCULATING THE ELECTRIC FIELD MAP OF TRIPLE GEM DETECTOR FOR THE FIRST PHYSICS RUN OF BM@N EXPERIMENT

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BM@N (Baryonic Matter at Nuclotron) [1] is the first stage experiment which is carried out at the NICA (Nuclotron-based Ion Collider fAcility) accelerator complex [2] located at Joint Institute for Nuclear Research in Dubna. The main purpose of the experiment is to study dense baryonic matter as a product of heavy ion collisions.

This work concentrates on the features of simulation for the core BM@N tracking detector based on triple GEM (Gas Electron Multiplier) system [3]. In particular, we will describe in detail the preparation of electric field map needed for detailed simulation of this detector. We will review the main steps of the field map preparation based on using special software such as GMSH [4], Elmer [5] and Garfield++ [6]: toolkits for finite element mesh generation, electric field calculation and simulation of physics processes in gaseous and semiconductor detectors.

Our computations are based on the particular conditions and properties of GEM chambers used in the first physics experimental run that scheduled to be performed in 2022. The principal difference of the future run from the previous is in their purposes. The previous runs, being focused on testing detector facilities, were mainly technical but the new ones are aimed to get some physics results that had been claimed in the scientific program of the BM@N experiment.

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DEVELOPMENT OF DCS FOR FORWARD SPECTATOR DETECTORS AT THE BM@N, MPD/NICA AND NA61/SHINE EXPERIMENTS

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The BM@N and MPD experiments at NICA facility (Dubna, Russia) will use the forward hadron calorimeters (FHCal) for centrality and reaction plane determination in the heavy ion collisions. Also the BM@N setup features Scintillation Wall and the Beam Hodoscope detectors for charged fragments measurements. The NA61/SHINE experiment at CERN is using two projectile spectator detectors (Main PSD and Forward PSD) for centrality and reaction plane measurements.

All detectors have light readout based on silicon photomultipliers. In each experiment forward detectors have several hundred readout channels.

Forward detectors share the common architecture that simplifies the development of the Detector Control System (DCS). The developed algorithms and software for the DCS of these detectors to control the bias MPPCs voltages and the temperature of MPPCs and its integration into the experiment-wide DCS will be reported.

STUDY OF THE SCINTILLATION DETECTOR PROTOTYPE FOR THE UPGRADED POLARIMETER AT THE INTERNAL TARGET STATION AT THE NUCLOTRON

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The prototype of a scintillation detector with various types of front-end electronics (FEE) have been developed. These types are with silicon photomultipliers (SiPM) readout. The paper presents the results of studies of a prototype scintillation detector, discusses the estimation of the time resolution. The presented prototype will allow obtaining and evaluating polarization observables measurements (beam polarization stability, polarization magnitude, etc.) at the polarimeter of the DSS project as part of the implementation of the first stage of the spin program at SPD NICA [1-3].

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DEVELOPMENT OF A NON-EQUILIBRIUM HYDRODYNAMIC APPROACH TO DESCRIBING THE EMISSION OF HIGH-ENERGY SECONDARY PARTICLES IN COLLISIONS OF HEAVY IONS OF INTERMEDIATE ENERGIES

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Developing the hydrodynamic approach in describing collisions of heavy ions of intermediate energies [1-6], we proposed to solve the kinetic equation together with the solution of the equations of hydrodynamics [2,3]. This made it possible to successfully describe the double differential cross sections for the emission of protons and pions in collisions of medium-energy heavy ions [2, 3]. We also managed to completely describe the spectra of protons, pions, and photons for the collision of carbon nuclei with a beryllium target in the energy range of 0.3–3.2 GeV per nucleon, obtained in the ITEP experiments [7, 8]. When describing these spectra, the correction for the microcanonical distribution [4, 5] was taken into account, and the contribution of the fragmentation process was also taken into account for the proton yields [6].

The contribution of the effects of short-range correlations SRC, which has recently received much attention [9], was also studied by us. As a result, it turned out that these effects are included in our approach, since we successfully describe the experimental data on the spectra of hard photons [10], which are described in [9] with the addition of a high-momentum component. Our approach is applicable to collisions of both light and heavy nuclei, which can be seen from a comparison of the description of the proton distributions in transverse momentum in the Au+Au reaction at an energy of 1.48 GeV per nucleon with experimental data and other theoretical approaches based on solving the Boltzmann equation, the quantum model molecular dynamics, etc. [11]. This can be extended to the energy range of the reptile complex NICA located at JINR (Dubna).

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DETECTION OF NEW PARTICLES-POSSIBLE CANDIDATES FOR THE ROLE OF DARK MATTER PARTICLES IN COLLISIONS OF PROTONS AND NUCLEI FROM SOFT PHOTONS SPECTRA

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Developing a statistical model of multiple particle production based on [1-3], an algorithm was proposed for finding the transverse momentum distribution of secondary particles produced in collisions of protons and nuclei [4]. The calculated spectra of Λ hyperons are consistent with experimental data and calculations based on the quark-gluon string model [5]

Analyzing, following [6], the experimental data [7] on the spectra of soft photons depending on the transverse momentum, in this paper it is proposed to interpret the hardening of the spectrum [7] as a manifestation of the contribution of a new X17 boson particle with a mass of about 17 MeV, which is a candidate for the role of particles dark matter [8, 9]. Based on the tube model, an algorithm for finding the mass of the X17 boson, as well as the X38 boson [5.6], discovered in Dubna, is proposed. Using the black body formula, it is possible to describe both the spectra of strange particles [4] and the spectra of new particles X17 and X38 with the found temperature already for a “cold” electromagnetic plasma, when compared with experimental data [7, 10] for soft photons.

Neutral bosons X17 and X38 are not baryons, they are not particles of the Standard Model and can form massive dark matter objects in astrophysics. The existence of the X17 boson mass, equal to 17 MeV, and X38, equal to 38 MeV, is substantiated based on the electromagnetic tube when two-dimensional QCD_2 and QED_2 are combined. The search for new particles possible candidates for the role of light particles of dark matter is very relevant [12].

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DESCRIPTION OF MESONS AND NUCLEONS IN EFFECTIVE MODELS OF QUANTUM FIELD THEORY ON THE LIGHT FRONT

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Hadron models based on effective Hamiltonians of quantum field theory on the light front are considered. The states of mesons and nucleons are modeled as quark-antiquark and 3-quark bound states, respectively. These models can be used for comparison with experimental data for electro-magnetic form factors of mesons and nucleons.

THERMAL PHOTONS PRODUCTION IN PROTON-PROTON COLLISIONS AT HIGH ENERGIES

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In proton-proton collision at high energies are produced two type photons: prompt and thermal. Prompt photons are produced at Compton scattering of quark-gluon and at annihilation of quak-antquark processes [1]. Thermal photons are produced in the processes with participation π mesons [2].

We constructed Feynman diagrams of the thermal photons production in following processes: 1. $\pi^+\pi^- \to \gamma\rho^0$, 2. $\pi^\pm\rho^0 \to \gamma\pi^\pm$, 3. $\rho^0\gamma \to \pi^+\pi^-$, 4. $\pi^+\pi^- \to \gamma\eta$, 5. $\pi^\pm\eta \to \gamma\pi^\pm$, 6. $\pi^+\pi^- \to \gamma\gamma$ and wrote matrix elements. Calculation of the square of matrix elements are performed using FeynCalc.

The dependence of differential cross section of processes production thermal photons on energy of colliding protons and on cosine of angle of scattering of photons are investigated. In calculation of differential cross section of these processes form factor of mesons also has been taked in account.

It is shown that the differential cross section of investigated processes decreased with increasing of energy of colliding protons. Comparison of differential cross section of processes has been carried out. The dependence of differential cross section of processes 1,3 and 4 on cosine of the angle of scattering photons is symmetric relative to 0 and it increases with the cosine of the angle in the intervals [–1, 0] and [0, 1]. The differential cross section of process 2 has a maximum at –1 cosine of the scattering angle of photons and decreases with increasing cosine of the angle scattering photons. The differential cross section of process 5 does not depend on cosine of the angle scattering photons. It is shown that accounting of the form factor of mesons reduces of differential cross section of processes.

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SYSTEMATICS OF REACTION PLANE DETERMINATION WITH THE MPD EXPERIMENT

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Studying the equation of state of strongly interacting matter is one of the main goals of the Multi Purpose Detector (MPD) experiment at the future NICA facility. Among the important observables in this study is final state momentum anisotropy relative to collision symmetry plane described with anisotropic transverse flow coefficients. This work addresses the systematics of participant and spectator symmetry plane estimation using different methods and subsystems of the MPD experiment and taking into account effects of azimuthal acceptance non-uniformity. The study is based on Monte Carlo simulations of MPD detector response to the particles resulting from Bi+Bi collisions at $\sqrt{S_{NN}}$=9.2 GeV produced with the DCM-QGSM-SMM event generator. The latter is characterized by realistic yields of spectator fragments allowing to obtain signals in Forward Hadron Calorimeters (FHCal) close to those expected in the real data.

SOURCE VELOCITY IN COLLITIONS OF 2.1 GeV PROTONS WITH GOLD TARGET

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One way of evaluating the degree of equilibration in reaction, as well as determine the average source velocity, is through invariant cross section analysis as a function of longitudinal and transverse velocity.

In the present work the source characteristics of multifragmentation are investigated for the p + Au collisions at 2.1 GeV. Beam of 2.1 GeV protons were obtained from the Dubna superconducting accelerator NUCLOTRON. Invariant cross sections of carbon fragments from target spectator were measured with the 4π device FAZA [1]. Fig. 1 shows the longitudinal versus transverse velocity plot ($\beta_{\perp}$ vs $\beta_{||}$) along points of constant invariant cross section for carbon fragments. The lines in Fig. 1 are fits to the data for a constant value of invariant cross section in the ($\beta_{\perp}$ vs $\beta_{||}$) plane.

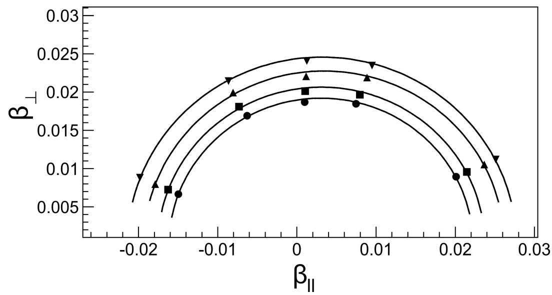

Fig. 1. Longitudinal versus transverse velocity plot along points of constant invariant cross section for carbon fragments. Points – experiment. Lines are fits to the data for a constant value of invariant cross section in the longitudinal versus transverse velocity plane.

It was found to a good approximation that the data for a given invariant cross section are isotropic; i.e., they can be described by a circle with fixed locus, corresponding to a single average source velocity. Mean source velocity ($\beta = v/c$) of target spectator is 0.0032 ± 0.0003. The research was supported by the Russian Foundation for Basic Research, Grant No. 19-02-00499.

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MEASUREMENT OF THE DEUTERON ANALYZING POWERS Ay, Ayy AND Axx IN dp- ELASTIC SCATTERING AT NUCLOTRON

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The results on the the vector Ay and tensor Ayy and Axx analyzing powers in deuteron-proton elastic scattering at large scattering angles are presented. These data were obtained at internal target at JINR Nuclotron in the energy range 400–1800 MeV using polarized deuteron beam from new polarized ion source. New data on the deuteron analyzing powers in the wide energy range demonstrate the sensitivity to the short-range spin structure of the isoscalar nucleon-nucleon correlations.

PROTON AND DEUTERON POLARIMETRY AT NUCLOTRON-NICA

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Extensive experience has been accumulated in deuteron and proton beam polarization measurements as well as in the the simulation of the pp-, pd- and dp-elastic scattering up to 1 GeV/nucleon for polarimeter upgrade at the Nuclotron Internal Target Station. Further development of the pp-, pd- and dd- colliding beams polarimetry at NICA is discussed. The first results of the simulation of these proceses at the total energy up to 27 GeV are presented.

HADRON PRODUCTION IN *pp* AND *AA* COLLISIONS WITHIN SELF-SIMILARITY APPROACH

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The self-similarity approach is applied to study the hadron production in mid-rapidity region in *pp* and *AA* collisions. Our calculations describe satisfactorily the experimental data on the inclusive p_T spectra of pions and kaons produced in *pp* and central *BeBe* collisions and their ratios as a function of initial energy $s^{1/2}$. We collect also data on ratios of baryon to anti-baryon yields in *pp* and *AA* collisions as a function of $s^{1/2}$ and find the similarity of these ratios for different colliding nuclei.

STUDY OF CUMULATIVE PROCESSES IN CORRELATION WITH STRANGENESS AND CHARM PRODUCTION IN HADRONIC COLLISIONS AT SPS AND NICA ENERGIES

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New mechanism [1,2] of strangeness and charm production was proposed in high energy hadronic collisions in association with the cumulative particle formation on the flucton. The concept of flucton [3], a “droplet” of dense cold nuclear matter, that might be formed in the target nucleus, was motivated by several observations [4-6] of particle production in a so-called kinematically forbidden, in reaction with free nucleons, region. The novel approach [1,2] is based on the joint consideration of the flucton and the relevant formation of strongly overlapping quark-gluon strings. In the last case, the fusion of quark-gluon strings might be responsible for the increased yields of particles containing strange or charm quarks. The first results of studies of possibilities for experimental observations of cumulative particles production that could correlate with strangeness and charm yields, were presented earlier in [7].

In our report we discuss the concept of new, compact detector we propose for registration of cumulative particles as a trigger for studies of correlation with strangeness and charm in the fixed-target experiments at SPS and NICA. We discuss, with the account of cumulative particle yield analysis [8], the estimations of strange and cumulative particle yields, selection of the kinematical regions and some preliminary conclusions about the structure of this compact detector using the Geant4 simulations.

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CHARMED PARTICLE PRODUCTION IN GEANT4

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Charmed particles production was observed and measured in fixed target experiments performed in CERN, Fermilab and DESY with hadron beams at energies from 200 GeV up to 900 GeV. The charmed particles production is studied by all RHIC and LHC collaborations. It is expected that the charmed particles will be copiously produced at the Future Circular Collider (FCC). Due to long life time of the particles, it will be needed to account their interactions with surrounded matter and detector materials. In order to meet the requirement, the charmed particles were introduced in the Geant4 toolkit. First of all, a list of the charmed particles according to PDG has been implemented. Their decay channels are not setting up until now, though there is a possibility for user to determine the channels in the Geant4. The next step was simulation of the charmed particle production in soft hadronic interactions. We followed to the Kaidalov – Piskunova approach [1,2]. The approach gives fragmentation functions of quarks into the charmed particles. It is assumed that there are no constituent charmed quarks in initial hadrons. All of these has been implemented in FTFP and QGSP hadronic generators of the Geant4 toolkit, and allow to reach a good description of known experimental data on the soft charmed particle production.

We have applied a simple scaling in calculation of cross sections of the charmed particles with nucleons [3]. We are going to generalize it for nuclear targets. We will consider some details of the implementation in our talk.

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MAGNITUDE AND SKEWNESS OF ELLIPTIC FLOW FLUCTUATIONS AT NICA ENERGIES

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In this work, we exploit the cumulant ratios: $v_2\{4\}/v_2\{2\}$ and $v_2\{6\}/v_2\{4\}$ to study the magnitude and skewness of elliptic flow fluctuations in Au+Au collisions at NICA energies in the framework of several state-of-the-art models of relativistic heavy-ion collisions. The agreement of $v_2\{4\}/v_2\{2\}$ ratio for different models with different initial conditions supports the assumption that dominant contribution to the final elliptic flow fluctuations is the participant fluctuations in the initial geometry.

MPD PROSPECTS FOR THE STUDY OF HADRON AND (HYPER)NUCLEI PRODUCTION AT NICA ENERGIES

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The MultiPurpose Detector (MPD) [1] is constructed to study strongly interacting matter at the NICA accelerator complex [2]. In this report, we present the main NICA physics goals and the concept of the MPD detector with an emphasis to the detector performance for the measurements of hadron observables (yields and ratios) as well as reconstruction of (hyper)nuclei.

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SEARCH FOR NUCLEON-NUCLEON CORRELATIONS IN NUCLEUS-NUCLEUS COLLISION AT THE MPD/NICA

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A proposal for an experiment to measure the cross section of pion, kaon, proton and antiproton production in a nucleus-nucleus collision in a kinematically forbidden region for nucleon-nucleon interaction on the MPD/NICA is considered. It is shown that this process can be separated from the kinematically allowed production process using the existing detectors of the MPD facility at an energy of 9.2 GeV. The data could be used to search for scaling dependence, which was observed earlier at lower energies [1]. Obtaining new results is of great importance for estimating the magnitude of the probability of the subthreshold heavy particles production process [2].

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TOTAL AND PARTIAL SHEAR VISCOSITY OF HADRONS IN AU+AU COLLISIONS AT INTERMEDIATE ENERGIES ACCESSIBLE TO NICA

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We calculate the total and partial shear viscosity of hadrons produced in central gold-gold collisions at intermediate energies [1,2]. For calculations of the collisions the transport model UrQMD is employed. The shear viscosity is obtained within the framework of Green-Kubo formalism. The hadron resonance gas (HRG) model is used to determine temperature and chemical potentials of baryon charge and strangeness out of the microscopic model calculations. Then, we determine the partial viscosity of main hadron species [3], such as nucleons, pions, kaons and Λ hyperons, by studying the relaxation of hot and dense nuclear matter in the box with periodic boundary conditions.

It is found that the decrease of the beam energy from E_{lab} = 40AGeV to 10AGeV leads to rise of baryon shear viscosity accompanied by drop of shear viscosity of mesons. In contrast to that of non-strange hadron species, the shear viscosity of kaons and Λ remains independent on energy within the studied energy range. Its ratio over the entropy density increases with the drop of temperature and rise of baryon chemical potential.

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METHODS FOR CENTRALITY DETERMINATION IN HEAVY-ION COLLISIONS WITH THE MPD EXPERIMENT

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Centrality is an important concept in the study of strongly interacting matter created in a heavy-ion collision whose evolution depends on its initial geometry. Experimentally collisions can be characterized by the measured multiplicities or energy of produced particles or spectator fragments. Relation between collision geometry and experimentally measured multiplicities is commonly evaluated within the Monte-Carlo Glauber approach.

We will present methods for centrality determination in heavy-ion collisions with the Multi Purpose Detector (MPD) experiment at the future Nuclotron-based Ion Collider fAcility (NICA). The multiplicity of charged hadrons is provided by the MPD Time Projection Chamber (TPC) and connected to collision geometry parameters using the Monte-Carlo Glauber model. The energy of spectator fragments is estimated with the MPD Forward Hadron Calorimeter (FHCal). We will also touch possibilities to determine centrality using the FHCal and Monte-Carlo Glauber model.

PERFORMANCE FOR SPECTATOR SYMMETRY PLANE ESTIMATION WITH THE BM@N EXPERIMENT

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The Baryonic Matter at Nuclotron experiment (BM@N) aims to study the area of QCD phase diagram at high net baryon densities and moderate temperatures with collisions of heavy ions at $\sqrt{s_{NN}}$ = 2.3–3.5 GeV. Anisotropic transverse flow is one of the most important observable phenomena in a study of the properties of matter created in such collisions. Flow measurements require the knowledge of collision symmetry plane, which can be determined from deflection of collision spectators in the plane transverse to the direction of the moving ions. BM@N performance for projectile spectator symmetry plane estimation is studied with Monte Carlo simulations using Xe+Cs collisions with beam energies of 4A GeV generated with the DCM-QGSM-SMM model. Investigated different data-driven methods to extract correction factor in flow analysis for the resolution of spectator symmetry plane estimated with the BM@N Forward Hadron Calorimeter.

STUDY OF SPECTATORS WITH FHCAL IN THE MPD/NICA EXPERIMENT

V. Volkov

The forward hadron calorimeters (FHCal) in the ongoing MPD/NICA (JINR, Dubna, Russia) experiment will be used to measure the centrality, orientation of the event plane, and to study the properties of spectators. The possibility of studying spectators in heavy-ions collisions with FHCal is provided by the fine segmentation of the calorimeter, which consists of 44 lead/scintillator modules. The properties of spectator matter as a dependence on centrality in Monte-Carlo simulations have been studied in this work. Several observables that describe the spatial-energy distribution of spectators in FHCal modules are presented. The observables were obtained by a two-dimensional fit of energy deposition in the modules of the calorimeter. The report shows how the distributions of the observables depend on the collisions impact parameters.

THE EFFECT OF CHARGED PARTICLE MULTIPLICITY FLUCTUATIONS ON CENTRALITY DETERMINATION AT NICA ENERGY RANGE

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Centrality determination provides a tool for comparing the anticipated measurements with the Multi-Purpose Detector (MPD) at NICA with results of other experiments and with theoretical model calculations.

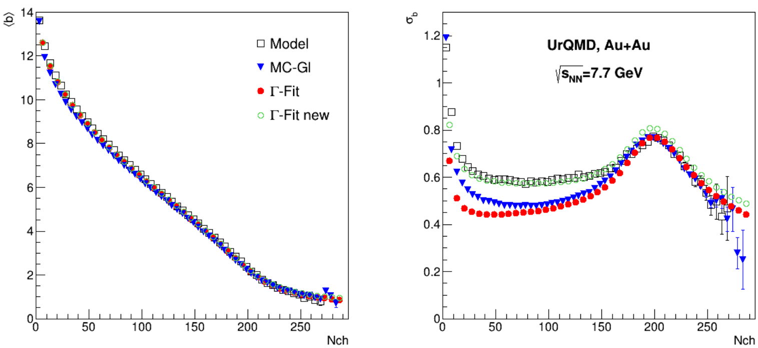

Fig. 1. Dependence of the mean value and RMS of the impact parameter on multiplicity for the UrQMD model.

In this work, a method based on inverse Bayes' theorem is considered for impact parameter reconstruction [1,2].

A new treatment of the fluctuations of charged particle multiplicity and the transverse energy is proposed to improve the procedure of the impact parameter reconstruction.

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MEASUREMENT OF THE TIMING RESOLUTION OF SCINTILLATION DETECTORS SAMPLES OF A FUTURE TIME-OF-FLIGHT NEUTRON DETECTOR FOR THE BM@N EXPERIMENT

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A new compact time-of-flight neutron detector is planned to be developed and produced. This detector will identify and measure the energies of neutrons produced in nucleus-nucleus collisions at energies up to 4 AGeV in the BM@N experiment at the Nuclotron (JINR, Dubna). The detector will be used to measure neutron yields and azimuthal neutron flows, which should be sensitive to the equation of state of dense nuclear matter and to the energy of symmetry, as it is shown in various theoretical models.

The novelty of the proposed neutron detector is the usage of small scintillators with an area of about 10-20 cm2 and a thickness of 25 mm as sensitive elements for the active layers of the detector. One silicon multipixel photon counter with a sensitive area of 6 x 6 mm2 is proposed to perform light readout from one of the sides of each of these scintillators. To achieve the required neutron energy resolution, the detector timing resolution of 100–150 ps is required.

The concept of the proposed time-of-flight neutron detector, the possibilities of its layout on the BM@N, as well as the results of the timing resolution measurements of the samples of scintillation detectors on cosmic muons for different types of scintillators, sizes, reflectors and photon counters are discussed.

ANISOTROPIC FLOW MEASUREMENTS FROM THE NA61/SHINE AND NA49 BEAM MOMENTUM SCAN PROGRAMS AT THE CERN SPS

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The NA61/SHINE experiment at the CERN SPS has recently extended its program for the energy scan with Pb ions. In the past, the NA49 experiment, which preceded NA61/SHINE, also recorded data for Pb-Pb collisions at different energies. Together, the two experiments cover a wide range of beam energies provided by the CERN SPS in the range 13–150A GeV/*c*. Analysis of the new NA61/SHINE data and reanalysis of the existing NA49 data using newly developed procedures allow for a new comprehensive systematic study of collective flow relative to the spectator plane.

We will present new NA61/SHINE results on directed and elliptic flow measurement in Pb-Pb collisions at 13 and 30A GeV/c relative to the spectator plane determined with the Projectile Spectator Detector. Also a new analysis of 40A GeV data collected by the NA49 experiment using forward spectator calorimeters (VETO and RCAL) will be shown. The flow coefficients are reported as a function of rapidity and transverse momentum in different classes of collision centrality. The new results are compared with existing results from the previous NA49 analysis and the STAR experiment at RHIC.

STUDY OF THE mPSD RESPONSE IN O+Ni COLLISIONS AT 2 AGEV AT THE MCBM

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The PSD forward hadron calorimeter will be used to determine the collision geometry at the CBM experiment, which is under construction at FAIR. To test the CBM subsystems, the mCBM experiment was started at the SIS18 beamline of GSI as a part of the FAIR Phase-0 program. One of the PSD modules (mPSD) equipped with the free-streaming readout electronics has been installed and tested at the mCBM in nucleus-nucleus collisions at interaction rates up to 5 MHz. In this report, the first experimental results of the mPSD response in the O+Ni collisions at a kinetic energy of 2A GeV are discussed and compared to simulated data of DCM-QGSM-SMM model.

READOUT ELECTRONICS FOR THE WIDE APERTURE SILICON TRACKING SYSTEM OF THE BM@N EXPERIMENT AT NICA

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BM@N experiment at NICA in Dubna is currently being upgraded for the study of dense nuclear matter in heavy-ion collisions. One of the major upgrades is a new hybrid tracking system consisting of the large-area Silicon Tracking System (STS) and seven GEM planes [1]. STS is based on the modules with double-sided microstrip silicon sensors of CBM-type. The data driven acquisition system of STS is relying on self-triggering readout channels and data processing chain is adopted for the operation with BM@N trigger [2].

The core components of the readout chain are Front-end Boards (FEB), GBTxEmulator board and GBTxEmulator Readout Interface (GERI) board. The front-end board is an integrated part of the STS module. The main components of FEB are eight STS-XYTER ASICs which are needed for the readout of one side of the silicon sensor. The GBTxEmulator board based on FPGA which emulates functionality of the CERN GBTx ASIC [3] and provides a bidirectional optical link between front-end electronics and data processing boards in the server nodes. The GERI board concentrates and pre-processes the data stream, filters the data according to the BM@N trigger signals and provides an interface to configuration and control of the readout electronics.

For the needs of integration into the global BM@N DAQ a trigger-based data filtering was developed and implemented. Methods of integration and synchronization of the STS readout chain with the common data acquisition system BM@N experiment are described.

Front-end electronics, electrical connections, data concentrator and architecture of data processing board are described in the report. The results of testing of a pilot version of the readout chain are presented.

Work is supported by RFBR 18-02-40047 grant.

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ONLINE DATA PROCESSING AND MONITORING OF THE BM@N EXPERIMENT

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The BM@N (Baryonic Matter at Nuclotron) experiment is the fixed target experiment and the first stage of the NICA (Nuclotron-based Ion Collider fAcility) accelerator complex located in the Joint Institute for Nuclear Research in Dubna. The experimental facility is designed to explore properties of dense strongly interacting matter in heavy ion collisions.

The data decoding and event reconstruction algorithms are being developed as part of the BmnRoot on top of the FairRoot framework – a ROOT program package developed primarily for the FAIR experiment. The monitoring system's frontend is based on the CERN jsROOT library. The online data processing pipeline is organized as several processes exchanging data via the ZeroMQ sockets. This approach makes the system flexible and easier to add new elements to the system as well as distribute calculation on several nodes. Also it is more convenient to monitor experiment by a distributed team. The QA system allows users to select reference run from past runs and impose it on the current run in order to detect possible deviations in the histograms.

One of the crucial parts of data processing is the signal filtering in the strip detector subsystems such as Gas Electron Multipliers (GEM), silicon strip detectors and Cathode Strip Chambers (CSC). They constitute inner tracker – the key part for track reconstruction. The decoding workflow includes iterative filtration, executing noise reduction.

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EFFECTS OF LOCAL PARITY NONCONSERVATION IN STRONG INTERACTIONS IN Pb-Pb COLLISIONS AT LHC ENERGY

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It is known that the global conservation of spatial parity is a well-established symmetry of strong interactions. So far, no pieces of evidence have been found for P- and CP-symmetry breaking in strong interactions.

However, QCD does not forbid local breaking of parity symmetry due to large topological fluctuations at high temperature with dynamical generation of configurations of nontrivial topological charge. The necessary condition for the observation of these effects is a sufficiently long lifetime of hot bubble which is accessible in central nucleus-nucleus collisions at LHC.

It was shown that the effect of local non-conservation of parity in strong interactions can be checked experimentally by the angular analysis of low-mass dilepton production in heavy-ion collisions [1-3] and by search of light hadron decays in specific channels which are forbidden by global parity conservation [4,5]. Pariaturly, the decays of scalar charged a0 meson into a photon and charged pion and into three charged pions can be referred to such processes.

In this work, the effects of local parity non-conservation have been implemented in the Monte Carlo realisation of the thermal model. The predictions of the invariant mass distributions of di-mesons and di-electrons are obtained in Pb-Pb collisions at LHC energy, taking into account the experimental resolution of the detectors. It is shown that the upgrade of the ALICE detector during the Long Shutdown 2 significantly improves the feasibility of these experimental studies at the LHC Run 3 [6].

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SMOKING GUN OF NUCLEAR CLUSTERIZATION IN COLLISIONS OF LIGHT RELATIVISTIC NUCLEI

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Interactions of ^{12}C nuclei with various targets were studied in BM@N experiment at NICA [1]. Studies of ^{16}O–^{16}O collisions are foreseen in future experiments after the LHC upgrade [2] as a part of a program to scan the size of colliding systems. As follows from calculations [3,4], the admixture of the alpha-clustered states in ^{12}C and ^{16}O leads to a triangular modulation of elliptic flow from the overlap region of colliding nuclei. It is also known [5] that forward alpha-particles are produced in fragmentation of relativistic ^{16}O in nuclear photo-emulsion. This suggests the impact of alpha-clusterization in ^{16}O also on spectator matter. First calculations [6] of yields of secondary nuclei (He, Li, Be, B, C, N) from fragmentation of ^{16}O with our Abrasion-Ablation Monte Carlo for

Colliders model taking into account pre-equilibrium clusterization of spectator matter (AAMCC-MST) [7] demonstrated general agreement with data [5]. However, the production of pairs and triplets of alphas was essentially underestimated together with the production of carbon [6] with respect to measurements [5].

In order to remove this discrepancy, in the present work AAMCC-MST was extended by accounting for clustered states in nucleon configurations of initial ^{16}O in addition to MST-clustering after the abrasion stage. Three nuclear density profiles in ^{16}O based on [4,8] were implemented in AAMCC-MST to sample the positions of neutrons and protons in ^{16}O, including one with accounting for clustered states. Results of calculations with all three profiles and with different sizes of intranuclear alpha-clusters were compared with the data on fragmentation of ^{16}O [5]. While the production of alpha-particles is underestimated for all the parameterizations of nuclear densities in ^{16}O, the results with the clustered nuclear density appear to be closer to the data. Further development of AAMCC-MST on the basis of the hierarchical clustering is planed.

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ROLE OF STRING FUSION MECHANISM IN FLUCTUATION STUDIES

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In the search for the critical point of strongly interacting matter, one of the key tools is to look at event-by-event fluctuations of different event observables expecting their non-monotonic behavior. It is crucial for the experiments to eliminate a possible influence of so-called trivial volume fluctuations on the physics observables of interest. This may be done e.g. by the accurate centrality selection used and/or by means of special measures using different estimators of initial conditions. It is also possible to apply some theoretical approaches in estimation of all the possible sources of unwanted fluctuations.

In this report we compare results obtained in two phenomenological models of particle production. The first one is the Monte-Carlo model of interacting quark-gluon strings of finite length in rapidity space [1]. It takes into account, event-by-event, the string fusion phenomenon caused by string overlap in the transverse plane. It is this process of fusion that modifies string fragmentation characteristics and changes the mean values of multiplicities and transverse momenta of produced particles. The second one is the modified multi-pomeron exchange model [2,3] that takes into account, in the effective way, the process of string fusion emerging with the increase of collision energy. Using these models and Monte-Carlo event generators, the calculations were done for the strongly intensive quantities [4] Δ[PT,N] and Σ[PT,N] and the combinants [5] of multiplicity distribution. Results are discussed.

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ON OPPORTUNITY OF STUDY OF LOW LYING EXOTIC STATES WITH HEAVY ION COLLISIONS

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Multi-Purpose Detector (MPD) detector that is currently under construction at the NICA facility nowadays. It has been proposed to design and build an additional detector that will compliment the current MPD set and increase its measurement capabilities. The main goal is to provide information from cosmic muons that pass the MPD detector in both in-beam and off-beam experiments. Hence, the detector is called the MPD COsmic Ray Detector (MCORD) [1]. MCORD will be able to collect and to analyze signals induced by particles coming from the center of MPD (muons and other particles escaping the MPD body). The threshold for muons that may escape the MPD amounts to about 600 MeV. This detector will be helpful for identification of high energy muons coming from pions and kaons decay, and pair of muons coming from some very rare meson decay processes. The study of decays of charmonium-like exotic states into J/Ψ and J/Ψ′ and their subsequent decays into muon pairs with kinetic energy of relative motion ≥ 600 MeV may also be foreseen. These results can shed light on the nature of low lying exotics that are one of the most mysterious states in modern physics [2, 3]. This research is of great importance in hadron physics and astrophysics.

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COMPARISON OF SOME KINEMATICAL CHARACTERISTICS OF PROTONS IN COLLISIONS $n^{12}C$ AND $p^{12}C$ AT 4.2 GeV/s

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It is known, the interaction of high-energy protons with nucleons and nuclei has been well studied experimentally in a wide range of primary energies, and due to the difficulties in obtaining monochromatic beams of neutral particles, experimental information on collisions of neutrons with nuclei (nA) obtained under the conditions of 4π-geometry very rare [1-3] and based on few statistics. Therefore, obtaining experimental data on nA collisions and comparing them with data on pA interactions at the same energy and for the same target nucleus is of considerable interest. The work is devoted to a comparative analysis of various kinematic characteristics of protons in $n^{12}C$ and $p^{12}C$ collisions at a momentum of 4.2 GeV/s.

Experimental material was obtained using a two-meter propane bubble chamber of the High Energy Laboratory of the Joint Institute for Nuclear Research (Dubna, Russia), irradiated with beams of protons, deuteron nuclei (d = ^{2}H) and helium-4 at a momentum of 4.2 GeV/s per nucleon at the synchrophasotron in Dubna [2]. The average values of the total and transverse momenta of protons with their average escape angles and speed in $n^{12}C$ and $p^{12}C$ collisions are obtained separately for events with and without negative pions in the final state of the reaction. The average value of the total momentum of protons produced in $n^{12}C$ collisions with n (π−) = 0 is much smaller than in $p^{12}C$ collisions , since most of the protons in this case come from the target. In the case when one or several negative pions are formed in an event, the average value of the total momentum of protons in $n^{12}C$ collisions is greater than in $p^{12}C$ interactions .

A comparative analysis of the mean values of various kinematic characteristics of protons produced in $n^{12}C$ and $p^{12}C$ collisions at 4.2 GeV/s has been carried out. The difference in the average momenta of protons in $n^{12}C$ and p^{1} C is related to the difference in the probabilities of proton conservation in the first case and recharging of the primary neutron by a proton in the second.

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QUARK-GLUON STRING MODEL (QGSM) AND ITS APPLICATION FOR INELASTIC DC INTERACTIONS AT A MOMENTUM OF 4.2 A GEV/S

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The construction of high-energy accelerators for hadrons and the creation of detectors that record reaction products are very costly. At the same time, there is a need to compare the experimental conditions and large-scale experimental data with the results of theoretical calculations. As a result, a large number of software generators for the collisions of hadrons and nuclei of different energies have emerged. These programs are based on a standard model (various phenomenological models) of strong and non-electric interactions. Of these, ISAJET and Lund University programs, including PYTHIA and FRITIOF, are popular. These programs open up almost all areas of transmitted momentum (P^2, quarks and from strong scattering of gluons to the formation and decay of hadrons). In this work, the main provisions of the Quark-gluon string model for describing inelastic interactions of light nuclei at high energies are presented. The main ideas of the CGSM model are given, such as the process of formation of quark-gluon strings and the choice of their limited number, modeling of string breaking with the formation of hadrons [1]. The data of theoretical calculations by CGSM are compared with the experimental results obtained for dC-inelastic interactions. The technique for obtaining experimental data is briefly described. Analysis and comparison of model and experimental information shows that the CGSM model reproduces well the interactions of light colliding nuclei at energies of 4.2 GeV/s, and it is applicable up to the energy of nuclear interactions of 10 GeV/nucleon [2-3]. Low experimental data on 4π geometry were obtained. Therefore, it is important to study the formation of cumulative particles in large experimental statistics.

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CONFINEMENT POTENTIAL FROM HOLOGRAPHIC APPROACH TO STRONG INTERACTIONS

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We derive and analyze the confinement potential of the Cornell type between two static color sources within the framework of a generalized Soft Wall holographic approach to strong interactions. This approach was originally developed for describing the linear Regge spectrum of light mesons. The "linear plus Coulomb" confinement potential is obtained both in the vector and in scalar channels. It is shown that the quantitative agreement with the phenomenology and lattice simulations is better in the scalar channel.

THE REGGE MESON SPECTRUM FROM HOLOGRAPHIC WILSON CONFINEMENT CRITERION

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Using the Wilson confinement criterion, a holographic model for finding a string-like spectrum of meson excitations is proposed. The model is applied to the vector and scalar mesons and a good agreement is obtained both with the existing experimental data and with some other known phenomenological approaches. The constructed model provides a novel realization of spontaneous chiral symmetry breaking between parity partners.

ULTRA LIGHTWEIGHT SUPPORT STRUCTURES AND GASEOUS COOLING SYSTEM FOR THE NOVEL SILICON PIXEL DETECTORS

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New research tasks in high-energy physics experiments require using the advanced materials and methods for the precise tracking and decay vertices registration of short-lived charged particles.

Therefore, very thin large area, coordinate-sensitive Si detectors with high granularity and the highest radiation transparency will be used for the innermost tracking layers on the next stage of the ALICE experiment at the LHC. Such vertex detectors can provide minimal distortions of the registered tracks because of the multiple scattering effects and their application is also being planned for NICA experiments at JINR. In present work, the conceptual ideas and results of developments of ultra lightweight support structures and cold nitrogen cooling system proposed for next-generation of radiation transparent vertex detectors are discussed [1].

Therefore, the lightweight and radiation transparent materials should be used to develop support structures and cooling system for new silicon pixel detectors. On the one hand, an ultra lightweight system has to be strong enough to support the detectors, on the other hand this system should be radiation transparent with the minimum material budget of its components. This means that all parts of the detector system, sensors, micro cables, support structures and cooling system should have a minimum amount of low-Z materials. The gaseous cooling of detectors is being considered as an appropriate option [2]. In this case, we need to avoid vibrations, that could happen for very thin (~ 20 micron), large area Si detectors in case of the non-negligible speed required for the gas flow. In order to reduce these micro-vibrations the low-speed flow of the cold gas was proposed.

In present work, our developments of ultra lightweight, support structures with cold nitrogen cooling system for new generation of thin, large area, coordinate-sensitive Si detectors are presented.

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TRANSVERSE MOMENTUM FLUCTUATIONS IN NICA AND SPS ENERGY RANGE

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Correlations between multiplicity of charge particles and mean transverse momentum were observed experimentally in p+p collisions from top SPS energy to LHC energy. The change in the correlation function's shape with collision energy was successfully described by the multi-pomeron exchange model as an interplay of string fusion and energy-momentum conservation [1]. Previously, it was shown that phenomenological resonance-to-strings transition leads to rapid changes in the magnitude of pt-n correlations at the NICA energy range [2]. The mean transverse momentum is sensitive to the initial energy density [3] and, therefore, its event-by-event fluctuations are strongly affected by the event (centrality) selection. In this contribution results of the pt-n correlations analysis [2] would be extended by Monte-Carlo simulations studies for the pt-n strongly intensive observables [4], pt cumulants [5] and two-particle pt correlation measures [6]. That would allow testing the influence of the resonance-to-string transition and the role of conservation laws of the given observables.

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Section 4. Neutrino physics and nuclear astrophysics

TESTING OF THE HIGH-ENERGY π AND K MESON PRODUCTION BY THE PRIMARY COSMIC PROTONS AND HELIUM NUCLEI

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The primary cosmic particles with very high energies are initiating huge cascades of various secondary particles in the atmosphere. The atmospheric muon spectrum at energies from 100 up to 10^5 GeV is formed in decays of the most energetic π and K mesons produced by the primary protons and more heavy nuclei with energies above the threshold and up to 10^7 GeV. The primary nuclei may be regarded as a flux of nucleons. A sophisticated scheme of simulations of the atmospheric vertical muon flux has been elaborated. The partial differential energy spectra of the atmospheric vertical muons in the air shower cascades initiated by primary cosmic nucleons with different fixed energies had been simulated with the help of the program package CORSIKA with statistics of 10^6. The suggested scheme of simulations provides a reasonable accuracy at high energies. The eight most popular hadronic interactions models QGSJET01, QGSJET II-03, QGSJET II-04, DPMJET 2.55, VENUS 4.12, EPOS LHC, SIBYLL 2.1 and SIBYLL 2.3 had been used to estimate these partial spectra. These partial spectra of muons have been convolved with the energy spectrum of the primary nucleons to estimate the atmospheric vertical muon flux. The known calculations of the primary cosmic proton and helium nuclei spectra produced in the supernova remnants had been normalized on the AMS-02 data and tested by PAMELA, ATIC-2, CREAM, ARGO-YBJ, ARGO-YBJ &FWCTA, KASCADE, KASCADE-Grande, Tunka, Ice Cube and Telescope Array TALE data. The energy spectrum of the primary nucleons had been estimated with the help of these spectra. At last, the simulated spectrum of the atmospheric vertical muons had been compared with the rather accurate measurements of the atmospheric vertical muon spectra at energies above 100 GeV (e.g., L3+Cosmic, MACRO, LVD, Ice Cube data). This comparison had demonstrated that all tested models failed to reproduce the atmospheric vertical muon flux correctly. The calculated muon fluxes happened to be below data by factors of 1.5÷2. Therefore, all tested models underestimate the production of the most energetic charged π and K mesons by the primary cosmic nucleons by the same factors at energies from 10^2 up to 10^7 GeV.

BARYON-ANTIBARYON ASYMMETRY IN *p–p*, *p–A* COLLISIONS AND STRING JUNCTION TORUS AS BARYONIUM

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The asymmetry of baryon/antibaryon production has been measured in many proton-proton, pion-proton and electron-proton experiments. In the framework of Quark-Gluon String Model (QGSM) the energy dependence of asymmetry tells us about the value of $\alpha_{SJ}(0)$, the intercept of String Junction Regge trajectory. In previous QGSM study, the value of intercept has been estimated as $0.5 < \alpha_{SJ}(0) < 0.9$. Here, SJ behaviors are accumulated in the model based on topological expansion in order to build a neutral object with zero baryon charge. By the way, QCD mass falling under the event horizon of Black Hole (BH) should be symmetric, or in other words, have no charge information. The baryon junctions are easily combinable with antibaryon ones in hexagons. Topologically, hexagon net can coherently cover only the torus surface. The net on the torus has discrete number of baryon/antibaryon junctions. This is only parameter that marks the mass/energy level of this object. It looks like DM particle, is not it? In high energy collisions at LHC, such pomeron loops are to be produced approximately in 1.2 percent of inelastic events. Furthermore, the torus configurations of matter have been revealed in many bright events in space. As an example, Chandra experiment has detected such dense "doughnut" near the event horizon of Super Massive Black Hole (SMBH), whose X-ray radiation is screened by 40%. This topological symmetry model of DM seems rather realistic and can help us to deal with an "arm wrestling" between the stiffness of toroid structure of QCD matter and the pressure of gravitational singularity at extremely heavy masses. On the other hand, the instabilities in structure of matter in SMBHs can cause the bursts of giant relativistic hadron jets with the masses of order the own BH mass.

ON THE POSSIBILITY OF USING THE QUANTUM-FIELD APPROACH TO MODELING THE INTERACTION OF MATTER WITH NEUTRINOS TO STUDY THEIR ROLE IN ASTROPHYSICAL PROCESSES

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Many effects in a material medium cannot be explained within classical physics and represent macro manifestation of the quantum nature of fundamental interactions. This is evidenced even by experimentally observed stability of material objects, as it is impossible within classical electrodynamics. It would be interesting to understand on what scales quantum physics no longer plays a significant role and, in particular, whether anything characteristic of it could arise in astrophysical processes. Whether, in particular, quantum objects such as neutrinos have a significant influence on them, is intensively studied recently in many scientific centres.

This talk presents the results of developing approaches to modeling the interaction of quantum spinor fields with extended material objects. They are based on the method proposed by K. Simanzik to build quantum spin field models in inhomogeneous space-time [1]. Its basic idea is to modify the action functional of the original model in a homogeneous and isotropic space-time by adding to it the "action defect" describing the interaction of a quantum field with spatial and temporal inhomogeneities. This imposes the requirement that the most important principles of the basis model (such as renormalizability, locality, and gauge invariance) must not be violated. In joint studies of the author and his colleagues this approach was applied to the modeling of the interaction of quantum electrodynamics fields with two-dimensional materials. The results have been published in reputable journals.

This experience was used to build a model of interaction of three neutrino fields with a highly inhomogeneous material medium [2]. The talk will present results of the study of its simplest version describing the interaction of neutrinos with a plane. It is shown that this model produces effects similar to the Mikheev–Smirnov–Wolfenstein resonance [3,4], but with a number of features. Under certain conditions, the plane can be transparent to low-energy neutrinos and almost completely reflects high-energy ones. Such a filtering process of neutrinos as their number in the core of a superheavy star increases during its gravitational contraction, may be one of the important mechanisms for supernova explosions. The filtration also has a significant effect on neutrino oscillations. Accounting for the specificity of neutrino interactions with two-dimensional materials can be useful for building experimental setups for research in neutrino physics.

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A MODIFIED QUASIPARTICLE MODEL IN THE EXPANSION OF EARLY UNIVERSE OF QUARK GLUON PLASMA

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A modified quasiparticle model approach is used in the expansion of early universe of quark gluon plasma. We also used Friedmann equation [1,2] to determine the precise time evolution of the thermodynamic parameters in the early universe of quark gluon plasma (QGP) [3]. The output for time variation of the energy density and the time evolution of temperature using finite value of thermal dependent quark mass [4,5] have plotted. The results show the time evolution of the early universe which also helps in the calculations of other thermodynamic variables like energy density, pressure, entropy etc. This provides deep understanding for the evolution of early universe of quark gluon plasma.

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DETERMINATION OF PARAMETERS OF THE MODEL WITH THREE STERILE NEUTRINOS ON THE BASE OF EXPERIMENT BEST RESULTS

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It is carried out evaluations of parameters values for the model with three active and three sterile neutrinos [1], namely, mixing parameters between active and sterile neutrinos and sterile neutrinos masses. When doing that, results of the BEST experiment (Baksan Experiment on Sterile Transitions) are used [2]. The BEST experiment intends to verification of the gallium anomaly at short distances, that is the deficit of electron neutrinos from radioactive sources. Besides it is taken into account experimental results concerning verification of accelerator [3] and reactor [4, 5] neutrino anomalies at short distances, as well some astrophysical data [6, 7].

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SYNTHESIS OF "LIGHT" HEAVY ELEMENTS UNDER EXPLOSION OF LOW-MASS NEUTRON STAR

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Observation of lantanides in the spectrum of kilonova after gamma-burst and gravitational waves registration [1] confirmed theoretical *r*-process scenario [2], connected with the neutron star merger (NSM) at the end of close binary system evolution.

After numerous investigations of the neutron star merger process and following registration of NSM it became definitely clear, that such a scenario is the main one for formation of majority heavy nuclei in the *r*-process. But Neutron stars evolution in close binaries depends strongly on their masses. Merger process is investigated rather well, but when masses of stars in close binary differ strongly the merger scenario develops in a different way [3] and nucleosynthesis of heavy elements as well [4].

In present report we considered the nucleosynthesis during the explosion of low-mass component in close binary, which lost its mass due to transfer of matter to the heaviest component and blowing up when hydrodynamically unstable configuration was reached [3].

The matter of the exploded remnant is expanding and explosive nucleosynthesis of new elements takes place before density decrease strongly. Nucleosynthesis mainly occurs in the mantle layers with initial electron-to-baryon ratio $Y_e \sim 0.3$–0.4. Nucleosynthesis in the considered scenario was calculated along evolutionary trajectories of passive particles, connected with different mantle zones. Based on performed numerical calculations it was shown that synthesis of heavy elements formed in the *r*-process is possible, at least the light part of them.

The work was done under financial support of Russian Science Foundation (project №. 21-12-00061).

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NEUTRON STAR PROPERTIES WITH DENSITY DEPENDENT BARYONIC INTERACTIONS

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Neutron stars (NS) are hydrostatically equilibrium stars, the matter of which consists mainly of neutrons and has a density of the order of the nuclear one. In NS a wide range of extreme states of matter is realized, therefore study of NS is important not only for astrophysics, but also for nuclear physics. Renewed interest in NS physics has been inspired by first registration of gravitational signal from the merger of two NS [1]. In recent years radii and masses of a number of NS were measured and NS with large masses were discovered.

Although in the simplest version the matter of NS consists of neutrons, protons, electrons, and muons, it is well known that at densities several times higher than the saturation density of nuclear matter, hyperons can arise. When the density increases, Λ-hyperons are supposed to be the first to appear, and we study NS consisting of nucleons, leptons, and Λ-hyperons. In this work we focus on the properties of ΛN-interaction, known from studies of hypernuclei, and their influence on the characteristics of NS.

In order to calculate the equation of state of NS matter we use the self-consistent Skyrme-Hartree-Fock (SHF) model - generally accepted method for describing baryonic systems [2,3]. Within this model there are two alternative ways to describe nonlinear effects: dependence on nucleon density (ρ^{α}) and three-body ΛNN force. These two options are equivalent in symmetric matter if $\alpha = 1$ and work equally good for hypernuclei. However they are nonequivalent in NS matter and this choice can play a crucial role in calculation of NS characteristics [4]. The choice of α in the density dependence case also can affect these characteristics significantly.

In the present work we examine a number of sets of parameters of hyperon-nucleon and hyperon-hyperon potentials. We calculate different characteristics of NS such as mass, radius and tidal deformability and investigate their dependence on the properties of interactions.

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ON THE STABILITY OF SPHERICAL NUCLEI IN THE INNER CRUST OF NEUTRON STARS

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The inner crust of neutron stars contains nuclei with large neutron excess. Furthermore, in the deepest layers they can take a substantially non-spherical shape (this region is typically referred to as mantle) [1]. The stability of spherical nuclei in inner crust with respect to fission was considered in [2]. The authors apply the fission instability criterion for spherical nuclei, derived by Bohr and Wheeler for terrestrial conditions [3]. It was predicted that spherical nuclei should lose stability when the ratio of nucleus volume to Wigner-Seitz cell volume (filling factor) reaches a value of 0.125 [2], as a result authors suggest that this instability can be a mechanism of transition to the mantle. However, according to our calculations within compressible liquid drop model, the spherical nuclei remain energetically favorable for filling factors up to 0.2 [4]. Obviously, this contradiction have two possible solutions: A) complex nuclear structures (e.g., [5]), which stays beyond scope of [4], correspond to the true thermodynamic equilibrium for filling factors 0.125–0.2; B) the fission instability is suppressed in the inner crust, as it was argued qualitatively in [6]. Here we demonstrate that the proposition B) holds true. Similar result was obtained in [7], but, as we argue here, it was based on incorrect conditions at Wigner–Seitz cell boundary.

In inner crust of a neutron star, the nuclei are immersed into degenerate electrons, which provides background charge density of the same order of magnitude as charge density inside the nucleus. This background creates an electrostatic potential, which supports spherical shape of the nuclei. As a result, spherical nuclei becomes stable with respect to quadrupole deformations for all values of the filling factor, if their number density correspond to the optimal value. However, if the number of atomic nuclei per unit volume is much lower than the equilibrium value, instability may arise and leading to nuclear fission and increase of nuclei number density. This phenomenon may be important in the formation of the crust in the early evolutionary stages of neutron stars.

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FINITE NUCLEI SIZE EFFECTS IN ELASTICITY OF NEUTRON STAR INNER CRUST

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When considering elasticity in terrestrial conditions, one can safely neglect the nuclear size and treat nuclei as point charges, which create the electrostatic potential for electrons. However, it is not the case for the deepest layers of neutron star inner crust, where the distance between nuclei becomes of the same order as their sizes (e.g. [1,2]). In these conditions, the electrostatic potential, induced by nearby nuclei and electrons, can affect nuclei shape and indeed, the most energetically favorable shape of nuclei can substantially differ from spherical one (so-called pasta-phases in the mantle region) [1,2]. Here we analyze the elasticity of the matter under these conditions. In comparison with [3], we consider not only the mantle region but also spherical nuclei of the deepest layers of the inner crust. We also take into account neutron skin as well as the fact that nucleon number density can be affected by deformation. The latter effect decreases elastic energy.

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YIELDS OF THE R-PROCESS IN NEUTRON STAR MERGER EJECTA AND ITS SENSITIVITY TO NUCLEAR MASS MODEL CHOICE

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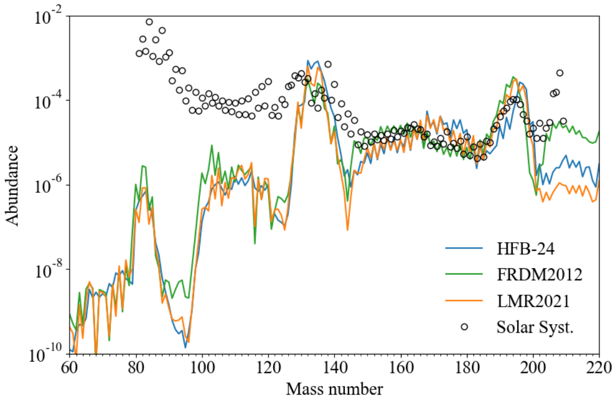
The astrophysical r-process of nucleosynthesis is widely considered to explain the production of major amount of nuclei beyond the iron peak. This nucleosynthesis mechanism poses great interest to both astrophysics and nuclear physics. Taking place at temperatures above 1 GK and very high densities, it is believed to occur in extreme astrophysical scenarios, such as neutron star mergers and supernova blasts. Thus the main approach in r-process study is computer simulation.

Nuclei that take part in r-process reaction chains are exotic due to high neutron excess. To get their characteristics required by nucleosynthesis simulations theoretical nuclear models are used. We study the impact of the nuclear mass model choice on the results of r-process calculation. Using three different theoretical mass tables [1,2,3] we have created three libraries of astrophysical nuclear reactions based on REACLIB [4] database. We used them to simulate r-process in neutron star merger dynamical ejecta with the help of the SkyNet [5] library. Obtained results show how our r-process simulation responds to the mass model variation.



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RESENT RESULTS OF THE KamLAND-Zen EXPERIMENT

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The KamLAND-Zen experiment provided new stringent constraints on the neutrinoless double-beta (0νββ) decay half-life in Xe-136 using a xenon-loaded liquid scintillator. Improved search was based on an upgraded detector with almost double the amount of enriched xenon and an ultra-low radioactivity container, corresponding to an exposure of 970 kg yr of Xe-136. This new data provides valuable insight into backgrounds, especially from cosmic muon spallation of xenon, and has required the use of novel background rejection techniques. We obtained a lower limit for the 0νββ decay half-life of $T_{1/2} > 2.3 \times 10^{26}$ yr at 90% C.L., corresponding to upper limits on the effective Majorana neutrino mass of 36–156 meV using commonly adopted nuclear matrix element calculations.

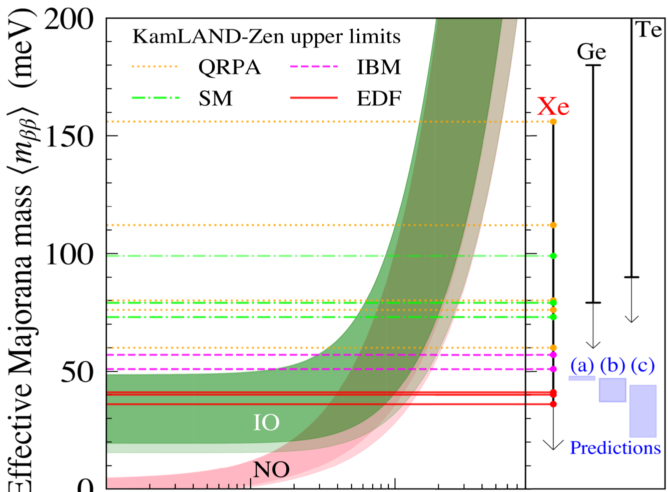

Fig. 1. Effective Majorana neutrino mass as a function of the lightest neutrino mass

INDUSTRIAL iDREAM DETECTOR TODAY

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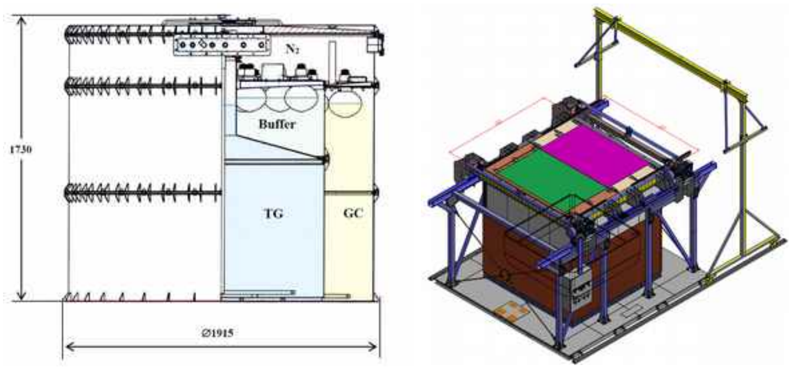
The industrial iDREAM detector was installed at Unit 3 of Kalinin NPP in spring 2021. Data collection had been going on since last spring and after 4-month break since last november, we has continued data collection this spring, evaluated liquid scintillator stability, background conditions, and would like tell about the first plans to upgrade the detector in the future.



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SIMULATION OF THE LSD RESPONSE TO THE NEUTRINO BURST FROM SN 1987A

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Using the Geant4 code, we have performed [1] a thorough simulation of the LSD detector response to the neutrino burst from SN 1987A. The neutrino flux parameters were chosen according to one of the models: the standard collapse model or the rotational supernova explosion model [2]. We showed that, depending on the chosen parameters, one can either obtain the required number of pulses in the detector or reproduce their energy spectrum, but not both together. The interaction of neutrino radiation both with LSD itself and with the material of the surrounding soil was taken into account in our simulation. We also explored the hypothesis [3] that the entire unique LSD signal at 2:52 UT was produced by neutron fluxes from the surrounding granite. However, this hypothesis was not confirmed by our simulation.

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(*α*,*n*) AND (*α*,*nγ*) YIELD CALCULATIONS WITH A NEW VERSION OF NeuCBOT FOR LOW BACKGROUND EXPERIMENTS

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Uranium and thorium are distributed in all natural materials surrounding us and, in particularly, in the construction materials of low background detectors. Therefore, the (*α*,*n*) and (*α*,*nγ*) reactions which occur as a result of *α*-decays of U, Th and their daughters generate intrinsic neutron and gamma backgrounds for the modern ultra-pure neutrino and dark matter detectors. To construct a low background experimental setup, selection of materials should be done on the basis of assays of the radionuclide relative concentrations and calculations of neutrons and gamma yields. The NeuCBOT program (Neutron Calculator Based On TALYS) can be used for the computation part. We present an updated version with new functionality namely use of partial cross sections for excited states of the daughter nucleus and calculation of the (*α*,*nγ*) reactions and the respective yields in addition to evaluation of the neutron yields in the (*α*,*n*) reactions. Also, a selection of different databases (TENDL, JENDL) and a graphical interface were added to the program. We repeated validation comparisons with other (*α*,*n*) data coming from measurements and calculations. A list of results of the neutron and gamma background estimations for many materials commonly used in low background detector was prepared. Among others the list includes plastics doped by gadolinium, structural plastics and construction titanium of various grades.

MEASUREMENT OF RADON DECAYS WITH THE LVD-SETUP FOR NEUTRINO SEARCHING

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The Large Volume Detector (LVD), located at the Gran Sasso Low Background Laboratory in Italy, is built to search for neutrinos from stellar core collapses in our galaxy. [1, 2].

The peculiarity of the search for rare events requires close attention to the background of the experiment, such as the natural radioactivity of the rock and detector materials [3] and particles of the interaction of cosmic ray muons underground [4].

The LVD detector measures gamma quanta from the decay of radon daughter nuclei.

Radon is the main source of the variable background component in the underground hall, whose concentration variations are composed of several components. Long-term, seasonal variations are associated with changes in rock moisture [5]. The daily variations of radon are affected by air mixing due to the opening of the gates in the hall [6]. We convincingly show the connection between the change in the concentration of radon nuclei in the experimental hall and the change in the count rate of background pulses from gamma rays in the detector.

We also point out the existence of another source of radon change, this is seismic activity. An increase in radon emanation a few days before an earthquake poses the problem of the possibility of predicting seismic events. We present some typical LVD time series patterns during major earthquakes in Italy in recent years.

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IMPLEMENTATION OF GLOBAL BETA-DECAY RATES PREDICTIONS TO ASTROPHYSICAL MODELS

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In nucleosynthesis of heavy nuclei, following neutron star merger (NSM) [1], short-lived not experimentally researched nuclei are involved. That is why for their formation modelling the global predictions of different nuclear parameters are needed. The beta-decay rate is one of the main important parameter of such short lived nuclei. Heavy nuclei abundance calculation, taking into account different nuclear parameters predictions, is in fact theoretical integral experiment, in which the opportunities of theoretical models can be compared on the basis of observations and calculations of heavy elements abundances.

Strong dependence of element abundances, produced in NSM scenario on beta-decay rates model [2] have shown strong difference in the abundances with different beta-decay rates predictions used. In present work we considered the role of beta-decay rates predictions in scenario of low neutron mass explosion, emerged at the end of close binary evolution of two neutron stars with different masses [3]. Different beta-decay rates predictions, such as random phase approximation (qRPA) [4], proton-neutron relativistic quasiparticle phase approximation (pn-RQRPA) [5] and finite amplitude method (pnFAM) [5], were applied to the same nucleosynthesis model [6], used earlier for NSM [2].

It was shown that different global beta-decay rates predictions [4–6], applied to nucleosynthesis calculations, leads to formation of realistic structure of the abundance curve of chemical elements during weak *r*-process. And contrary to nucleosynthesis in NSM-scenario, the formation of heavy elements in the region between first and second peaks weakly depend on beta-decay model.

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DISTRIBUTION ON ELECTRON ENERGY IN TWO-NEUTRINO DOUBLE BETA DECAY OF ^{100}Mo

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Nowadays a considerable attention is paid to experiments on two-neutrino double beta decay of stable isotopes. In large-scale projects a great amount of data on 2ν2β-transitions is accumulated, which gives the possibility to build the intensity distribution on total emitted electrons energy.. These information can be used in searching for new physics, for example, aimed at investigation of neutrino statistics [1], Lorentz violation effects [2], two-neutrino double beta-decay with sterile neutrinos [3].

In measurements, produced with the help of NEMO-3 detector, which is capable to reconstruct the full topology of ββ processes, characteristics of more than 600 000 2ν2β-decays of ^{100}Mo have been recorded [4].

In order to provide a way for new physics searches it is necessary to determine the nuclear mechanism of 2ν2β-transition. In the same way as for the ordinary β-decay, it is reasonale to consruct Kurie plot for double beta-process [3]. Kurie plot has different form for two kinds of 2ν2β-amplitude : when contribution of lowest 1^+ energy level of intermediate nucleus dominates – single state dominance, SSD, and for the case of higher-states dominance, HSD. Kurie plots for ^{100}Mo two-neutrino double beta-decay were built for SSD mechanism with a certain addition to amplitude of low-lying excited 1^+ states of intermediate nucleus ^{100}Tc [5], for HSD mechanism, and for double beta-decay with emission of sterile neutrino, corersponding to both SSD and HSD nuclear mechanisms.

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NEW RESULTS FOR DOUBLE BETA DECAY OF ^{106}Cd

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Search for $\beta^+\beta^+$, β^+EC, EC/EC decay of ^{106}Cd was performed at the Modane underground laboratory (LSM, France, 4800 m w.e.) using the low-background multi-detector spectrometer TGV-2 [1] and ^{106}Cd with enrichment of 99.57%. The detector part of the spectrometer is composed of 32 HPGe planar type detectors each with sensitive volume of 20.4 cm^2 × 0.6 cm. 16 foils of ^{106}Cd with a thickness of 70(10) μm, and a total mass of ~23.2 g (~1.3 × 10^{23} atoms of ^{106}Cd) were inserted between the entrance windows of detectors. The distance from foils to detectors is about 1.5 mm. The 16 pairs of detectors with cadmium foils were mounted one over another in a common cryostat tower. The energy resolution of detectors are ranged from 3.0 to 4.0 keV at 1332 keV γ-line of ^{60}Co. The design of the detector part of TGV-2 delivers high detection efficiency for useful events (single and multiple coincidence) and strong suppression of external background. The passive shielding of the TGV-2 consist of copper (≥20 cm),, an airtight box against radon, lead (≥10 cm) and a neutron shielding made of borated polyethylene (16 cm). Additional suppression of background was achieved by using coincidence techniques and filtering electronic and microphone noise in the low energy region (<50 keV) by digitizing the detector response with different shaping times (2 and 8 μs) [1]. Double coincidences between two characteristic KX- rays of Pd detected in neighboring detectors were analyzed to search for 2νEC/EC decay of ^{106}Cd to the ground 0^+ state of ^{106}Pd. From the preliminary calculation of experimental data accumulated with TGV-2 spectrometer and ~23.2 g of ^{106}Cd during 43000 h (phase III of experiment TGV-2), new limit on 2νEC/EC decay of ^{106}Cd to the ground 0^+ state of ^{106}Pd – $T_{1/2} > 1.7 \times 10^{21}$y (90% C.L) was obtained. Limits on 2νECEC decay of ^{106}Cd to excited states of ^{106}Pd and $2\nu\beta^+\beta^+$, $2\nu\beta^+$EC decay of ^{106}Cd to the ground 0^+, and excited states of ^{106}Pd were significantly improved in comparison with previous phase II of the TGV-2 experiment [2]. They are ranged from 5.0 × 10^{20} y to 1.2 × 10^{21} y at 90% C.L.

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SEARCH OF PERIODICAL AND APERIODICAL VARIATIONS OF NUCLEUS DECAY PARAMETERS

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Possible temporal variations of nucleus decay parameters were studied extensively in the last years, their observation can be the signal of unknown physical effects. Several experiments reported the annual and daily decay rate oscillations in alpha and beta-decays of some radioactive nuclides at the level of .05 % [1,2]. Also, correlation of Mn-54 *e*-capture decay rate with electromagnetic solar activity was reported [1]. BSTU–PhIAN–INF collaboration studies decay rate variations in inverse beta-decay (*e*-capture) of Fe-55 isotope. In this process K-shell electron absorbed by nuclei and electron neutrino emitted; it accompanied by X-ray with energy 5,9 or 6,4 KeV which in our set-up detected by cooled Si-Pin detectors. Measurements of decay rate performed in 2016 -2021 , demonstrate that together with observed Fe-55 decay exponent with life-time 1004 days, oscillation period 29.5 +/- 1.5 days corresponding to moon month is found with amplitude (.22 +/- .04)% ; possible model of such decay rate deviations considered in [3,4].

Possible influence of electromagnetic solar activity was studied during 2015–2022 for Fe-55 decay rate, simultaneously with Co-60 beta-decay rate measured by germanium detector in Novosibirsk INF at the distance 2800 km from Moscow [5]. The deviations of similar form and size from exponential decay low at the average level (.55 +/-.004)% were detected in both experiments during October–December 2018. Supposedly, they can be related to solar activity minimum started in the beginning of 2019. In addition, eight decay rate dips of the order 1% with duration from 50 to 208 hours were found. It is shown that their occurrence correlate with x-ray solar flare events with significant reliability, existence of such correlation can have important practical applications [4]. SOLARIS project of our collaboration plans to perform simultaneous measurements of Fe-55, Co-60 decay parameters at International Space Station and Earth labs. to study their correlations with electromagnetic solar activity, in particular, with x-ray solar flare events .

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VARIANTS OF INTENSIVE ANTINEUTRINO SOURCES ON THE BASE OF ^{8}Li ISOTOPE

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The winning properties combination of the β^{-}-decayed ^{8}Li isotope (short $T_{1/2}$= 0.84 s, hard and known $\bar{\nu}_e$-spectrum ($E_{\bar{\nu}}^{max}$= 13 MeV and $<E_{\bar{\nu}}>$ = 6.5 MeV) and availability of lithium are the undoubted base to consider ^{8}Li as the very perspective isotope for construction of the $\bar{\nu}_e$ source as the powerful instrument for different neutrino experiments. In spite of the high antineutrino flux from nuclear reactors the spectrum are characterized with significant errors ((4–6)% precision at energy up to ~6 MeV) caused by unknown schemes of decays, time variations, presence of the spent nuclear fuel, that put together cause an unsolved puzzles in precision and interpretation of neutrino oscillation results [1].

The construction of the intensive $\bar{\nu}_e$ source is possible in different schemes basing as on the nuclear reactor (as neutron source for (n,γ)-activation of purified ^{7}Li) as on the tandem scheme of the accelerator with neutron producing target plus lithium blanket (neutron converter) irradiated by ^{7}Li(n,γ)^{8}Li activation [2]. In the source realized in transport regime (first variant) an activated ^{7}Li is pumped in the close cycle through the active zone of the reactor; further (in cycle) it is delivered close to the neutrino detector. The scheme really allows to decrease the total spectrum errors in order of values [3]. Another feature of this concept is high count rate ensured in the compact (about m^{3}) neutrino detector – ~ 4×10^{4} of $(\bar{\nu}_e, p)$–events (m$^{-3}\times$day$^{-1}\times$GW^{-1}) [4].

In the other perspective realization the proton beam strike into the heavy-element-target and produces the significant neutron yield for the lithium blanket irradiation. The scheme is considered for energies up to ~600 MeV for different heavy targets (W, Pb, Vi, Ta). The density of 8Li creation is simulated in details that allowed to propose an effective blanket scheme with central lithium containing volume enclosed by carbon (acting as an effective neutron reflector) and outer thick water layer for diminish the neutron escape. The analysis of ^{8}Li distribution in the blanket allows to propose an alternative approach of tandem schemes based on developed compact accelerators with proton energy about several tens of MeV that opens another important possibility - to construct a small-volume- $\bar{\nu}_e$-source (of short dimension ~70 cm) that is exclusively important for search of sterile neutrinos in case of $\Delta m^2 \sim 1$ eV^{2} [5].

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LOW RADIOACTIVE AMMONIUM ACETATE FLUX

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The background event is a critical indicator, in all low background experiments. With the rate of signal events of detector, it is crucial to minimize the presence of radioactive isotopes. Solder and flux is one of the essential materials for making reliable electrical connections in sensitive parts of the experiment. Literature dates report a problem with unacceptable radioactive contamination of commercially available fluxes.

In this work we continued to analyze the low-background flux problem and to produce CH_3COONH_4 organic flux from pre-purified materials. The main application of the flux is for EDELWEISS and CUPID-Mo experiments, which use bolometric technique in LSM underground laboratory for direct Dark Matter detection and for 0ν2β search, respectively. An instrumental neutron activation analysis (INAA), Inductively Coupled Plasma Emission Spectrometry (ICP-AES) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) have been performed to estimate the radioactivity level and impurity content of the products. Additionally, the composition of a high purity commercial ammonium acetate flux (CH_3COONH_4 OSCh 5-4) was analyzed by the same methods to assess the purity of the «custom–made» ammonium flux. The concentration of all impurities in commercial ammonium flux is more significant than custom-made analog. These dates report the advantage of synthesis method of custom-made flux.

RADIO DETECTION OF NEUTRINOS IN ANTARCTICA

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The radio detection of UHE neutrinos is currently being actively developed. Radio experiments carried out in Antarctica (ARIANNA, ARA, ANITA balloon experiment) are able to scan huge volumes of ice in search of neutrinos.

The scale of the experiments is growing - work is underway to deploy an array of radio detectors in the Greenland Ice Sheet, it is planned to build a new radio detector at the South Pole (IceCube Gen-2 radio) and launch a balloon experiment PUEO.

The detection method is based on the Askaryan effect predicted by a Soviet physicist in 1962. Due to this effect, UHE neutrino-induced cascades in ice radiates in the radio range. And the radio transparency of polar ice makes it possible to cover large volumes of the target with sparse array of radio antennas.

In this work, the abilities of AURA experiment to detect UHE neutrino were explored.

The AURA is a pilot radio experiment whose antennas are deployed in IceCube holes in polar ice at a depth of 200–1500 m. The experiment was carried out from 2006 to 2011 to study the background conditions at the South Pole. Its distinguishing feature is the presence of deeply located antennas.

In the work it is shown which radio noise sources are present at the South Pole and how they affect on the efficiency of neutrino detection. The relationship between settings of the trigger system and the thermal noise level recorded by the equipment has been studied. And the possibilities of the AURA experiment for detecting UHE neutrinos are presented here.

DETERMINATION OF THE ENERGY OF HIGH-ENERGY PROTONS (1 TeV AND HIGHER) BY THE LFM METHOD

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Calorimetric methods are currently practically the only way to directly measure the characteristics of high energy (TeV and higher) cosmic nuclei. The primary particle, interacting with the substance of the calorimeter, gives rise to a cascade of secondary particles in it. To measure the characteristics of the cascade, the dense matter is interbedded with special detectors. Based on the measurements of signals from these detectors, a cascade curve is formed. If the cascade curve has reached a maximum in the calorimeter, then the primary energy is reconstructed quite accurately. However, to measure the maximum of the cascade, the calorimeter must have a sufficiently large thickness (and so large weight). When using thin calorimeters, the primary energy is determined with a large error (30–70 percent when measuring hadronic cascades) due to significant fluctuations in the development of the cascade curve. In this regard, the energy spectrum of cosmic rays for energies of 1–100 TeV is currently poorly understood, since different experimental groups present different spectra of cosmic rays.

In this paper, to solve this problem, it is proposed to use the Lessening Fluctuation Method (LFM) based on correlation curves. In this method, instead of cascade curves, correlation curves of the dependence of the cascade size on the rate of cascade development are used. The cascade development rate is understood as a quantity equal to the difference in the cascade sizes at two measurement levels, divided by the thickness of the calorimeter, during the passage of which this change in the cascade size occurred. The rate of cascade development depends on the primary energy and therefore it can be used as an additional quantity to improve the accuracy of primary energy reconstruction. The correlation curves almost do not fluctuate and make it possible to determine the energy of cascades that have not reached a maximum. To test the LFM, we simulated the passage of cascades formed by protons with energies of 1–10 TeV through the PAMELA collaboration calorimeter. Based on the simulation, it was shown that the correlation curves almost do not fluctuate. This makes it possible to significantly reduce measurement errors (up to ~10 percent when measuring hadron cascades). Moreover, LFMs make it possible to correctly determine the energy of cascades that have not reached their maximum. This makes it possible to solve the problem of the large weight of the calorimeter.

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PRECISION MEASUREMENT OF ^{144}Ce – ^{144}Pr BETA-SPECTRUM

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Beta-decay is a specific decay process that undergoes a reaction with thee-particle product composition that results in continuous spectral shape of electrons or positrons. The shape of the spectrum was described already in 1934 by E. Fermi [1], but such description appeared to be valid only for allowed transitions (ΔI = 0,1 $\Delta\pi$ = 1). Involvement of nuclear exchange in other types of transitions complicates such decay description and often makes it necessary to perform experimental evaluation.

Precision beta-spectra measurement always had a great importance in some fundamental physics problems including neutrino physics, e.g. a ^{144}Ce – ^{144}Pr source is one of the most suitable to search for neutrino oscillation into serile state for sterile neutrino mass around 1 eV. Magnetic and electrostatic spectrometers have high resolution, but at the same time usage of such kinds of equipment involves the size and cost issues. Since electron mean free path at the energy of 3 MeV (which is basically the maximum energy of a beta-transition for the long-lived nuclei) does not exceed 2 g/cm^{2,} electron registration could be effectively performed with the solid state scintillators and semiconductors.

A strong probability of backscattering from detector surface is present in case of semiconductor detectors and is dependent upon the detector material. One possible way of solving this issue is a precise simulation of the spectrometer response function that is quite promising as it could be used in a very simple target-detector setup. Another solution to this problem is usage of 4π geometry [2], that fully covers the radioactive source and is able to register the backscattered electrons.

In this work we present the results of ^{144}Ce – ^{144}Pr spectrum measurement performed with two setups of both types and controlled with the shape of an allowed $0^{-}–1^{1}$ transition in ^{144}Pr, having precision that was substantially increased with respect to the previous studies of these beta-spectra. We have obtained parameter values for the parameterized transition shape factor that is compared with the other experiments and could be used for electron antineutrino spectrum definition.

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A NEW OUTLOOK ON THE SQUARE-WELL POTENTIAL APPROACH FOR ASTROPHYSICAL FUSION REACTION

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Latest achievements in experimental study of light nuclei fusion reactions relevant for nuclear astrophysics in the deep subbarrier region required the development of models that make it possible to describe the reaction cross section at low energies [1]. Today there is no unified approach to describe such reactions: a) with excluding of the potential choice ambiguity [2]; b) with the description of the resonant nature of the cross section [3] and its hindrance for low energies [1].

As a first approach we can consider the square-well potential, which allows a simple analytical expression to determine the transmission coefficients and hence the reaction cross section. As was shown in [4], this model gives us the possibility to describe the fusion cross section in the low-energy region for ^{16}O + ^{16}O nuclei with sufficient accuracy.

In present work, the square-well model was applied to the light nuclei (^{10}B, ^{12}C, ^{14}N, ^{16}O, ^{18}O, ^{20}Ne) fusion reactions important for nuclear astrophysics. Functional dependences for the potential depth and well's radius were obtained. Artifacts associated with abruptly changed shallow potential well: overestimations of the channel radius, anomalous behavior of the imaginary potential for a number of reactions were determined.

It was shown that, within the framework of used model, a satisfactory description can be achieved for all investigated reactions.

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HIGH PRECISION NEUTRINO CROSS SECTION MEASUREMENTS WITH THE ENUBET MONITORED NEUTRINO BEAM

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The main source of systematic uncertainty on neutrino cross section measurements at the GeV scale is represented by the poor knowledge of the initial flux. The goal of cutting down this uncertainty to 1% can be achieved through the monitoring of charged leptons produced in association with neutrinos, by properly instrumenting the decay region of a conventional narrow-band neutrino beam. Large angle muons and positrons from kaons are measured by a sampling calorimeter on the decay tunnel walls (tagger), while muon stations after the hadron dump can be used to monitor the neutrino component from pion decays. This instrumentation can provide a full control on both the muon and electron neutrino fluxes at all energies. Furthermore, the narrow momentum width (<10%) of the beam provides an O(10%) measurement of the neutrino energy on an event by event basis, thanks to its correlation with the radial position of the interaction at the neutrino detector. The ENUBET project has been funded by the ERC in 2016 to prove the feasibility of such a monitored neutrino beam and is cast in the framework of the CERN neutrino platform (NP06) and the Physics Beyond Colliders initiative. The ERC project has entered its last year and the efforts are now devoted to the final tuning of the beamline shielding elements. These studies are being pursued exploiting a powerful genetic algorithm that scans automatically the parameter space of the focusing beamline in order to find a configuration minimizing halo particles in the tagger while preserving a large meson yield. Realistic particle identification algorithms have been setup to reconstruct muons and positrons in the decay tunnel with high signal to noise ratio on an event-by-event basis. A full Geant4 simulation of the facility is employed to assess the final systematics budget on the neutrino fluxes with an extended likelihood fit of a model where the hadro-production, beamline geometry and detector-related uncertainties are parametrized by nuisance parameters. In parallel the collaboration is building a section of the decay tunnel instrumentation that will be exposed to the T9 particle beam at CERN-PS in autumn 2022, for a final validation of the detector performance and as a proof of the effectiveness of the technique. In 2019-2022 ENUBET has devised the first end-to-end simulation of the facility and demonstrated that the precision goals can be achieved in about three years of data taking employing neutrino detectors of moderate mass (ICARUS at FNAL, ProtoDUNE at CERN). The technology of a monitored neutrino beam has been proven to be feasible and cost-effective, and the complexity does not exceed significantly the one of a conventional short-baseline beam. The ENUBET results will play an important role in the systematic reduction programme of future long baseline experiments, thus enhancing the physics reach of DUNE and HyperKamiokande. In our contribution, we summarize the ENUBET design, physics performance and opportunities for its implementation in a timescale comparable with next long baseline neutrino experiments.

NEW APPROACHES TO NEUTRON MONITORING IN LOW BACKGROUND NEUTRINO EXPERIMENTS

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In this work the new methods for neutron detection in low background experiments are presented.

During study of background conditions of νGeN[1] and Ricochet[2] neutrino experiments is has been shown that low intrinsic background helium-3 filled tubes are suitable not only for well known detection of thermal neutrons, but also for the fast neutrons with energies up to few MeV. Data obtained with the detectors at the above mentioned neutrino sites were compared with results of ambient neutron flux measurements at Dubna.

Alternative to the ^{3}He could be NaI (Li+Tl) [3] detectors. One such of the detectors loaded with 1% of ^{nat}Li was experimentally studied. Its properties and response were measured. In the study, a high intrinsic background of the detector was revealed. This background results in significant uncertainty with identification of neutrons, especially for measurements designated for the fluxes at the level below 10^{-3} n cm^{-2} s^{-1}. Nevertheless, the MC calculations based on our data shows that in a case of the detector loaded with 2% of ^{6}Li and with its background reduced to the lowest values of available NaI detectors, it will becomes possible simultaneous measurement of low level fluxes for thermal (by the reaction on ^{6}Li), epithermal (by the method proposed in [4]) and fast neutrons [5]. That possibility, together with traditional γ–measurements, looks very promising for background characterization at neutrino experiment sites.

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ELECTRON AND POSITRON SPECTRA FROM PAMELA BY MULTIVARIATE DATA ANALYSIS METHODS

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For 10 years, since 2006 to 2016, PAMELA, a satellite-borne experiment, had been conducting measurements of cosmic rays [1]. Currently, one of the open problems is researching cosmic-ray electron and positron energy spectra, also their time dependencies. The apparatus is estimated to measure these spectra combined from 50 MeV up to 1–2 TeV (600–700 GeV to determine the sign of charge) [2,3]. By the moment, the PAMELA collaboration has published results on 2006–2009 electrons and positrons spectra [3,4], complementing which with the data for the rest period of the measurements with the PAMELA instrument is the priority goal of the ongoing work.

This work presents a new approach to processing the PAMELA experimental data, and preliminary results obtained using it. Besides the previously used complex analysis of parameters extracted from the detectors systems, particular attention is given to machine learning methods to process this data. As such a tool, the TMVA package of the ROOT software is used [5], which is applied for multivariate data analysis. By means of preliminary program training on the test sets of parameters derived from modeling electrons and positrons passing though the PAMELA detectors with GEANT4 package [6], this method enables optimizing the experimental data processing while raising its selection efficiency due to the 1.5 times, compared to the ones obtained before. As an example of the application of the method, this approach has been used to obtain the electron and positron fluxes and their time dependencies, such as the flux ratios of positrons and electrons, positrons and protons, for the whole PAMELA data collection period.

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STUDY OF TAGGED NEUTRINO BEAM CHARACTERISTICS AT THE U-70 ACCELERATOR

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In accelerator-based neutrino experiments, the momentum of an interacting neutrino is known with poor accuracy. The type of neutrino interacting in the detector is not known definitely also.

These problems could be solved by using tagged neutrino beams. The idea of tagged neutrino beams is that, simultaneously, with the registration of neutrino interaction, a special tagging station measures the momentum of the parent particle, as well as the momenta of other charged particles from its decay. Based on the reconstruction of the $\pi(K)^{\pm} \rightarrow \mu^{\pm}\,\nu_{\mu}(\bar{\nu}_{\mu})$ or K_{e3} decays kinematics of parent particles from measured data it is possible to reconstruct the momentum and the type of a produced neutrino with a high accuracy [1, 2].

One of the problems that arise when constructing of tagged neutrino beams is how to relate the neutrino interaction to the corresponding parent particle decay. For this, both temporal and spatial referencing of events registered in the neutrino detector and in the tagging station detectors are used.

In this paper, we describe a technique for the tagged neutrino production from $\pi^{\pm} \rightarrow \mu^{\pm}\,\nu_{\mu}(\bar{\nu}_{\mu})$ decays at the U-70 (Protvino) accelerator channel. The calculated characteristics of the channel for the formation of a beam of parent particles $\pi\pm$ are presented. Various options of the tagging station design are considered. The main characteristics of the obtained tagged neutrino beams are presented.

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Section 5. Development of charged particle accelerators and ionizing radiation sources

COMPTON GAMMA-RAY SOURCE BASED ON 500 MEV ELECTRON ACCELERATOR: UNIQUE PARAMETERS AND POSSIBLE APPLICATIONS

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The perspectives and the program of experimental research in the field of nuclear physics on the projected source of monoenergetic γ-quanta based on the Compton backscattering effect of laser radiation from a linear electron accelerator with an energy of 500 MeV are discussed. It is planned to create a facility with a high-intensity beam of monoenergetic γ-quanta with energies from a few to 30 MeV.

The outstanding parameters of the facility, primarily in terms of monochromatization and beam intensity, will make it possible to obtain new unique data in the field of the structure of atomic nuclei, the physics of photonuclear reactions, including the photofission reaction, and will make it possible to implement methods of both direct measurements and induced activity at a qualitatively new level. New data obtained using monoenergetic photons will make it possible to obtain new reliable information about a number of fundamental problems of electromagnetic interactions of atomic nuclei, primarily, such as the collective modes of nuclear excitations, the relationship between various decay channels of highly excited states of nuclei, the mechanisms of reactions with the emission of various the number of nucleons. The main problems that will be studied at the facility are the structure of the giant dipole resonance (GDR), the parameters of nuclear deformation, and the characteristics of such GDR formation processes as isospin and configurational splitting of the GDR. The implementation of the induced activity method with the beam parameters that are planned to be achieved will make it possible to obtain data on the cross sections of partial photoneutron reactions with high accuracy and reliability and solve the long-standing and well-known problem of significant discrepancies in the results of different photonuclear experiments.

The unique parameters of the γ-quantum beam at the facility will also make it possible to advance significantly in the field of research in nuclear astrophysics. For the first time, it will be possible to measure the cross sections of photonuclear reactions in the region of the corresponding energy thresholds on bypassed nuclei, which are necessary for studying the currently unresolved scientific problem of the origin of such nuclei. A separate program of research on the projected γ-radiation source will be devoted to the study of nuclear photofission. Using a beam of quasi-monoenergetic photons with high resolution, mass, charge, and energy dependences of photofission fragments corresponding to decays of well-defined excited states in different minima between fission barriers will be studied.

COMPTON X-RAY SOURCE BASED ON 50-MEV ACCELERATOR AND ITS APPLICATIONS

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Laser-electron X-ray source based on inverse Compton (Thomson) scattering is a novel type of high spectral brightness X-ray sources. The state-of-the-art design of electron accelerators and high power lasers had paved the way for a construction of these compact facilities that are able to produce a nearly synchrotron-quality X-ray radiation for material and life science studies and many other fields [1, 2]. The essential added values are the generation of picosecond X-ray pulses and tunable output photon energy spectrum with a potential extension towards the region of gamma radiation.

The presentation deals with the main principles, layouts and possible applications of Compton X-ray sources based on a 50-MeV electron accelerator specified for production of X-ray photons with the energy of 20–45 keV. The design options include a utilization of an electron storage ring for high average photon flux generation (see Fig.1) [3].

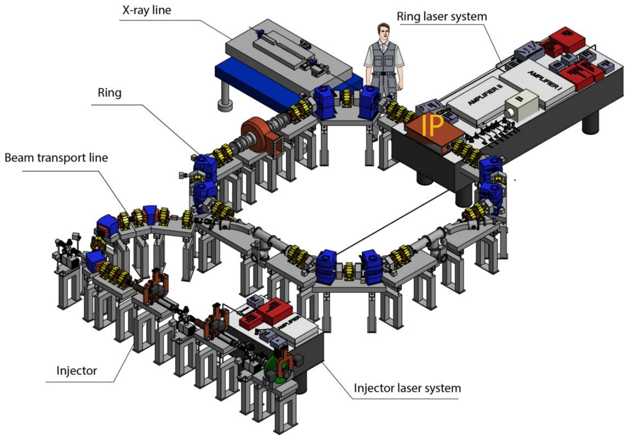

Fig. 1. Compton X-ray source LEXG.

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HIGH-POWER ELECTON ACCEERATORS FOR THE PRODUCTION OF MEDICAL RADIOISOTOPES

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In present time there is a tendency to avoid nuclear reactors in favor of electron accelerators as the main instrument for the production of medical radioisotopes. The report is devoted to high-power industrial accelerators developed by different manufacturers, including Laboratory of Electron Accelerators MSU Ltd. The main requirements for an electron beam are considered based on the existing methods of the radioisotopes production. The advantages and disadvantages of various schemes of high-power accelerators, beam transportation systems, and other are discussed in the article.

THE EXPERIMENTAL RESEARCH OF CYCLOTRON DC-280 WORK

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The DC280 is the high current cyclotron with design beam intensities up to 10 pμA for ions with energy from 4 to 8 MeV/nucleon. It was developed and created at the FLNR JINR. The first was extracted from the cyclotron on January 17, 2019. Experiments on acceleration of ^{84}Kr, ^{12}C, ^{40}Ar, ^{48}Ca, ^{48}Ti, ^{52}Cr and ^{54}Cr beams production were carried out. The following intensities of accelerated beam have been achieved: 1.43 pμA for $^{84}Kr^{+14}$; 10 pμA for $^{12}C^{+2}$; 9,2 pμA for $^{40}Ar^{+7}$; 7,7 pμA for $^{48}Ca^{+7}$. The long time experiments were done in 2020–2022. The features of work of High Voltage axial injection systems, buncher systems and Flat-top systems were explored. The work of accelerator was stable and high efficiency. The total acceleration efficiency from ion source to transport channel was about 46%.

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ELECTRON ACCELERATOR FOR NEUTRON THERAPY AND RADIOISOTOPES PRODUCTION

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The paper vows to the studying the possibility of high-power electron accelerators for neutron therapy and radioisotopes production. Computations are performed for both applications, and the results are normalized to the characteristics of the modern-day MEVEX accelerator (average electron current 4 mA at a monoenergetic electron beam 35 MeV).

The unifying problem for applications is the task of cooling the target: at a beam energy ~ 140 kW, almost half or more of this energy is released directly into the target. Therefore, a liquid heavy metal was chosen as a target to combine high quality thermohydraulics with maximum production of both bremsstrahlung radiation and photoneutrons. The target was optimized using precise codes for the tasks of radiation transport and thermal hydraulics. Optimization was carried out for the installation as a whole: 1) the target configuration; 2) the composition of the material and the configuration of the photoneutron removal unit for neutron capture therapy (NCT) and 2) the scheme of generating bremsstrahlung for radioisotopes production. The photoneutron block provides an acceptable beam quality for NCT with a large neutron flux density at the output: ~ $2\cdot10^{10}$ $cm^{-2}s^{-1}$, which is an order of magnitude higher than the values at the output of existing and projected reactor beams. Such intensity at the beam output will allow to abandon the fractionated irradiation in many cases. As for radioisotopes production, using optimal reaction channel (γ, n) 43 radioisotopes in 5 groups were received. For example, by the $^{100}Mo(\gamma, n)^{99}Mo$ reaction the precursor ^{99}Mo of main diagnostic nuclide ^{99m}Tc with specific activity ~ 6 Ci/g and total activity of the target 1.8 kCi could be produced after 1 day irradiation exposure. The proposed schemes of generation and extraction of photoneutrons and bremsstrahlung have a number of advantages over traditional methods: a) the use of electron accelerators for the production of neutrons is much safer and cheaper than the use of reactor beams; b) the accelerator with the target and the beam output unit with the necessary equipment and tooling can be easily placed on the territory of the clinic; c) the propose liquid gallium target for NCT, which also serves as a coolant, is an "environmentally friendly" material: its activation is relatively small and quickly (four days) decreases to the background level.

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2. Yu. A. Kurachenko, *et al.*, DOI: 10.12737/1024-6177-2019-64-5-48-53

LUE-200 ACCELERATOR – THE DRIVER OF THE PULSE RESONANCE NEUTRON SOURCE IREN

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The linear electron accelerator LUE-200 was designed and built at the Joint Institute for Nuclear Research (Dubna) as a driver for a booster-type neutron source with a multiplying target – an active zone with an integral neutron yield of $\sim10^{14}$ s-1, which determines the energy and power of the accelerated particle beam. The accelerator was designed and put into operation in stages. In 2009–2010 the physical start-up of the IREN installation was carried out as part of the first stage of the accelerator with a non-multiplying target (electron gun, one accelerating section, one klystron, one modulator). The first stage of the accelerator worked for the experiment for several thousand hours at a cycle frequency of 10–25 Hz with a beam current of 1.5–2.0 A, a duration of ∼ 100 ns and an energy of 30–35 MeV (spectrum maximum). In 2016, the second accelerating section was installed and launched (+ the 2nd klystron with a modulator). As a result of the launch of the second stage of the accelerator (2016–2019), an increase in the energy of accelerated electrons up to 70 MeV was achieved, with an average electron beam power of up to 0.6 kW at a cycle frequency of 25–50 Hz.

The problems of achieving the design parameters of the accelerator and the possibility of the accelerator developing as a neutron source driver without a breeding core are considered. The plans for the development of the accelerator provide for an increase in the cyclicity of the accelerator to 100–120 Hz and an increase in the beam power to 1.5 kW, which will make it possible to obtain an integral neutron yield from a non-multiplying W target up to $3 \cdot 10^{12}$ s^{-1}.

ELECTRON ACCELERATORS DESIGN AND CONSTRUCTION AT LOMONOSOV MOSCOW STATE UNIVERSITY

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The report presents the results of the development of linear electron accelerators with energy from up to 10 MeV, performed at the Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, as well as in Laboratory of Electron Accelerators MSU. Over the past year, more than 30 accelerators of six different types have been delivered to customers. Linear accelerators for mobile, stationary and train cargo inspection systems with interlaced energies and pulse repetition rate up to 2 kHz, accelerators for radiography, a sterilization accelerator with beam parameters that are adjustable over a wide range, and an accelerator for a radiotherapy complex are described.

CONTINUOUS-WAVE ELECTRON LINACS FOR SCIENCE AND INDUSTRY

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SINP MSU developы normal conducting continuous-wave linear electron accelerators since 80s. Continuous-wave linacs compared to pulsed machines make it possible to obtain electron beams with more stable energy and lower energy spread, reduce detectors loading while maintaining the average intensity of events during an experiment. We present an overview of continuous-wave accelerators for both nuclear physics research and applied purposes, including superconducting accelerating systems. We analyze the features of the design and operation of that type of accelerators, the prospects for the development of this area.

ENERGY CONVERSION IN ELECTRONICALLY CONTROLLED DISCRETE ION-PLASMA DYNAMICS INSTALLATIONS

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The technique and technology for the creation and formation of electronically controlled ion and plasma fluxes in the magnetic fields by grouping the flows with setting certain sequences of the self-following have been worked out to solve the problem of controlled nuclear fusion. The operation of the units is based on the physical principles of plasma and ion flows compaction with a discrete change in the control parameters of magnetooptical systems. Theoretical and applied aspects of the magnetodynamic flow of controlled plasma simulation are considered. The description of an example circuit for the plasma neutron generator and the rationale for the discretization of compacted plasma and ion flows based on the introduction of the concept of flows discretes are considered. The processes of experimental installation of an electronically controlled ion generator and the characteristics of a prototype industrial installation are considered. Nuclear reactions suitable for modifications of such generators are considered. It is planned that the electronically controlled plasma energy converter device will have the design thermal power more than 10 kW, electric power more than 5 kW. On the basis of the technology under consideration, the neutron generator with the plasma target will be created with the impulse of neutron flux from 10^{10} c^{-1}.

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BIOLOGICAL PROTECTION CALCULATION OF THE ELECTRON ACCELERATOR MT-25 FLNR JINR BY USING FLUKA SOFTWARE PACKAGE

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Physical experiments to study collinear cluster tri-partition are planned on the cyclic electron accelerator MT-25. This is a new type of multibody decay that requires, due to the small cross-section of the reaction, work at the maximum intensity of the electron beam for research.

The purpose of this work is to study the radiation fields that occur at the maximum intensity of the electron beam outside the biological protection of the microtron at an energy of 25 MeV.

In the course of the work, measurements of the dose rate of neutron and bremsstrahlung radiation were carried out. Beyond the biological protection of electron accelerators, they are the main components of radiation hazard. For measurements, a mobile measuring stand was used, the main elements of which are neutron and gamma radiation dosimeters UDBN-01 and UDBG-01.

According to the results of measurements at elevated beam currents, significant excess of the dose rate of braking radiation was detected at some points of the existing protection. Protection calculations were performed to eliminate weaknesses using the FLUKA [1] software package created for Monte Carlo simulation of physical processes. At the same time, one of the tasks was to conduct a comparative analysis of the measured and calculated data, since there is practically no work on experimental verification of the reliability of the results of the specified software package for electron accelerators in the energy range up to 25 MeV.

Based on the results of calculations, a new project of local protection around the braking target assembly is presented. The measurement results carried out with the installed new protection showed that outside the microtron room, the power of the equivalent dose of braking radiation coincides with the calculation results and does not exceed the maximum permissible value of 1.2mSv/hour (according to the rules of NRB-99/2009).

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NMR-BASED INJECTION FIELD MEASUREMENT SYSTEM FOR MEDICAL PROTON SYNCHROTRON

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One of the main processes in a proton synchrotron is capture of particles during injection. For successful capture, it is necessary to measure the magnetic field in the orbit with high accuracy. Widely used Hall sensors have many disadvantages: not very high precision and long-term stability, low radiation resistance, angular dependence and etc. All these cause difficulties in setting of the synchrotron and reduce the stability of its operation, which is especially important for medical accelerators. Therefore, the development of new methods for control of the injection field, will improve the stability of medical synchrotrons and reduce the treatment time [1].

The purpose of this work is to develop a high-precision NMR-based system for measuring and controlling the injection magnetic field for the medical proton synchrotron [2].

The developed system is based on a pulsed proton NMR-gaussmeter. The magnetic field measurement is made by measuring the frequency of spin echoes after 180-degree pulses in Carr–Purcell–Meiboom–Gill sequence. The measuring probe is installed in the vacuum chamber of the synchrotron in close proximity to the injection channel. The NMR-gaussmeter is built on a modern electronic element base. Control, frequency measurement and data transfer are realized by high-speed ARM-microcontroller. The NMR-gaussmeter is configured and controlled using PC-software designed in Lab Windows CVI.

The measuring probe provides an NMR-signal from the quasi-constant synchrotron's magnetic field of about ≈1000 Gs (corresponding to proton injection energy of ≈1 MeV) with the possibility of digital tuning of the resonant frequency in the range of ±50 Gs. The magnetic field is measured with an accuracy of no worse than 0.1 Gs. The measurement time is 20 ms. The signal-to-noise radio is at least 5.

The developed system makes it possible to measure the injection magnetic field in real time directly in the acceleration cycle and to ensure the stable capture of particles.

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OPTIMIZATION OF OPERATING MODES OF MEDICAL SYNCHROTRON FOR PROTON IMAGING APPLICATION

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Proton therapy is one of the most developing forms of radiation therapy [1]. The release of most of the proton energy and, consequently, the maximum damage to biological tissues occurs in the immediate vicinity of the region where the proton beam stops. The range of protons in the patient's body must be predicted with submillimeter accuracy to maximize the physical benefits. In current clinical practice, radiation planning for proton therapy is done using an X-Ray computed tomography (CT) data of the patient. The use of X-Ray CT for proton treatment planning requires software that uses empirically derived calibration functions specific to each scanner. The process of converting the Hounsfield units obtained from the CT into the relative stopping power of protons leads to an uncertainty in the path of particles in the patient's body. Thus, the best solution would be to use proton imaging, a method in which the relative stopping power of the proton beam is reconstructed directly.

Proton imaging requires, firstly, a higher energy of the proton beam, and secondly, lower intensities of the output by the beam than those used for therapy. However, existing proton medical facilities do not fit these requirements. As part of this research work, to develop new modes, we used the synchrotron of Prometheus proton therapy complex [2]. The main feature of the facility is the ability to extract a proton beam in the range of 30–330 MeV. The limiting energy of the extracted beam is sufficient to carry out the procedure of proton imaging of the whole body of the patient without any restrictions. Currently, the standard intensity of the extracted proton beam is 2×10^9 protons/s.

There is no implemented solution that satisfies the requirement of a low intensity of the extracted proton beam specifically for imaging purposes. The use of therapeutic intensities in diagnostics will harm healthy tissues. In the present study new mode of operation of a Prometheus synchrotron with ultra-low intensity extraction and methods for control of low intensity proton beams have been developed. Proposals have been formulated for modifying proton therapy complexes based on this synchrotron to implement the proton imaging. The mode being developed will allow developing the research capabilities that can be provided by the Prometheus synchrotron.

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THE OPERATIONAL METHOD FOR CALCULATING THE BIOLOGICAL PROTECTION OF LOW-ENERGY HEAVY ION ACCELERATORS

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Simple analytical formulas for operational evaluation of the yield and angular distribution of neutrons, which are necessary for calculating the biological protection of heavy ion accelerators with energies from 1 to 6 MeV/nucleon, are presented. Activities on creation of the new multipurpose isochronous cyclotron DC-140 [1] at the FLNR, JINR became the reason for the development of a method for operational preliminary calculation. The results of the calculation were compared with the results of calculations using the LIZE++ [2] and FLUKA[3] programs and with the available experimental data in the literature.

As a result of the comparisons, it can be argued that the proposed method for calculating the yield and angular distribution of neutrons from thick targets can be used to quickly assess the necessary biological protection of heavy ion accelerators under construction and reconstruction with energies from 1 to 6 MeV/nucleon. The deviation of the results of these calculations from the more accurate ones does not exceed a factor of two, which is comparable with the results of deviations in the calculation of biological shielding associated with a certain variety of spectra of produced neutrons and deviations in the protective properties of the materials used or their thickness.

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4 MeV ENERGY PROTONS FOCUSING BY DIELECTRIC CAPILLARY IN THE AIR

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A classical method of the charge particle microbeams formation is based on magnetic or electrostatic ion focusing with preliminary input beam collimation. An alternative method of the microbeams formation is using of the capillary. New systems of transformation, control and transfer of the charged particle beams can be developed on a basis of this effect, particularly for obtaining the micron and submicron-sized beams which are interested for elemental and structure analysis, nanolithography, medical and biological applications, radiation technologies [1-3]. This method is the easiest and cheapest one for using in comparing with the existing micron radiation methods.

Experimental studies of transfer and focusing processes of the 4 MeV initial energy proton beam are carried out. For proton beam transportation into the air the SterilleFemtotips 11 dielectric capillary with 58 mm length (d_{in} = 1,5 mm, d_{out} = 92 ± 3 μm; d_{in} = 1,5 mm, d_{out} = 0,5 ± 0,2 μm) are used. EGP-10 accelerator [4] is used as a proton source.

The optimal distances from capillary to research object are determined as well as time when the least divergence of the beam is observed. Proton energetic spectra are obtained after passing of the protons through the capillary with and without the conductive layer. The method of the beam size determination using the semiconductor detector is proposed. Proton beam sizes at the beam ejection into the air are determined.

Recommendations of formation of proton micron and submicron-sized beam at EGP-10 accelerator are made basing on obtained experimental data.

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MONITORING OF PULSED INTERMEDIATE-ENERGY NUCLEON BEEMS USING AIR ACTIVATION

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Pulsed nucleon beams are used for radiation therapy at charged particle accelerators and for science material studies at ionizing radiation sources. Secondary radiation from the interaction of the beam with biological tissue and material is used to control the beam parameters and the absorbed dose [1, 2].

Proton therapy unit and pulsed neutron source have air channels for beam formation. Intermediate energy nucleons are non-elastically scattered by air atoms (nitrogen, oxygen, argon, etc.) and creates short-lived radionuclides (life tame from 20 ms to 100 s) in spallation process. Gamma and beta radiation from the decay of radionuclides can be used to pulsed nucleon beam monitoring. An activation monitor for direct measurement of the medium energy nucleon flux was based on MKS-01R radiometer and a single-board Raspberry Pi2 microcomputer. The monitor has been tested when detecting radiation particles from activated air at the proton therapy unit and at the pulsed neutron source.

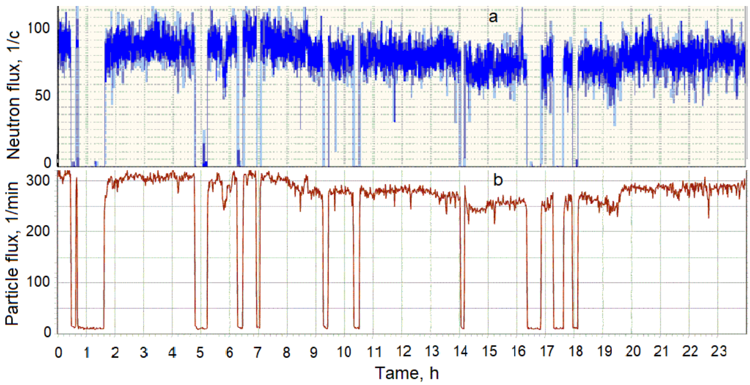

Fig. 1. Time diagrams of the neutron beam fluxes of the pulsed neutron source (a) and the gamma and beta radiation from activated air (b).

The absorbed dose of the proton beam in cell cultures using Gafchromic film and the pulsed neutron flux using UDBN detector were measured. The sensitivity of the monitor to neutrons estimated from these data was about 0.02–0.1 pulses/(n/cm^2). The monitor allows to control pulsed beams of protons and neutrons with an energy of 20–200 MeV at a frequency of up to 50 Hz.

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NON-DESTRUCTIVE MEASUREMENT OF DETAILED TRANSVERSE BEAM DISTRIBUTION WITH THE USE OF AN IONIZATION MONITOR

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The constant monitoring of the uniformity of the density distribution of the flux of the accelerated particles is required in various applied fields as such as the studies of biological objects and of radiation resistance of electronic devices. The ionization monitor has been developed at FLNR JINR in order to make the non-destructive detailed high precision measurement of the transverse profile of a wide beam of accelerated particles. The monitor design is aimed at measuring the concentration of residual gas ions arising along on the beam path. The distribution of the ions is proportional to the distribution of the particle flux density. The ions are extracted from the beam region by a constant electric field larger than 0.2 kV/cm and then are accelerated by a sawtooth voltage with a frequency of 2 Hz. During the extraction the ions get the kinetic energy proportional to the distance traveled in a constant field and to the value of the subsequent accelerating voltage. The extracted ions enter two consecutive electrostatic analyzers separated by a plate with 1 mm slit. Ions can enter the second analyzer through this slit only if they were created in a narrow beam region, which position depends on the value of the sawtooth voltage. The monitor sensitivity is increased by MCP (Micro channel plate) placed after the analyzers. The collector divided into 31 strips is located after the MCP. The current from the strips is digitized by several ADC (Analog to digital converter) channels. The first coordinate of the ion formation position is determined by the number of the collector strip. The second coordinated is extracted from the value of the sawtooth voltage measured by another ADC. The number of employed ADCs allows every second measurement of a detailed two-dimensional distribution with 31x31 points on a beam cross section up to 45 mm in diameter. Because the ions of the residual gas are collected from the beam path 90 mm long, the sensitivity of the monitor is almost two orders of magnitude higher than the existing analogs [1, 2]. The monitor can also be used to measure the profile of secondary beams.

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EMISSION NANOSTRUCTURE SOURCES IN MULTI-WIRE PROPORTIONAL CHAMBERS WORKING AT LHC

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The results of research of the origin of the spontaneous electron emission sources generation in multi-wire proportional chambers (MWPC) at LHCb experiment in Large Hadron Collider (LHC) [1] are presented. Formation of dotted carbon nanostructures on cathode copper foil with sp^1, sp^2, and sp^3 hybridization of electron levels is shown up as a result of complex research by atomic-force microscopy (AFM), elemental analysis and Raman spectroscopy methods of cathode samples from MWPC demounted from facility. Carbon nanostructures presence in the area of cathode spontaneous emission currents generation is proved by effect of resistive shift in current-voltage characteristic (I-V curve) measurements by AFM methods. Moreover according to AFM morphology of the surface of these structures resembles the results of research of nanocarbon formation derived under laboratory conditions at high temperature in vacuo.

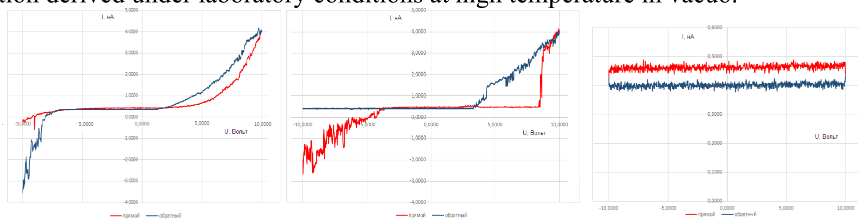

Fig.1. Standard I-V curves obtained in spontaneous electron emission area: a - bipolar hysteretic type; b – unipolar type; c – linear type.

Frenkel-Pool model [3,4] is chosen for analysis of the emission ability of the cathode formations by hysteresis I-V curve due to absence of the significant morphological defects increasing the aspect ratio on the cathode surface. According to this model electrons are emitted by electrically active impure centers in cathode carbonized layer at reaching the activation energy (E_o). Estimation based on obtained I-V curves shows that $E_o \sim 0.05$–0.06 eV for MWPC cathode samples.

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MODELLING OF ION TRANSFER PROCESSES IN A MAGNETO-OPTICAL SYSTEM OF SOLENOIDS AND MAGNETIC QUADRUPOLE LENSES WITH DISCRETE FLOW COMPACTION

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To optimize the processes of nuclear fusion on the ion-plasma generator [1], a model was constructed that describes the dynamics of particle motion inside the fusion chamber. The synthesis chamber is a magneto-optical system of solenoids and quadrupole lenses, thereby performing the functions of confining and focusing ion flows. Using known formulas for the magnetic field of a finite-dimensional solenoid [2] and solving these equations numerically, it is possible obtain the distribution of the magnetic field for a system of solenoids. Performing a similar calculation for magnetic quadrupole lenses, it is possible calculate the superposition of a system of such fields, thereby obtaining the general picture of the magnetic field inside the synthesis chamber presented in [1].

The plasma dynamics inside the synthesis chamber can be described using the equations of magnetohydrodynamics. In our case, the plasma moves in a magnetostatic field, but which varies discretely. Calculations have been made for individual magnetic quadrupole lenses consequence for charged particle flows compacting in strong magnetic fields, including pulsed ones, and their advantages have been well studied and known [3–5]. Ion fluxes are considered as an ideal gas when describing particle velocities and describe them by Maxwell's equation. By changing the parameters of the magnetic lens, it is possible to change the parameters of the currents inside the synthesis chamber, which just affect the distribution of particles in space, which leads to a more structured target for more accurate further analysis bombardment by other streams. As the result of the work, graphical dependences of the distribution of microcurrents and concentrations in the optimal sequence of solenoid and quadrupole magnetic fields are obtained.

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ALGORITHMS FOR DESIGNING POWERFUL MULTICAVITY KLYSTRONS

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To calculate the characteristics of high-power klystrons, the two most commonly used approaches. In the first case, the initial-boundary value problem for the system of Maxwell's equations and the equations of motion of relativistic charged particles are solved jointly by a numerical method. This formulation allows not only modeling the processes of interaction of beams with a high-frequency field, but also taking into account many important physical effects (multipactor, dark currents, breakdown phenomena, etc.), but it requires large computational resources.

Another approach uses simplified semi-analytical models, such as one-dimensional models of charged disks and plates, or two-dimensional models of rings and bars. In this case, the calculation of a multicavity klystron takes seconds or minutes, which allows in the preliminary design to carry out multiparameter optimization of the parameters of a powerful multicavity klystron with modest computing resources. The Super S-tau Factory project [1], carried out by the Institute of Nuclear Physics of the Siberian Branch of the Russian Academy of Sciences, makes the development of a 50-megawatt S-band klystron especially topical. The paper describes the algorithms for calculating and designing such a klystron, as well as the characteristics of the program created for this purpose. Comparisons of the results obtained by this program with the results of calculations using the CST Microwave Studio are given.

Algorithms for designing individual elements and assemblies of advanced multi-beam klystrons and sheet-beam klystrons (electron guns, cavities etc.) based on the boundary element method are described in the author's monograph [2].

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FOURIER-IR SPESTROSCOPIC STUDIES OF n-C_6H_{14} AND n-C_6H_{14} + H_2O SYSTEMS

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Radiation-catalytic processes for the production of molecular hydrogen from a mixture of hexane and hexane-water It is of great interest to discover new ways of conversion and use of ionizing radiation for the production of molecular hydrogen, which is a universal energy carrier. The results of the research may be important to clarify the mechanism of the processes that occur under experimental conditions under the influence of ionizing radiation in the hexane, hexane-water system, as well as under natural conditions in oil and gas fields under the influence of natural radionuclides.

In the presented work, Fourier-IR spestroscopic studies of n-C_6H_{14} and n-C_6H_{14} + H_2O systems were performed. The results of spectroscopic studies suggest that the ratios of the intensities of the absorption bands characterizing the CH_2, CH_3 groups vary depending on the dose rate (valence and deformation oscillations of CH_2 and CH_3 are 2800–2970 cm^{-1} and 1300–1500 cm^{-1}, respectively. 1 are located in the spectral regions). Absorption bands - (CH_2) belong to the long chain type of type n (n≤4) and CH_2 lattice oscillations (spectral region ν = 650–850 cm^{-1}). During radiolysis of the n-hexane + water system (3:1) after gamma radiation, 5 new bands are observed in the frequency range ν = 2600–2700 cm^{-1}, which indicates that the decomposition of n-hexane produces heavier paraffin during radiation-chemical processes. - The change and distribution of the maximums and intensities of absorption bands in the chain region of (CH_2) (ν = 650–850 cm^{-1}) indicates the formation of paraffins of type C_1 - C_5. The formation of C_1 - C_5 products is confirmed by the spectra of gases in the system under study. The decomposition of water in the studied system is followed by the formation of absorption bands of OH-groups in the spectra in the frequency range ν = 3000–3600 cm^{-1} (valence region), ν = 1700–1600 cm^{-1} (deformation region). The formation of olefins as a result of radiolysis of the n-hexane + water (3:1) system was not observed in the IR spectra.

THE EFFECT OF THE "FLAT-TOP" RESONANT SYSTEM OF THE DC-280 ACCELERATOR ON THE ACCELERATED ION BEAM

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In 2018, the world's first Superheavy Element Factory (STE) was put into operation at the Flerov Laboratory of Nuclear Reactions (FLNR) of the Joint Institute for Nuclear Research (JINR) – based on the new DC-280 cyclotron [1].

A feature of this accelerator is the increased total efficiency of beam transmission in the accelerator (from the ion source to the target of the physical installation) to the level of 50%. Increased efficiency of beam transmission in the cyclotron chamber is achieved using a "flat-top" system [2]. The principle of operation of the "flat-top" system is to add an additional high-frequency (HF) voltage to the main one, which operates at the 3rd harmonic relative to the main accelerating system DC-280. The "Flat-top" system was designed to create a flat shape of the vertex of the accelerating voltage of the cyclotron

The work was carried out, during which the effect of the additional accelerating system "flat-top" on the beam of accelerated ions was studied and verified. This technology makes it possible to reduce the energy spread in accelerated ion clumps and implement an effective single-turn output, which consequently increases the efficiency of beam transmission.

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COMPACT NEUTRON CALIBRATION SOURCE BASED ON ^{252}Cf RADIONUCLIDE AND A SILICON SEMICONDUCTOR DETECTOR

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This work will demonstrate the operation of a model of compact neutron calibration source. Compact neutron calibration source is highly needed for calibration and response function determination of WIMP-oriented dark matter detectors and electron antineutrino detectors. This could be done with neutron calibration source with either known neutron energy spectrum, or by time-of-flight (ToF) neutron energy reconstruction.

Suggested neutron calibration source is based on Californium-252 radionuclide which undergoes spontaneous fission producing neutrons with a continuous spectrum and a semiconductor detector. The latter upon registration of fission fragments signal provides a time reference of the moment of neutron creation.

For registration of the fission fragments signal we used a silicon semiconductor detector with thin entrance window. Performed investigations have proved that such a detector may withstand exposure of up to 10^9 of fission fragments before the critical degradation of its operating parameters occurs [1]. The spectra of neutrons and γ-quanta produced during the spontaneous fission of ^{252}Cf nuclei were recorded with help of PMMA scintillator equipped with photomultipliers of type 97. The scintillator represents a cylinder with a wall thickness of 7 cm and an internal diameter of 13 cm. In the center of scintillator cylinder a ^{252}Cf source and a semiconductor detector were placed.

These two registration channels for neutrons and fission fragments, respectively, operates in the coincidence mode in order to establish the correlation between the fission fragments and neutron / γ-quanta signals, which, in turn, can be separated by accounting the delay time of the neutron arrival. Therefore, the possibility of using a combination of the semiconductor detector and ^{252}Cf radionuclide as a compact neutron calibration source will be demonstrated.

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INVESTIGATION OF SECONDARY ELECTRON EMISSION PROCESSES IN ACCELERATOR CHARGED PARTICLE BEAM MONITORING SYSTEMS

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Today, charged particle accelerators play an important role for the study of the nuclei structure, elementary particle physics and for the production of radionuclides used in medical technologies. An important condition for these accelerators operation is to improve the quality of the extracted beams. Therefore, one of the main instruments of accelerator and beam technologies are the systems for charged particle beams diagnostic, which make it possible to obtain information about the main parameters of the beam: beam profile, beam current, beam emittance. To monitor charged particle beams and increase their intensity on the targets are often use sensors. The operation of such sensors based on secondary electron emission processes. In this work, the monitoring system for charged particle beams (consists of a scanning gold-plated tungsten wires grid and placed inside of the accelerator beam pipe) is discussed. The beam particles interact with the wires and knock out secondary electrons. As a result, each wire becomes a current generator and current is proportional to the intensity of the beam particles. By measuring the current from each wire, one can reconstruct the beam profile and investigate the secondary electron emission processes.

In present work the mechanisms of current distributions caused by space charges of secondary electrons formed during the passage of heavy ion and proton beams (used cyclotron of the A. F. Ioffe Institute, Russian Academy of Science) through a grid of thin scanning wires were studied. Also a model for the visualization of the beam profile was developed, and the main parameters of secondary electron emission processes with beam intensity were determined.

Section 6. Applications of nuclear methods in science and technology

CONTACTS FOR SELF-SCANNING SiC ENERGY CONVERTERS IN NANO-MICROWATTS RANGE

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The authors investigate the beta-electrons energy conversion into electrical energy inside 3C–SiC*/Si heterostructures doped with carbon-14 [1], which acts as an internal source of primary electrons spectrum and as the radioisotope nuclear energy accumulator. The question is raised in connection with the description of the endotaxy effectivness at the structural level, which means the growth of the doped single-crystal film inheriting the crystallographic orientation of the transformed Si-phase. The analysis of the technological aspects of the formation by endotaxy of high-temperature stable and radiation resistant β-SiC/Si heterostructure with respect to the concentration distribution of point defects of various nature, deep centers [2] and their probable association models with the participation of an impurity is the main way to increase the physical sensors reliability. The analysis of reversible association processes opens up ways to optimize the kinetics of diffusion mass transfer and microalloying during the phase transformation of silicon substrate into the silicon carbide film [3]. The dependences of the neutral defects concentrations on the factors of supersaturation of the gas phase by the conditional atomic concentration of carbon, on the concentration of impurities in the gas phase, as well as on their own defects of various nature, have the potential for the formation of deep levels in the forbidden zone and the potential for association [3]. The efficiency of the created structures depends on the combination of radionuclide activity and the formation of the contact area, which is confirmed by the beta spectrum research by the authors.

The dependence of the carrier generation efficiency on the activity or the introduced concentration of the radioisotope in the crystal lattice, taking into account the phase formation is evaluated. It is important to evaluate the possibility of structures metallization in order to collect nonequilibrium charge carriers taking into account changes in the work function. At this stage chips of structures with the size from 1x1 mm are used. At the same time, it is important to investigate the degree of influence of boundary effects. Research in the framework of this work also includes consideration of the band structures of the device, since there is an understanding of the alloying effect impurities with radionuclide on the position of energy levels in the band structure.

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FLEXIBLE SCENARIO FOR BACKGROUND SUPPRESSION IN HEAVY ELEMENT RESEARCH

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New algorithms to operate with new analog spectrometer of the DGFRS2 installed at DC-280 cyclotron setup are presented. The main goal of application of these algorithms is to search an optimal time correlation recoil-alpha parameter directly during the acquisition C++ code execution. A new real-time flexible algorithm is presented in addition to the conventional ER-α one which is in use for a few years at the DGFRS1 setup installed at the U-400 FLNR cyclotron. Note that the spectrometer operates together with the 48×128 strip DSSD (Double Side Strip Detector; 48×226 mm^2) detector and low-pressure pentane-filled gaseous detector (1.2 Torr; 80×230 mm^2) are presented schematically. First beam test results in ^{48}Ca-induced nuclear reactions are presented too.

LOOKING FOR AN ELECTRON BRIDGE IN ^{229m}Th

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The isomeric state ^{229m}Th has the energy of 8.3(2) eV [1]. The small natural width and the location of the transition in the optical range give hope for the use of this state as an oscillator with a quality-factor several orders of magnitude higher than the Q-factor of the systems currently in operation.

Changes in the electron shell with changes in the degree of ionization, chemical environment, environmental parameters and the presence of external fields can have a significant impact on the probability of both discharge and settlement of the isomeric state through the mechanism of electronic bridges. Knowledge of the features of the decay of the isomer under the condition of the energy prohibition of direct electron emission will allow us to determine the optimal parameters of the feeding of the isomer using the electronic bridge mechanism. The “tuning" of the electron shell can increase the probability of isomer excitation by several orders of magnitude [2]. The probability of discharge through electronic states is a good indicator for such adjustment.

The existing limitation on the lifetime of the isomer in a singly-charged thorium-229 ($T_{1/2} < 10$ms [3]) ion allows us to hope for using the lifetime of the isomeric state as an indicator of the width of the electronic bridge.

The report presents the details of the preparation of an experiment to search for the decay of the isomeric state of thorium-229 through the mechanism of an electronic bridge. The method [4, 5] of formation of a beam of ions of the thorium isomer, the scheme of ion transport and preparation of a thin source and registration of conversion electrons will be considered.

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CONJUGATE OBJECTS IN QUANTUM COMMUNICATION

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The basis of quantum communication is a set of methods for transfer of information encoded with the help of quantum states of elementary particles. The carrier of a unit of quantum information in this case is a qubit – a two-level quantum system (a photon with vertical and horisontal polarizations, an electron with two basic states, an ion of a hydrogen molecule H^+_2 with basic states of electron localization at the first or second proton, etc.). Nuclear objects - nucleons can also be considered as a qubit with two basic states in the isospin space.

In [1], we construct the algebraic model for the study of few-nucleon systems with non-abelian superselection rules, and in [2], this model was applied to describe the transfer of quantum information in the presence of constraints by superselection rules by isospin. Isospin is a non-abelian charge and it is convenient to describe such charges based on the framework symmetric tensor C*-categories. In [2], it was shown that the transmitted number of classical messages encoded in qubits is equal to the number of coherent superselection sectors, taking into account their multiplicity. Within the framework of algebraic model, superselection sectors can be defined as a class of unitary equivalence of an irreducible endomorphism [ρ] (as an object of the C*-category) of the algebra of observables of the system.

In the study of the quantum communication, as well as quantum cryptography, due to the compensating property, the conjugate charge also plays an important role. In this paper, a study is carried out of conjugate superselection sectors [ρ]* corresponding to a conjugate object (charge) of the category. It is shown that the constructed conjugate object satisfies the required conjugate equations. Classes of morphisms intertwining super-selection sectors and certain functions over these morphisms are studied, which allow us to identify the properties of the conjugate charge generating certain superselection rules.

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PERSPECTIVES OF INORGANIC SCINTILLATOR GAGG APPLICATION FOR PRECISION ELECTROMAGNETIC CALORIMETRY

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Scintillation crystals made of a new promising material $Gd_3Al_2Ga_3O_{12}$ (GAGG) are considered because of their high radiation resistance, density and light yield [1, 2]. These crystals can be used in addition to lead tungstate ($PbWO_4$) crystals for development of a new generation electromagnetic calorimeter with good spatial and energy resolutions in a wide energy range. $PbWO_4$ crystals enable accurate detection of high energy photons, while the addition of GAGG crystals makes it possible to precisely measure photon energies down to a few MeV.

Different options of composite electromagnetic calorimeter based on PWO and GAGG crystals are considered to optimise spatial and energy resolutions in a wide energy range (from 1 MeV to 100 GeV). Optimisation is based on GEANT4 simulations with accounting of light collection using different photodetectors and a noise of electronics. The simulations are verified using measurements of GAGG samples obtained with radioactive sources and test beam measurements of $PbWO_4$ based Photon Spectrometer of the ALICE experiment at CERN [3].

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CALIBRATION OF RADIOISOTOPE DEVICES

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Radioisotope density meters and radioisotope level gauges are intend for non-contact continuous measurement of the density or filling level of liquid, emulsion, chemically harmful substances (liquid sulfur, polymer products of gas condensate, acids, alkalis, etc.) in closed or open capacities. Radioisotope densitometers and radioisotope level gauges contain main 3 blocks: a gamma radiation source block, a detector block, and a block for analyzing and processing information about the measured substance. In the studies, the tightness of Cs-137 closed radiation ionization sources was made by the immersion method [1], Cs-137 source (type of GCs7.012.8) were charged into blocks of gamma sources and a lead screen 15 mm thick was installed in front of the collimator of gamma source block. The radioisotope densitometers (Endress+Hauser AG, Switzerland) was calibrated using a special technique with using metal calibration container with liquid imitators based on a mixture of bromoform ($CHBr_3$) stabilized with resorcinol and ethyl alcohol (C_2H_5OH) [2] having different densities (Fig 1). Then ready-made calibrated radioisotope devices on the liquid emulsion pulp production line at the hydrometallurgical plant of the Navoi Mining and Metallurgical Combine were mounted. The radioisotope level gauge – M7213 scintillation probe (Mesacon Messelektronik, GmbH Dresden) on a special stand using a mixture of bromoform and ethanol [2] was calibrated. A calibrated scintillation probe radioisotope level gauge was installed outside the body of the flow channel to control the filling level with liquid glass on the production line for the production of fiber-optic cables.

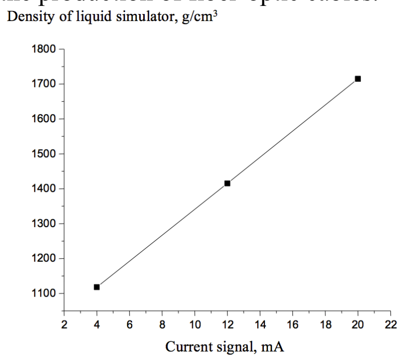

Fig 1. Dependence of the current strength on the density of liquid simulator (left); calibration of the radioisotope densitometer (right).

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TO TESTING OF THRESHOLD SILICA AEROGEL CHERENKOV DETECTORS ON COSMIC RAYS

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At present, threshold aerogel Cherenkov detectors based on SiO_2 with chosen refractive indices (hereinafter referred to as "threshold detectors") are widely used for studies in physics of elementary particles (in particular, for separating charged pions and kaons, see about it, e.g., in [1] and in references therein). Since the number of Cherenkov photons is small compared to that from scintillators, it is required to test such threshold detectors and measure their significant characteristics on accelerator beams and / or on cosmic rays. In our case, the detector, when the entire aerogel block is viewed by a set of photomultiplier tubes (PMTs), such characteristics are the distribution of the number of "activated" PMTs, the total detection efficiency, etc.

Usually (see, e.g., [1]), at cosmic ray testing of some threshold detector, several horizontal plastics (viewed by their PMTs) form telescope around vertical axis. Signals from these detectors are used as a trigger for testing of the threshold detector placed on the same axis. In [1], layers of Pb with additional plastic detectors behind each Pb layer are installed ahead and behind the tested threshold detector to separate particles with energies higher than thresholds for production of Cherenkov radiation. However, because of complicated content of incident cosmic rays, initial distributions of their energies, and spreads of ionization losses, there are restrictions on definiteness of energies (and velocities) of the registered particles (mostly muons). Moreover, such testing installations are rather bulky and heavy.

In the present work instead of layers of Pb, we added to trigger detectors the small threshold detector which made from the same aerogel as the tested detector, installed just behind the tested detector, viewed by single PMT of the same type as for the tested threshold detector, and plays the role of Cherenkov monitor with its total detection efficiency close to 100%. This efficiency level is ensured by the small sizes of the aerogel ($5 \times 5 \times 9$ cm^3) and of the PMT photocathode diameter (~5 cm). In our case, the number of Cherenkov photons in the photocathode sensitivity region (260–610 nm) generated by a muon in the Cherenkov monitor is about 200. Due to the small sizes of the monitor, a sufficient number of photons always hit the PMT photocathode for a signal to appear even when using PMTs with moderate quantum efficiency.

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RELATION OF GAMMA-IRRADIATED NA-BENTONITE CLAY MINERALOGY TO ORIGIN OF GUNASHLI PETROLEUM

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Petroleum is a product of the diagenesis of fundamental organic compounds in organic matter that accumulated with fine-grained sediment in a low-energy environment deficient in oxygen. The diagenesis takes place during burial, under the influences of heat, time and pressure – probably in the presence of clay catalysts[1].

Contempory science does not yet know any microbe which really generates n-C_{11} – n-C_{22} alkanes, phytan, pristan and aromatic hydrocarbons. In present work was studied the smectite dehydration under gamma rays – its relation to structural development and hydrocarbon accumulation in Gunashli oilfield, Azerbaijan. Radiation – induced damage in Na-bentonite clay caused formation of arenes, cycloparaffines, branched and unsaturated hydrocarbons, namely generation of hydrocarbons from Gunashli oil field [2,3].

It was revealed that the process of destruction of silico-alumina nucleus of clay minerals is becoming more active in a particular sequence of cation out let of crystal lattice: $Fe^{3+} > Ca^{2+} > Mg^{2+} > Na^{+} > K^{+} > Si^{4+}$. Exept for the destruction of a solid phase of clays, there is radiolysis of pore water, which results in the formation of free radicals. The catalytic conversion of hydrocarbons of petroleum occurring on contact with irradiated solids. The main essence of radiocatalytic processes is transferring the unbalanced charges formed by absorbed ionizing radiation energy on the surface of the catalyst to the system[3,4]. Under the effect of ionizing radiation valence electrons(F) and hole centers(V) form in bentonite clay crystals.

The experimental results discussed in the work[5] confirm that the $CaCO_3$ – FeO – H_2O system generates the suite of hydrocarbons in characteristic of natural petroleum. Proposed catalyst sodium–bentonite clay (Alpoid deposit contains more than 85% of Na-montmorillonite-(Na,0.5Ca)0.7(Al,Mg,Fe)4(Si,Al)8O20(OH)4·XH_2O) consists of complex oxides and water. This research gives a new approach for study the metamorphism of crude oil [6].

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EVIDENCE OF RADIOCATALYTIC ACTION IN GENERATION OF GUNASHLI PETROLEUM

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The problem of determining the genesis of petroleum is essentially chemical in nature. An explanation must be given for the formation of large numbers of n-alkanes, branched alkans, cycloparaffines, olefins and arenes from the original material throughout geologic history. Biodegradation of crude oil is evidence of early generation [1]. Oil generation commenced at the end of Pliocene and continues at present at depths between 6000 and 12,000 m [2] .

The aim of this study was to investigate the changes of Gunashli petroleum generation on the surface of the catalyst, irradiated with gamma rays. The catalytic role of clay could be explained by facilitating the appearance of intermediate structures. It can be considered that in active status, the catalyst creates a structural availability so that the hydrocarbon molecules can penetrate its pores. Ionic species in the composition of clay acts as unsaturated hydrocarbons, facilitating noncovalent bonds to break under the action of nuclear radiation. Generated carbenium ions due to the acidity ($H^{*+}AlO_3$) of bentonite take part in the transformation process of hydrocarbons [3]. The raw bentonite sample used in these experiments has nanostructured composition [3,4]. The changes taking place in raw bentonite, under ionizing radiation, can be interpreted as involving the creation of a structure with radiation defects. Sodium bentonite has a single water layer containing Na^+ as exchangeable ions (with swelling properties).

The water radiolysis process leads to formation the following primary products:

$$H_2O \xrightarrow{ionizing\ radiation} e^-_{eq}, H^*, HO^*, HO^*_2, H_3O^+, OH^-, H_2O_2, H_2$$

It has been investigated the dynamics of dose –dependent changes in the amount of transformed hydrocarbons. By using the method of SEM, EDX, XRD and FT-IR, spectroscopy has been discussed possible mechanism of radiocatalytic transformation of hydrocarbons under gamma-irradiation in presence of Na-bentonite clay. The stable radiolysis product, H_2, resulted in the above reactive systems, was determined quantitatively by gas-chromatography.

The crude oil samples were irradiated with gamma radiation from the ^{60}Co isotope under static conditions, within vacuum sealed quartz tubes at room temperature. The dose rate was 10.5 Rad/sec.

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VALIDATION OF NUCLEAR DE-EXCITATION MODELS OF GEANT4 TOOLKIT

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Geant4 is a powerful Monte Carlo modeling toolkit [1] to describe the propagation and interactions of particles and nuclei in various media. It was originally designed for experiments at the LHC, but its area of application is rapidly extending well beyond high energy physics to low energy nuclear physics, astrophysics, space science, medical physics and radiation protection [2].

Nuclear reactions induced by hadrons and nuclei are modeled by Geant4 as multistage processes. In particular, the Binary Cascade (BIC) [3] and Liege Intranuclear Cascade (INCL) [4] models are used to simulate the emission of fast particles at the first cascade stage resulting in an exited nuclear residue. Depending on the excitation energy calculated per nucleon of the residual nucleus E^*/A various decay processes take place. At $E^*/A < 2$ MeV the evaporation of neutrons, protons and alpha-particles from residual nuclei [5] is modeled, while the Statistical Multifragmentation Model (SMM) [6] is employed to simulate the decays into nucleons and multiple nuclear fragments at higher excitation energies. Nuclear de-excitation models of Geant4 were validated in its early version of 9.1 [7].

In the present work we validate nuclear de-excitation models of recent Geant4 versions 10.4 and 11.0 by means of standalone tests for specific residual nuclei and excitation energies. Calculation results are compared to measured energy spectra of evaporated neutrons, protons and alpha-particles [8] and to charge distributions of secondary fragments calculated with FORTRAN version of SMM [6]. A detailed analysis of the momentum distributions of SMM products is performed and several suggestions to improve the results of the modeling were reported to Geant4 developers. After the revisions, the latest versions of de-excitation models of Geant4 can be used in our Abrasion-Ablation Monte Carlo for Colliders model (AAMCC) [9] to simulate the properties of spectator matter in collisions of relativistic nuclei.

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TARGET DESIGN FOR EXPERIMENTAL INVESTIGATION OF ADS WITH PROTON AND LIGHT ION BEAMS

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A particle accelerator coupled with a subcritical fission reactor (accelerator driven system – ADS) can realize a safe, clean and efficient source of energy. We showed that in spite of the majority's opinion with respect to the optimal beam for ADS (considered to be proton with energy 1–1.5 GeV) light ion beams at lower energies are more efficient [1–3]. Aspects related with the core structure and composition, the optimal value of the criticality coefficient k_{eff}, the particle beam and the accelerator type were analyzed. The larger pitch to diameter ratio possible to achieve in ADS (~2 for a core cooled with lead or lead bismuth eutectic – LBE) allows to accommodate higher power densities, keeping the coolant velocity below 2 m/s in order to minimize the corrosion effects on the cladding and structural materials. The role of a Be converter with large dimensions (radius 10–20 cm, length 100–120 cm) is emphasized. In the presence of a long Be converter a beam of ^{7}Li with energy 0.2 AGeV is equivalent from the point of view of the net power produced with a beam of 1 GeV proton, and a beam of 0.25 AGeV ^{7}Li is equivalent with a beam of 1.5 GeV protons. This allows to obtain the same net power with a 2.5 times shorter accelerator with lower cost for the power plant building and maintenance. The apparition of a tail towards thermal energy in the neutron spectrum allows to obtain the needed value of the criticality coefficient k_{eff} in a given geometry with a lower enrichment, increases the breeding capability of the core and ensures a deeper burning of the actinides in one cycle. Until 25% of the actinides can be fissioned in one cycle in ADS with Be converter in comparison with 6–7 % that can be achieved in a fast reactor. The analysis of the power evolution after beam stopping and the investigation of possible insertions of positive reactivity during transients concluded that metallic fuel allows a core with keff 0.988, when fuels with melting temperature higher than the clad (as oxide, carbide, nitride) needs a lower value of 0.985 for keff. The maximum energy gain of protons is obtained at 1.5 GeV when they are accelerated in a linac (G ~14), and at lower energy (0.75–1 GeV) when a cyclotron is used. In both situations ion beams starting with ^{4}He realize higher energy gain than protons. Ion beams offer the possibility to obtain energy gain from 25 (with 0.25AGeV ^{7}Li beam) to 45 (with 0.75 AGeV ^{16}O and ^{20}Ne beam).

A proposal for the design of a target dedicated to the experimental study is presented. The design of the experimental target must reproduce at a small scale the situation in a real ADS. The interest is to determine the minimal dimensions and minimal amount of fuel necessary for a correct reproduction of the ratio of the energy released (amount of fissions) produced with proton and ion beams. Two designs are analyzed. In the first, the target consists of rods from enriched U (15% ^{235}U) with diameter 2 cm and length 120 cm, distributed in 6 layers (~200 rods) inside a cylinder from Pb with length 150 cm and radius 70 cm. The central part of cylinder is empty, allowing the placement of different converters. In the second variant the rods are placed in a graphite target, surrounded by a 10 cm Pb blanket. Due to the softer neutron spectrum, the use of graphite target allows to diminish significantly the number of fuel rods (~20 rods with 15% ^{235}U).

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ESTIMATION OF THE DEGREE OF AGREEMENT OF EMPIRICAL RANDOM VECTORS USING CENTRAL MOMENT FUNCTIONS

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A methodology for estimating the degree of agreement M of empirical random vectors (RV):$\nu(k) = (\nu_0, \nu_1, \dots, \nu_l)$ of frequencies$\nu_i(k = i)$ of counts k of registered particles by samples of small volume

$$\sum_0^l \nu_i = n < 20\,,0 \le \nu_i \le n$$

and average $\overline{k} < 5$ was developed.

The degree of agreement of the vectors is estimated by the test statistics of the closeness of the projections of the fractional order functions $1 < S$ of the central moments $\mu(\nu(k), S)$ RV– ν:

$$\mu(\nu, S) = \frac{1}{n-1}\sum_1^l (k_i - \bar{k})^S = Re(S, \mu(.)) + i \cdot Im(S, \mu(.)), i^2 = -1,$$

Where $Re(.)$ and $Im(.)$ is real and imaginary components of the central moments function $1 < S$. As a test statistic to estimate the agreement of projections $\mu(S)$ there was proposed a metric

$$\Phi = \sum_{S_0=0}^{S}\left(\frac{\left(Re(\mu_{1,g}) - Re(\mu_{1,h})\right)}{\left(Re(\mu_{1,g}) + Re(\mu_{1,h})\right)}\right)_i^2 + \left(\frac{\left(Im(\mu_{1,g}) - Im(\mu_{1,h})\right)}{\left(Im(\mu_{1,g}) + Im(\mu_{1,h})\right)}\right)_i^2 \cdot$$

$$\cdot \frac{1}{S_m - S_0}$$

The methodology is based on the mutual one-to-one correspondence of the random vector $\nu(.) = (\nu_0, \nu_1, \dots, \nu_l), \sum_0^l \nu_i = n < 20\,, \nu_i(k = j)$, in the sample and the complex function of fractional order $1 < S_0 < S_m \leq 5$ of central moment of vector $\nu(.)$.

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METHOD FOR PROCESSING AND ANALYSIS OF HOMOGENEITY OF LARGE SETS OF SMALL-VOLUME SAMPLES OF LOW-INTENSITY RADIATION STREAMS

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A method for processing and analyzing sequences of samples of variation series of values of identifiers $I(\nu(.))$ of random vectors (RV) - ν for their corresponding samples of small volume $n \leq 20$ of counts $k_i = 0; 1; 2 \ldots$ of registered particles was proposed. The identifier $I(\nu(.))$ is a functional in the form of a scalar product RV $\nu(.) = (\nu_0, \nu_1, \ldots, \nu_l)$ of frequencies $\nu_i(k = i)$ of values of counts k_i in the sample

$$\sum_0^l \nu_i = n < 20\colon\ I(\nu) = I(\nu|a) = (\nu a) = \nu_0 a_0 + \cdots + \nu_l a_l$$

where $a = (a_0, \ldots, a_l)$ – is not a randomly given vector. For a given number M of vectors $\nu(.)$ the frequency distribution of $I(\nu)$ values represents sequences of ordered groups of peaks formed by:

1) similar in components ν_i RV
2) of homogeneous peaks formed by homogeneous RVs.

To evaluate the homogeneity of RV and peaks, it was proposed a test statistic G and a criterion of agreement based on the metric

$$G = \frac{1}{q}\left[\sum_{l=1}^{l}[(x_{im} - x_{ir})/(x_{im} + x_{ir})^2]\right]^{1/2}, 0 \leq G \leq 1.$$

It was shown that the homogeneity estimation of peaks considered also as random vectors m and $r M_{1,m}, M_{2,m}, \ldots, M_{l,m}; M_{1,r}, M_{2,r}, \ldots, M_{l,r}$ can be performed by the degree of their collinearity $|M_m||M_l|^{-1} \cdot M_m \cdot M_l = cos\theta$, where θ-is the angle between vectors and equality of $|M_m| = |M_r|$ modules.

The proposed method allows identifying combinatorial types of RV, predicting frequencies of their realization $1 < M_j$ and peaks formed by them - also random vectors $M_{jm}, \ldots, M_{qm}$ with

$$\sum_l^q M_{j,m} < 10.$$

The method is effective at $n < 20$; average $\bar{k} < 5$.

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THERMOLUMINESCENCE TRAPPING PARAMETERS OF IRRADIATED K-FELDSPAR

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Isothermal decay of TL glow curve of the irradiated K-feldspars has been investigated at an ambient temperature. A suggested procedure enables the isolation of peaks at the low-temperature region of the TL glow curve. An analysis of the values of the symmetry factor suggests that bimolecular mechanisms are responsible for the kinetics of decay processes, as the values of parameter μ [1] vary around 0.52. The values of the calculated activation energy do not show systematic correlation with the temperature at the investigated temperature region of TL glow curve. The frequency factor values of the isolated peaks change within the physically meaningful figures (within the order of 10^9 to $10^{13} s^{-1}$) and in good agreement with the literature [1]. ESR and TL investigations revealed that [2], when feldspars such as microcline and albite are irradiated at liquid nitrogen temperature, both Al-Oh+ and a hydrogen radicals are formed. As soon as the temperature of the samples rises to room temperature, the hydrogen radical eliminates completely and Al-Oh + -Al centers appear. Thermal annealing at 1000 °C leads to the formation of two new hydrogen radicals which are relatively stable even at room temperature. It has been suggested that they could act as killers for Al-Oh + -Al centers in both feldspars which might be the case in the current situation.

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SIMPLE EXPLANATION OF THE EXPERIMENTAL ^{57}Fe MÖSSBAUER ISOMER SHIFT OF IRON COMPOUNDS

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According to the existing concept, an increase in electron density on ^{57}Fe nucleus must lead to a decrease in Mössbauer isomer shift (IS). The rise of oxidation state of iron (escape of electrons from the valence shell) usually leads to the decrease in IS, which is explained by the shielding effects.

We suggest applying the approach of the valence shell hybridization to explain the regularities of the IS change [1]. It is easy to show that two electrons on 4s-orbital create the electron density at the iron nucleus, which is equivalent to the density created by the full set of fully filled $4s4p^n3d^m$-hybridized orbitals:

$$|\psi_s(0)|^2 = \sum_{i=1}^{1+n+m} \left|\psi_{sp^n d^m}^{(i)}(0)\right|^2,$$

where n = 0…3 and m = 0…5 are the numbers of the 4p and 3d-orbitals involved in the hybridization. Using this property, we can suggest that the directional chemical bonds, which iron cation establishes with surrounding anions, influence on the IS; this influence being independent on the number of the bonds. Assuming that the IS is proportional to the average bond length, we can explain the observed experimental dependencies. At the same time, d and p-electrons do not create a density on the nucleus. But they affect the ionic radius of the iron ion and, consequently, affect the interatomic distances. Moreover, we concluded that the electron shell of each anion of the iron polyhedron can make noticeable additional contribution to the electron density at the iron nucleus. This makes it possible to explain the dependence of the IS on the iron coordination number.

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SEARCH CRITERIA FOR MINERAL DEPOSITS IN THE ZONES OF MODERN AND ANCIENT VOLCANISM ON URANIUM AND THORIUM AND THEIR FISSION PRODUCTS

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In the work, by the method of gamma-spectroscopy [1,2], new data are presented on the deep recharge of the Nizhnechutinsk oil field by ascending gases and hydrotherms with different elemental composition. It has been established that formation waters, as well as oils, are enriched in As, Br, Ba, Re, Ir, Au, REE in the fluid replenishment zones. In this case, the greatest differences relate to the distribution of uranium and thorium over the area of the deposit and over the underlying oil reservoirs.

The results of the studies indicate the overlap and coexistence of deposits of hydrocarbons and ore minerals in the area of ancient volcanism, while the criteria for the influence of the manifestation of deep processes are both the well-known ratios of uranium and thorium (U/Th and/or Th/U) and the established we determined the values of the ratios Th/Ba, Mo/U, Ba/Mo.

The elements Ba and Mo are fission products of uranium and thorium. In this regard, we assume other types of mineralization, associated not with the release of magmas of different composition and post volcanic hydrotherms, but with known exhalation mineralization. According to our ideas, this type of mineralization is accompanied by a constant emanation of radioactive elements U, Th and elements of their radioactive decay along the zones of development of modern and paleovolcanic formations. At the same time, oils in the Upper Devonian deposits are enriched in a number of elements, the associations of which depend on the temperature of the ascending gas flows. Taking into account the results obtained, the search for deposits of solid minerals and hydrocarbons is carried out not only in terms of U/Th, but also according to the new criteria we have established – certain values of the ratios Th/Ba, Mo/U, Ba/Mo in the composition of rocks and accumulations of hydrocarbons.

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HIGH ENERGY IONOLUMINESCENCE DECAY IN Al_2O_3

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Time-resolved ion beam induced luminescence (ionoluminescence, IL) measurements, especially those when the luminescence decay is registered after single ion impact may be efficiently used for real-time characterization of irradiating materials. Temporal resolution of single ion technique, not limited by beam pulse duration has enabled to reveal new interesting features in dynamics of dense electronic excitations in vicinity of swift ion trajectory [1,2]. The start pulses in such experiments are produced using electron emission from carbon foils generated by incoming ion. In this report we present the design of the IL detection system at IC-100 FLNR JINR cyclotron in which the start pulses are formed using electron emission immediately from the target surface. Such approach allows to narrow the instrumental response function and minimize inaccuracy in lifetime measurements arising due to dispersion in ion velocities. The experimental set-up has been used for studies of time-resolved ionoluminescence of intact and pre-damaged Al_2O_3 single crystals during single 1.2 MeV/amu Ne, Ar, Kr and Xe ion impact.

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INFINITE ELECTRON OSCILLATIONS NEAR THE CELL SEPARATOR IN THE SIMPLEST REACTOR

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Today, there are many unsolved mysteries in the physics of atmospheric lightning discharge. The unexplained phenomenon of atmospheric electricity is gamma-ray bursts observed since 1994 by space gamma-ray observatories (for example, BATSE, Fermi), created for observing gamma radiation from astrophysical sources. Mysterious natural gamma radiation of the earth's atmosphere is called Terrestrial Gamma-ray Flushes (TGFs). Long-term observation of TGF made it possible to establish that, apparently, this natural phenomenon is based on the acceleration of relativistic electrons in the electric fields of thunderclouds. Actually, the fundamental phenomenon is the avalanche-like multiplication of fast electrons in matter. This phenomenon was proposed by Gurevich [1], it is called runaway breakdown.

If we investigate the propagation of relativistic avalanches of runaway electrons at a sufficiently large value of the electric field in the case of two adjoining parts of the cloud with opposite directions of the electric field. In the simulation, this configuration can be described as a system of two cells with different field directions and called the simplest reactor. Under certain conditions of the system, the initiation of feedback is possible. Electrons due to the presence of a field in the system will be accelerated, and when they get into the field in the opposite direction, they will turn. Along the way, they will emit gamma quanta, on which the field does not act, thus playing a key role in the formation of a non-stop process.

In this paper, electrons were described that exist in the system and, under the action of a field, can begin to oscillate near the plane of separation of two cells, thereby maintaining feedback in the system of a simple reactor. This relationship can exist even at small cell sizes and small margins. This means that for the explosion criterion in a reactor, not only the gamma feedback is essential, but also electronic communication, contributes to the development of gamma communication.

The purpose of this work was to study the process of gamma and electron multiplication for the simplest reactor, by modeling on GEANT4. The studies were carried out for particles with an energy of 5 MeV at a height of 10 km from the Earth's surface.

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RELATIVISTIC RUNAWAY ELECTRON AVALANCHE ACCELERATION IN COMPLEX THUNDERSTORM ELECTRIC STRUCTURES

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Thunderstorms in the Earth's atmosphere produce short and intense gamma-ray bursts [1]. Such bursts are called Terrestrial Gamma-ray Flashes (TGF). One of possible mechanisms of thunderstorm gamma-radiation – acceleration of Relativistic Runaway Electron Avalanches (RREA) in thunderstorm electric fields [2]. Gamma-rays are produced by relativistic electrons bremsstrahlung.

RREAs are formed by secondary cosmic rays within thunderstorm media. In strong electric fields RREAs are further multiplied by positive feedback mechanisms, which can lead to self-sustainable high-energy particles generation in thunderstorms (infinite feedback) [2,3]. In complex thunderstorm electric structures RREAs are multiplied efficiently due to high-energy particles exchange (reactor feedback) between different electric regions (cells) [3].

In this research, reactor feedback by runaway electron transport between cells is studied. It is shown that runaway electron propagation between cells with its further acceleration and multiplication plays an important role in the RREA dynamics. The conditions necessary for TGF by this mechanism are derived.

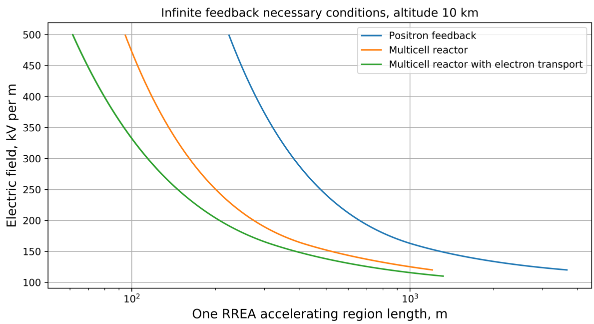

Fig. 1. The comparison of the conditions necessary for TGF development. Blue line – TGF due to infinite positron feedback in uniform electric field, orange line –gamma-ray reactor feedback in the multicell structure. Green line – runaway electron transport between cells.

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COMPTON SCATTERING OF ENTANGLED AND DECOHERENT ANNIHILATION PHOTONS

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At present, positron emission tomography (PET) is one of the most effective instruments for the medical diagnostics. This method is based on detection of two 511 keV gammas produced in positron-electron annihilation in organic tissue. According to the theory, these annihilation photons are in entangled quantum state and have mutually perpendicular linear polarizations. This feature is suggested to be used in future generation of PET-scanners, where the angular correlations of scattered annihilation photons can be applied for suppression of backgrounds and improvement of image quality. It is supposed that the angular correlations are quite different for the scattered annihilation photons in entangled and decoherent quantum states that allows the rejection of decoherent photons and hence to improve the signal/noise factor. Nevertheless, the experimental comparison of Compton scattering of entangled and decoherent annihilation photons was not done till now. We constructed the setup that allows the identification of the quantum state and the study of angular correlations of scattered annihilation photons. First experimental results on Compton scattering of entangled and decoherent annihilation photons are presented.

DETERMINATION OF THE OXYGEN CONTENT IN THE INVESTIGATED SAMPLES USING DELAYED NEUTRON COUNTING TECHNIQUE

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In the present work delayed neutron registration technique have been applied to the issue of oxygen content definition in the samples of the known mass and morphology. For this purpose the set up have been assembled on the neutron physical research channel of Tandem-3M accelerator of SSC RF–IPPE which consists of the charged particles beam deflection system, integrator of the current of charged particles hitting the neutron generating target, primary neutron beam monitor, spectrometer of primary neutrons, pneumatic transport system of the samples under investigation, 4π-detector of neutrons, constructed on the base of helium-3 filled proportional counters and experiment control system. Oxygen content have been determined using comparative analysis of the measurement results of the temporal dependences of delayed neutron intensity after irradiation of the control sample and investigated samples in the fast neutron flux generated in the Li(d,n) reaction from infinitely thick lithium target. Experimental procedure due to the temporary nature of delayed neutron emission phenomenon have been consisted in the carrying out the cyclic consequence of the stages of sample irradiation by neutrons generated from the target, sample movement to the neutron detector and the measurement of the temporal dependence of delayed neutron intensity.

INFLUENCE OF NEUTRON DETECTOR STRUCTURAL MATERIALS ON FAST NEUTRON DETECTION

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Some nuclear reactions on nuclei in neutron detector structural details even so as aluminium are induced with energy increasing. Nuclear reactions induced by neutrons between 5 and 20 MeV energy are under consideration. They causes background events in gaseous and scintillation detectors with ^{3}He, ^{7}Li and ^{10}B isotopes. The events and neatron scattering and nucleus activation disturbs measurement results, leads to detector excitation without neutrons.

Interaction of neutron with an energy of more than 5 MeV with aluminum, silicon and oxygen nuclei as the main materials of new position-sensitive detector is considered. Interaction of neutron with converter nuclei: ^{3}He, ^{7}Li and ^{10}B is considered also.

MEASUREMENT OF YIELDS AND ANGULAR DISTRIBUTIONS OF Γ-QUANTA FROM THE INTERACTION OF 14.1 MeV NEUTRONS WITH OXYGEN, PHOSPHORUS AND SULFUR NUCLEI

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The study of inelastic scattering of fast neutrons by atomic nuclei is of great importance for fundamental and applied neutron-nuclear physics. Reactions induced by neutrons are the unique source of information for describing the processes of strong interaction between nucleons. Inelastic scattering processes are used to study the characteristics of excited states of target nuclei [1]. The practical use of the (n,n'γ) reaction requires the expansion and refinement of experimental data on this process. Research on the inelastic scattering of fast neutrons has recently become more active in connection with new prospects for the production of nuclear energy using fast neutron reactors.

The purpose of the experiment was to refine the available data on the yields and angular distributions of γ-rays from inelastic scattering of 14.1 MeV neutrons by natural composition of oxygen, phosphorus and sulfur nuclei. The work was carried out within the framework of the scientific program of the international TANGRA (TAgged Neutrons and Gamma RAys) project at Frank Laboratory of Neutron Physics of the Joint Institute for Nuclear Research in Dubna (Russia).

Inelastic scattering was studied by the Tagged Neutron Method [2], in which neutrons with an energy of 14.1 MeV produced in the d(t,α)n reaction are "tagged" by detecting alpha particles. Gamma quanta from the (n,n'γ) reaction were recorded by the "Romasha" multidetector system [3]. Experimental data are shown and discussed in comparison with previously published data.

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USING TAGGED NEUTRON METHOD FOR ON-LINE ANALYSIS OF MATERIALS ON CONVEYOR

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This paper discusses the application of the AGP-K conveyor analyzer to solve the problem of controlling the elemental composition of material on the conveyor. The result of the analyzer operation is given and the obtained data are discussed.

The results of using tagged neutron method for on-line analysis of materials on conveyor are presented. The method of tagged neutrons makes it possible to determine the concentrations of the desired elements inside objects contactless, due to the large penetrating power of neutrons.

The Tagged Neutron Method consists in irradiating the object of analysis with beams of fast neutrons with an energy of 14.1 MeV, which are formed in the reaction $d + {}^{3}H \rightarrow {}^{4}He + n$. [1–3] In this reaction, the neutron and the α-particle fly apart in almost opposite directions. Therefore, by registering the α-particle accompanying the neutron, it is possible to determine the direction of neutron departure. This procedure is called tagging of neutron. A fast neutron with an energy of 14,1 MeV enters the substance of the object and interacts with the nuclei of the substance in inelastic scattering reactions (n, n'γ). Since each chemical element has its own characteristic gamma spectrum, it is possible to conduct an elemental analysis of the object under study.

Irradiation of the material on the conveyor occurs by a beam of fast tagged neutrons with an energy of 14 MeV from the ING-27 portable neutron generator manufactured by NL Dukhov All-Russian Scientific Research Institute of Automation (VNIIA), gamma quanta from inelastic scattering reactions are recorded by a system of 14 scintillation detectors based on a BGO crystal. Tagged neutron is carried out by registration of α-particles formed in the reaction $d + {}^{3}\text{H} \rightarrow {}^{4}\text{He} + n$, which makes it possible to reduce the influence of the background by 200 times. The analyzer also includes power systems, data collection systems and biological protection.

The analyzer provides data on the elemental composition of material on the conveyor every 40–60 seconds. The results of the analyzer operation for control of sinter are discussed.

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APPLICATION OF TRITIUM LABEL FOR THE DETECTION OF NANODIAMOND FILMS ON THE SURFACE OF COLLAGEN TISSUE

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Bioprosthetic heart valves based on bovine pericardium are widely used in the field of cardiac surgery worldwide. The main component of bovine pericardium is collagen tissue that is treated with chemical agents to prevent calcification and preserve the elastic properties of the biological tissue. In the present study we tried to improve the mechanical properties of biological tissue by application of additional nanodiamond-based coating and characterized the coating by means of radiotracer method.

Nanodiamonds show high potential application as a drug carrier because of functionally developed surface as well as high specific surface. Moreover, it is possible to introduce tritium label directly bonded with diamond surface by means of tritium thermal activation method. In the present research we used tritium labeled nanodiamonds to measure its mass on the surface of collagen tissue and nanodiamond-based coating stability *in vivo*.

The other problem of xenogenic heart valve prostheses is the development of disease caused by microorganisms. From this view point nanodiamonds can be consider as a carrier of drugs of prologue action. Here we used amikacin and levofloxacin, which were labeled with tritium for determination of its adsorption and desorption from nanodiamond surface *in vitro* and *in vivo*. Peculiarities of nanodiamond-antibiotic adsorption complexes formation and its application onto collagen tissue will be discussed in the presentation.

To prevent calcification process collagen tissue must be coated with biopolymer like chitosan. Tritium labeled chitosan was used for coating characterization in the experiments *in vitro* and *in vivo*.

Thus, preparation and characterization of nanodiamond-antibiotic-chitosan coatings using tritium labeled compounds as well as improvement in the mechanical characteristics that can be reached with such prepared coatings will be discussed in the presentation.

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DEVELOPMENT OF THE CRITERION FOR THE IDENTIFICATION OF CONTRAST AGENTS IN PHOTON-COUNTING COMPUTED TOMOGRAPHY

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The identification of substances is one of the tasks in the development of a new multi-energy X-ray tomograph based on the Widepix detector. The Widepix detector is one of Medipix series detectors, which are hybrid semiconductor pixel detectors, developed by the Medipix collaboration. This detector has a high spatial resolution and is capable of detecting radiation in different energy ranges, which makes it possible to use it in photon-counting computed tomography (PCCT) [1].

This report presents the development and the results of applying a criterion for identifying contrast agents for samples containing various concentrations of lanthanum. This criterion was investigated on the basis of energy information presented in the form of a 2D image and a reconstructed 3D tomogram. The developed criterion is also capable of estimating the concentrations of substances in samples without using the entire energy spectrum, which makes it possible to reduce the time of sample irradiation and the time of data collection.

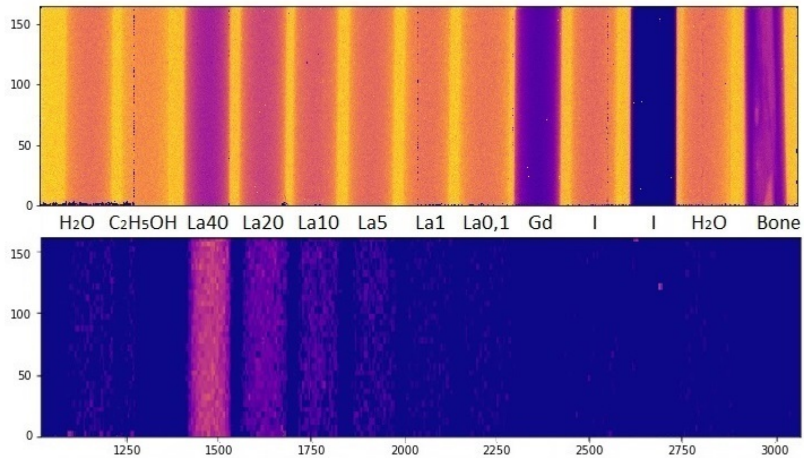

Fig.1. X-ray Images of a phantom with various samples (top) and the same phantom after applying the criterion to select La (bottom).

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NEUTRON RESPONSE FUNCTION OF $CEBR_3$-NAI(TL) PHOSWICH SPECTROMETER FOR 1.0 ÷ 5.5 MEV NEUTRON ENERGY RANGE

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The γ-spectrometer [1] which was assembled from 9 $CeBr_3$-NaI(Tl) phoswich detectors [2] is a unit of the MULTI facility at the FLNR, JINR (Dubna) for studying the γ-emission in exotic decay of neutron-rich weakly bound nuclei like β-decay through giant dipole and pygmy resonances. It was reported [1] a high time and energy resolution, high peak and suppression efficiency of this spectrometer operated in the Compton suppression mode. This report is devoted to neutron detection efficiency and influence of neutron background on γ-spectra, particularly spectra obtained in the Compton suppression mode.

The energy dependence of neutron detection efficiency at E_n = 1.0–5.5 MeV energy range has been investigated. The measurements were carried out by the method of tagged neutrons and ^{239}Pu/^{9}Be source. The α-decay of ^{239}Pu is not accompanied by γ-emission. Only γ-quanta E_γ = 4.43 MeV from the ^{9}Be(α, n)^{12}C* reaction can accompanied the neutrons in about 60% of reaction events. These γ-quanta can be used as a trigger in the method of tagged neutrons and for E_n measuring by Time-of-Flight.

The main characteristics of the γ-ray spectrometer are presented: energy resolutions Δ*E*, *n*-γ detection efficiency δγ(*E*) and $\delta_n(E)$ depending on the γ and *n* energy, respectively. The special attention was focused on the studying of neutron detection efficiency $\delta_n(E)$ of the $CeBr_3$ component of phoswich detectors for Compton suppression mode. The pulse shape analysis of phoswich detector scintillation pulses was carried out by VME unit Mesytec MDPP-16 QDC pulse processor [3]. The neutron detection efficiency was obtained from tagged neutron spectra normalized to published [4] neutron spectra from a ^{239}Pu/^{9}Be source.

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ON THE QUESTION OF NUMERICAL SIMULATION OF THE EXPERIMENT ON COMPRESSION AND HEATING OF A TARGET IN A MAGNETIC FIELD

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The paper discusses issues related to the study of the conditions for the generation of powerful particle fluxes and high-energy radiation in a nonequilibrium plasma with a strong magnetic field, so called magneto-inertial fusion (MIF) [1–7]. Authors have developed mathematical models and computer codes for laser driven – LD MIF and plasma jet driven – PJD MIF target implosion in an externally applied magnetic field [8–14]. Developed numerical method allows one to perform computer simulation for calculation of the magnetized target parameters.

Modeling of physical processes that occur during the interaction of powerful energy flows (density $q \sim 10^{12}$–10^{15} W/cm^2) with the plasma target involves solving the system of equations of magnetic hydrodynamics, the radiation transfer equation, supplemented by the equations of state of substances. Applications such MIF devices for materials technologies, neutron and radiation sources, propulsion systems and others are considered and discussed.

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COMPARATIVE ANALYSIS OF VARIOUS VARIANTS OF MAGNETIC INERTIAL FUSION

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The paper presents a comparative analysis of various variants of magnetic inertial fusion. The main thermophysical parameters of such installations with high-pulse energy lasers and high-speed plasma jets are determined. It is shown that modern thermonuclear plants, as well as those under development, can be used for a wide range of research and directions.

Comparison of various options for the implementation of magnetic inertial fusion allows us to see a wide range of unexplored tasks and, accordingly, the trajectory of action soon. The work also compared laser installations that are used for the implementation of MIF. Namely MagLIF, Z-Machine, NIF and OMEGA. In addition, the article mentioned other installations with a description of their use in various experiments. The paper also talks about some startups of the last ten years that will be implemented soon.

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INVESTIGATION OF CRYSTAL AND MAGNETIC STRUCTURES OF MULTIFFERROIC MATERIAL UNDER HIGH PRESSURE

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Magnetoelectric multiferroics, where a ferromagnetic and a ferroelectric order coexist and are coupled in a single phase, have been a hot topic in condensed matter physics for a long time owing to their ability to facilitate next generation applications. Mainly, understanding of the magnetoelectric effect in single-phase materials is one of the most exciting and interesting topics of research in the solid-state physics. $Pb(Fe_{2/3}W_{1/3})O_3$ (PFWO) belongs to the family of Pb-based multiferroic relaxor ferroelectric complex perovskites ($AB'_{1-x}B''_xO_3$). It is generally accepted that this material exhibits a disordered perovskite structure, where Fe^{3+} and W^{6+} ions are randomly distributed at the centers of the BO_6 octahedra. However, recently studies have revealed the presence of the set of superlattice reflections, which indicates some kind of B-cation ordering in PFWO which had been thought to be totally disordered. It was found that the crystal structure of PFWO should be described by a partly ordered cubic perovskite (i.e. Fm−3m), also, the weak ferromagnetic properties and excess magnetic moment of PFWO can be understood based on non-random distribution of Fe cations between the 4a and 4b sites. Despite intensive studies, understanding the exact nature of its multifunctional properties of PFW has remained a challenge for decades. The knowledge of relationship between magnetic and crystal structure of such compounds, which can be obtained from high-pressure investigations, is very essential for understanding the nature and mechanism of physical phenomena observed in it. In addition, the detail studies of structural changes under extreme conditions were not carried out.

In present work was performed neutron diffraction studies of PFWO at high pressures and low temperature. Neutron powder diffraction measurements at high pressures up to 7 GPa were performed with the DN-12 diffractometer at the IBR-2 high-flux pulsed reactor [FLNP, JINR, Dubna, Russia] using the sapphire anvil high-pressure cell. In order to improve the understanding of the lattice instabilities the Raman spectroscopy studies of the vibration spectra of the compound under pressure up to 30 GPa were performed. The crystal structure of this compound also has been studied by X-ray diffraction at high pressures. Pressure dependences of the volume, unit cell parameters and of magnetic moments of antiferromagnetic (AFM) phase, Neel temperature were also calculated. With increasing temperature and pressure, slight decreasing of the magnetic moments of iron ions in PFWO were observed, however, although the crystal structure remains stable up to high pressures with a space group Pm-3m. Some Raman modes have been found on the Raman spectra, which in such compounds are correlated with the existence of nanoregions, however, with increasing pressure, these modes noticeably widen and vanish.

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COUPLING CORROSION- AND PRESSURE-ASSISTED STRESS BUILDUP WITHIN THE ZIRCONIUM IN PWR PIPES

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The corrosion in the pipelines of pressurized water reactor is a catastrophic event, leading to the ultimate fracture and failure [1,2,3]. Herein, we develop a real-time framework for the accumulation of compressive stresses via coupling corrosion-induced and the internal/external fluid pressure, where the former causes the irreversible (plastic) deformation the latter leads to the reversible (elastic) compression. In this regard, we quantify the real-time infiltration of the oxygen within the metal matrix in the curved boundary, leading to the augmentation in the volume [4] and we compute stoichiometrically the resulted equivalent oxide thickness. Subsequently, we compute the accumulated compressive stress in real time from both elastic and plastic events, which could be used as a measure for anticipation of the onset of mechanical failure. The developed analytical framework could be utilized for quantifying the design parameters for safe operation of the transport pipes, particularly in applications related to the high-pressure and highly corrosive environments.

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CALCULATION OF TARGET COMPRESSION BY POWERFUL LASERS AND JETS IN A MAGNETIC FIELD

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Magneto-inertial fusion (MIF) is based on the heating of a plasma formation consisting of deuterium and tritium, due to the implosion of the target wall (laser beams with high pulse energy (laser driven – LD MIF) or/ and high velocity plasma jets (plasma jet driven – PJD MIF)), passing through a strong shock wave through the target waves (provided that the external pressure exceeds the thermal pressure of the material of the target wall, and the speed of the thermal or ionization wave is lower than the speed of the shock wave), acceleration of the target wall and the generation of a shock wave in the fusion plasma [1–14].

Authors have developed mathematical models and computer codes for LD and PJD MIF target implosion in an externally applied magnetic field. The main plasma and magnetic field parameters along the radial coordinate are calculated. From the numerical point of view this problem is quite complicated. To overcome the difficulties, both significant computing power and the development of special algorithms are required. The numerical method satisfies these requirements. Developed numerical method allows one to perform computer simulation for calculation of the magnetized target parameters.

Modeling of physical processes that occur during the interaction of powerful energy flows (density $q \sim 10^{12}$–10^{15} W/cm^2) with the plasma target involves solving the system of equations of magnetic hydrodynamics, the radiation transfer equation, supplemented by the equations of state of substances

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STUDY OF SORPTION PROPERTIES OF MODIFIED STRUCTURAL MATERIALS FOR NUCLEAR POWER ON GAMMA-QUANTUM BEAMS OF LINEAR ACCELERATOR

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The energy crisis is currently one of the pressing global problems. And one of the solutions to this problem is the use of a highly efficient resource - nuclear energy. The use and development of this resource is constrained by the safety factor in the operation of nuclear reactors. Today, concrete is widely used as a material for radiation protection: it is cheap, it is easy to form structures of various shapes, and it is a good absorber [1]. Radiation shielding concrete is a composite with special fillers. It is widely used for shielding against gamma rays and neutrons due to its good shielding properties and is the biological barrier of choice in nuclear reactors and other nuclear installations. However, despite this, the process of radiation damage to cement, which is part of concrete, and the effect of different concentrations of chemical elements on its radiation resistance are still insufficiently studied. Therefore, the study of materials used to provide radiation protection is an actual direction.

In this work, studies were carried out on three samples of cement with different contents of B_4C, Fe_3O_4 and $BaSO_4$. To study the coefficients of linear absorption of gamma quanta in the samples under study, an Elekta Axesse electron accelerator with gamma quanta energies of 10 and 15 MeV was used as a source of gamma quanta. The samples were made at Cairo University (Egypt). To obtain the linear attenuation coefficients of the samples, the technique developed earlier by the authors was used [2].

As a result, experimental linear attenuation coefficients for samples with various impurities were obtained, and it was shown that cement with a high $BaSO_4$ content is a good absorber of 10 and 15 MeV gamma quanta. However, such samples must be studied for radiation resistance from neutron radiation.

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RADIATION RESISTANCE OF SIC DETECTORS UNDER NEUTRON IRRADIATION

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The results of an investigation of silicon carbide (SiC) detectors when irradiated with neutrons are presented. SiC detectors were manufactured on the basis of the epitaxial layer of 4H-SiC n-type conductivity [1, 2]. The thickness of n-type epitaxial layer was 50 μm. Schottky barrier contacts with a diameter of 3.0 mm were made by vacuum evaporation of a double layer of Ni and Au 10 and 30 nm thick. The initial energy resolution of detectors was < 25 keV for α-particles.

The radiation resistance of SiC detectors was studied experimentally by analyzing their characteristics before and after fast neutron irradiation with integral fluxes of $5.1 \cdot 10^{13}$, $5.4 \cdot 10^{14}$, $3.4 \cdot 10^{15}$ n/cm^2. The irradiation was carried out at the pulse reactor IBR-2M (JINR, Dubna). The α-source ^{226}Ra (E = 4.8, 5.5, 6.0, 7.7 MeV) that was used for calibration and control of spectrometric characteristics of SiC detectors.

It is shown that after neutron irradiation, significant degradation was observed: the peaks from the alpha particles shifted towards smaller channels and became much wider; with an increase in the flux, the energy resolution degrades by two, ten and twenty times; the charge collection efficiency (CCE) decreased from 100% to 96%, 70% and 1% (operating voltage 350 V) at the neutron irradiation fluxes of $5.1 \cdot 10^{13}$, $5.4 \cdot 10^{14}$, $3.4 \cdot 10^{15}$ n/cm^2, respectively.

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THE APPROBATION OF ION-PLASMA TECHNOLOGY FOR REACTOR GRAPHITE DEACTIVATION

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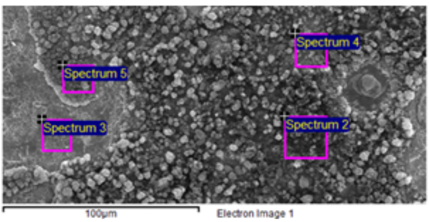
At present time a wide search of effective technology to deactivate reactor graphite is very acute due to the large volumes of accumulated irradiated graphite in the world (about 100 thousand tons) and the challenging problem of uranium-graphite reactors decommissioning period. The ion-plasma technology (IPT) for deactivation of reactor graphite has advantage compared with traditional radiochemistry in versatility (IPT works with any kind of radionuclides) and in the absence of the additional secondary liquid radioactive wastes (IPT buffer media is inert gas forming no chemical compounds with radionuclides). Our technology provides ion sputtering of irradiated reactor graphite surface in the "shortened" microplasma discharge in argon (it is wide known that the dose-forming ^{14}C isotope is localized mainly inside of near-surface layers of reactor graphite blocks). The microplasma discharge is ignited between the reactor graphite (cathode) and the tantalum electrode collector (anode) under discharge parameters: current density (0.001–1) A/cm^2), voltage (300–1000 V), argon pressure (0.01–1 atm.), discharge gap (1–5 mm). During reactor graphite treatment in the microplasma discharge, the graphite surface is sputtered and the sprayed carbon atoms are deposited on the anode surface. The results of SEM analysis of above microplasma exposed collector tantalum electrode surface (Fig. 1.) are concept proving and demonstrating workability of our ion-plasma technology.



Spectrum (atomic %)	C	O	Ta
Spectrum 2	92.83	5.21	1.96
Spectrum 3	79.52	5.61	14.87
Spectrum 4	93.15	4.20	2.65
Spectrum 5	93.71	3.87	2.42

Fig. 1. SEM image and X-ray microanalysis elemental composition of Ta anode surface.

Technology is patented in collaboration of Intro-Micro LLC, Concern Rosenergoatom JSC and Rosatom [1] and is also suitable for Fukushima NPPs accident dismantling efforts.

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SiC NUCLEAR RADIATION DETECTORS AFTER IRRADIATION BY HEAVY IONS AND NEUTRONS

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Silicon carbide (SiC) is very perspective material for fabrication radiation-tolerant electronics, high-temperature electronics as well as for nuclear radiation detectors for working in harsh environments. SiC has obtained increasing interest due to achievement of a high purity level in the crystal structure and considerable thickness (> 100 μm) in the epitaxial layer. SiC is mostly investigated for its physical properties, e.g.: the band gap energy of the polytype 4H-SiC is 3.26 eV, the mean energy of electron-hole pair creation is 7.78 eV, the electron saturation drift velocity is $2 \cdot 10^7$ cm/s and the breakdown voltage is $2 \cdot 10^6$ V/cm at room temperature. Detectors based on high quality epitaxial layer of 4H-SiC show a high radiation hardness, good spectroscopic resolution and can operated not only at room but also at elevated temperatures (~300°C) [1,2].

Our detector structures [3] were prepared on a 25 μm or 50 μm thick nitrogen-doped 4H-SiC layer (donor doping $< 1 \cdot 10^{14}$ cm^{-3}) grown by the liquid phase epitaxy on a 4" SiC wafer (donor doping $\sim 2 \cdot 10^{18}$ cm^{-3}, thickness 350 μm). Circular Schottky Ni/Au contact (diameter 3.0 mm, thicknesses 10/30 nm) to 4H-SiC layer was formed through a contact metal mask, while full area Ti/Pt/Au contact (thicknesses 10/30/90 nm) was evaporated on the other side (substrate).

Electrical characteristic of prepared SiC detectors were measured using Keithley measuring complex, which consisted of 4200A-SCS Parameter Analyzer, 2657A High Power System and CVIV Multi-Switch. Current-voltage and capacity-voltage (C–V) measurements were performed up to 300 V. The reverse breakdown voltage exceeded 300 V and the reverse current was below 10 pA. From C-V measurements the depletion thickness and doping concentration profile were calculated. Spectroscopic parameters were measured with alpha sources ^{226}Ra and ^{238}Pu and FWHM of SiC detectors varied round of 20 keV for 5.5 MeV α-particles energy.

SiC detectors were irradiated by high-energetic beam of heavy ions of Xenon with energy of 165 MeV at the IC-100 cyclotron of the Joint Institute for Nuclear Research (JINR) in Dubna up to dose $1.5 \cdot 10^{10}$ cm^{-2}. We also studied the effect of the degradation of these detectors under impact of neutrons at the neutron reactor IBR-2 (JINR) up to dose $3.4 \cdot 10^{15}$ cm^{-2}.

Prepared SiC detectors shown good energy resolution and high radiation resistance against heavy ions and neutrons and will be used in experiments at JINR.

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THE MEASUREMENT OF THE LOW LEVELS OF RADIOACTIVITY BY LIQUID SCINTILLATION ALPHA AND BETA SPECTROMETER QUANTULUS 1220

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The Quantulus 1220 is a liquid scintillation counting (LSC) system for the quantitative measurement of extremely low levels of alpha and beta activity. With both passive and active shielding, the Quantulus 1220 employs a universal background reduction system which is optimized according to type of analysis.

The active shielding is the asymmetric liquid scintillator guard. The active shielding is used in anticoincidence with the analogue to digital converter (A/D converter). This means that if the guard registers a signal simultaneously with a coincidence signal in the detector the guard detector will inhibit the A/D conversion.

In the Centre of Isotopic Research (CIR) of FGBU "VSEGEI" Quantulus 1220 is used for radiocarbon (^{14}C) dating of various organic objects (wood, peat, soil, bottom sediments, bones), dating young bottom sediments using ^{210}Pb as well as determination the tritium content in water.

The minimum detectable concentration of tritium in water is approximately 1 Bq/L.

The obtained results are presented as the alpha and beta decay spectra of radioactive isotopes with calculations of the specific activities and radiocarbon ages.

POSITION SENSITIVE FAST NEUTRON DETECTOR BASED ON THE DOUBLE-SIDED SILICON STRIP DETECTORS

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A two-coordinate position-sensitive silicon detector of fast neutrons [1] was developed at Joint Institute for Nuclear Research (JINR), Dubna, Russia within the framework of the TANGRA (TAgged Neutron and Gamma RAys) project [2].

The detector is composed of four double-sided 300 µm thick silicon plates with the dimensions of 60×60 mm^2 divided into 32x32 strips on both sides with strip's pitch of 1.81 mm. The X and Y strips of neighboring detectors are connected to each other, forming a single detector unit with 64x64 strips and 120x120 mm^2 size.

To reduce the number of readout channels a special multiplexor electronics has been developed reducing the total number of readout channels to 6: one fast common start signal; four slow position channels (2 for each side) and one clock synchronization channel. The data from the detector are read out and analyzed by a multichannel 100 Mhz digitizer.

The performance of the detector was tested with a 256-pixel ING-27 generator of 14.1 MeV tagged neutrons, which made it possible to reconstruct a 2-dimensional map of the tagged neutron beams. It was also used for measuring the neutron beam profile with the energies of ~4 MeV generated in *d–d* reaction at the EG-5 accelerator.

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SIMULATION OF THE FAST READOUT SYSTEM FOR MCP-BASED BEAM-BEAM COLLISIONS MONITOR FOR NICA EXPERIMENTS

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The event-by-event selection of nucleus-nucleus interactions with well-defined initial conditions of the interaction point (IP) location in the experiment at NICA collider, beam-gas collisions suppression, precise event time definition, as well as control of luminosity, are important both for data collection and for the off-line analysis of the results of upcoming measurements at JINR. For these purposes, the compact Fast Beam-Beam Collisions Monitor (FBBC) based on the micro-channel plates (MCPs) was proposed recently in [1]. Position and time sensitive, multi-anode MCP detectors allow to get, for each bunch crossing, the information on the IP coordinate, on the multiplicity and of arrival times of charged particles formed in the collision.

In the present work, we estimate both the capabilities of the fast, precise timing measurements scheme and, in addition, of the collision centrality determination in AA collisions. The scheme is based on the method of delayed coincidences using high-speed comparators. We carried out the modeling of the system prototype within the framework of the Quartus [2] environment. Results allow us to state that it is possible to determine the response time of the detector with an uncertainty of about 50 ps. Using the coincidence schemes will make it possible to identify the number of spectators and, based on the processing of timing information, to make conclusions about the centrality of interaction in each event.

The estimated speed of the analysis scheme is less than 20 ns per each event. This allows us to propose this FBBC readout system, based on the high-speed comparators, as the fast, bunch-by-bunch crossing pre-trigger, both in terms of the IP position and the class of centrality.

This research has been conducted with financial support from St. Petersburg State University (project No 93025435).

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USING THE TAGGED NEUTRON METHOD FOR DETERMINING THE CONCENTRATION OF CARBON IN SOIL

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Monitoring the content of soil organic carbon (SOC) is one of the most important tasks in the field of global climate change, in the development and implementation of measures aimed at reducing greenhouse gas emissions [1].

Existing methods of soil analysis [2] mainly involve the selection of bulk samples and work in the laboratory, which leads to a significant complication of obtaining analytical results, to additional use of human and time resources, and in some cases to the unreliability and insufficient accuracy of the data obtained.

The tagged neutron method (TNM) [3, 4] can be used for fast nondestructive elemental analysis of various substances and materials, in particular, without sampling. The method uses neutrons with an energy of 14.1 MeV, which have a high penetrating power. An important advantage of the method is the possibility of using portable tagged neutron generators, which makes it possible to carry out field measurements.

We present some results of test measurements and model simulations, which will help to assess the accuracy limits of the method in terms of reproducibility and repeatability of determining the carbon content in mock soil samples using TNM.

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TOF MEASUREMENT OF LOW-ENERGY NEUTRON SCATTERING BY DEFORMED NUCLEI

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The measurement of cross sections for neutron scattering by deformed nuclei in the energy range from 1 keV to 3 MeV is possible on the time-of-flight (TOF) channel of a pulsed neutron source based on a linac proton beam trap. The use of a beam with a duration of 0.3 μs will make it possible to measure neutron cross sections in this energy range with a resolution of (1–30)% over a 50 m span. Using elastic neutron scattering on W sample, the neutron spectrum was measured in the TOF channel of a pulsed source at an accelerator beam current of 1 μA (Fig. 1).

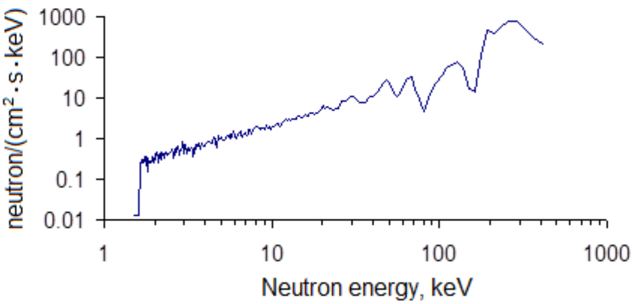

Fig. 1. Neutron spectrum at the 50 m base of the TOF channel of a pulsed neutron source at an average proton current of the linear accelerator of 1 μA.

Measurement of the inelastic neutron scattering cross section at the threshold of excitation of rotational states of deformed nuclei up to 0.5 MeV is relevant for nuclear power engineering. When calculating the dynamics of nuclear reactors, it is necessary to take into account the energy dependence of the neutron strength functions of nonspherical nuclei, which can be determined from the measured total cross sections in the range from 1 keV to 2 MeV. The measured differential cross sections for elastic and inelastic scattering would make it possible to reveal shell effects associated with input states and semimagic numbers.

The measurement errors of neutron cross sections in the TOF channel are estimated. With an accelerator pulsed current of 10 mA and a frequency of 100 Hz, the total cross sections for the Ba and Ce nuclei can be measured with an accuracy of 1% for 1 shift of the accelerator. Differential cross sections in the range of angles from 30° to 150° can be measured with an error of (1–15)% per day of accelerator operation.

ADSORPTION MODIFICATION OF NANODIAMONDS WITH TRITIUM-LABELED CATIONIC SURFACTANTS AND POLYSACCHARIDES

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The radiotracer method is a powerful instrument for studying different physico-chemical processes for example adsorption. Using radiotracer technique allows to quantify tritium-labeled substances up to 10^{-14} mol. Tritium thermal activation technique allows protium substitution with tritium in almost any organic compound without significant changes in its chemical structure [1]. Nanodiamonds modified with biopolymers and antiseptic drugs are prospective modifiers of biocompatible materials [2].

We developed method of obtaining of tritium-labeled hyaluronic acid by tritium thermal activation with specific radioactivity of 52 GBq/g with preserved molecular mass distribution [3]. Method included unlabeled hyaluronic acid dialysis through membrane, hyaluronic acid lyophilization and tritium incorporation by thermal activation. The labeled hyaluronic acid was purified by dialysis that was being controlled by high-performance liquid chromatography.

With use of radiotracer technique with tritium-labeled compounds (alkyltrimethylammonium bromides, miramistin, chitosan, hyaluronic acid) we studied their adsorption on detonation nanodiamonds. We proposed mechanisms of formation of nanodiamond-sorbate complexes with different electrokinetic potential in water suspensions.

The double and triple complexes of nanodiamond with different sorbates under investigation are prospective for biomedical applications. For this purpose, the sorbates retention on nanodiamond was studied in different media including biological-alike media. Using tritium-labeled compounds allowed confident quantification of substances desorbed from nanodiamonds surface and substances adsorbed on nanodiamond surface even in biological-alike media.

Complexes nanodiamond-miramistin-chitosan and nanodiamond-miramistin-hyaluronic acid were obtained and characterized for the first time.

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TRITIUM LABEL IN STUDYING PROTEIN-LIGAND INTERACTION: SELF-ORGANIZATION AT THE INTERFACES

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Tritium is the only radioactive isotope of hydrogen and it is an appropriate radiolabel for organic molecules including surfactants, peptides, proteins and etc. Moreover, tritium as a tracer can be also used for analysis of protein-ligand complex formation at the interfaces, including liquid-liquid system that is a model of cellular membrane. In the present study we developed a novel approach to the study complexes formation between protein and organic ligand at the interfaces as well as in the bulk of the solution. We used lysozyme as a model protein and as an enzyme of medical purpose. Surfactants, including ionic and non-ionic, low and high molecular weight substances and even humic substances, were considered as a ligand.

The procedure of analysis of protein-ligand intermolecular interactions includes two important radiochemical stages. First, studying adsorption of both protein and ligand at the liquid-liquid interface by means of tritium labeled compounds and liquid scintillation spectrometry as a scintillation phase technique [1]. To this end both protein and organic ligand required to be labeled with tritium and we used tritium thermal activation method for radiolabeling [2].

The second radiochemical study includes the bombardment of the protein-ligand mixed adsorption layer with tritium atoms following by the analysis of tritium distribution in the components of the target. In the case of protein, it was subjected to total hydrolysis and determination of the specific radioactivity of each amino acid. On the bases of lysozyme structure phenylalanine and proline were chosen as reference amino acid residues for determining protein orientation in the mixed adsorption layer that was done for the adsorption layers with ionic and non-ionic surfactants.

The developed approach allowed us to reveal the encapsulation of lysozyme with humic substances and in conjunction with classical methods of protein structure analysis to describe completely lysozyme-surfactant complexes. The main results obtained with tritium labeled lysozyme, cationic, anionic and non-ionic surfactants, and humic substances will be discussed in the presentation.

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MULTIPARAMETRIC REGISTRATION SYSTEMS IN RADIOCHEMISTRY

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This paper discusses aspects of the application of multiparametric ionizing radiation detection systems (MPSR) for the analysis of the composition of liquid radiochemical samples. Liquid active samples may occur, for example, in experiments or production processes of hydrometallurgy or activation analysis.

Currently, MPSR are not widely used in radiochemistry, but such a systems are successfully applied in nuclear physics, high-energy physics, biology, medicine. This is due not only to the high cost of such systems, but also for historical reasons. According to the authors, using of MPSR is becoming relevant for online monitoring at hydrometallurgical plants of a new generation, in experiments on radiochemical stands, activation analysis.

By MPSR we mean multi-detector registration systems in which signals coming from detectors are either continuously recorded on a data carrier and/or processed online. An important feature of such systems is the availability of temporary information. Devices called digitizers have become widespread for such systems, which record the signal coming from the detectors in the form of a continuous time series to the storage device, then processed offline. Another common method is to work in "list mode" for each channel, when the signal is pre-processed by classical methods of nuclear electronics and then only the signal amplitude and timestamp are recorded. In both cases, the signal can be represented as a set of amplitude spectra, as well as various coincidences. The paper proposes to use for these purposes the following set of scintillation detectors: beta-, two gamma-, X-ray detector, as well as an immersion silicon alpha detector. Mathematical data processing is supposed to be supplemented by digital filters. The paper discusses the decay schemes of various radionuclides, appropriate choice of detectors, the choice of methods of registration and mathematical processing. The exposure times estimated in trial experiments.

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4π-METHODS FOR TOTAL REACTION CROSS SECTION MEASUREMENTS

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A review and analysis of experimental 4π-methods for total reaction cross section σ_R measurements are presented. The methods for σ_R measurements are based on the 4π-technique of registering prompt γ-quanta and neutrons in a solid angle close to the full angle $\Omega = 4\pi$.

The description the method applied to measuring γ-detection efficiency $\varepsilon(M_\gamma)$ for various values of γ-multiplicity M_γ are presented. The experimental facility and 4π scintillation spectrometer for σ_R measurement are described.

The comparison and analysis of the two experimental 4π-methods developed at FLNR JINR, Dubna for σ_R measurements in the reactions with neutron-rich weakly bound nuclei are presented. The first method is based on the mean value of the detection efficiency $\langle\varepsilon\rangle$ which does not depend on γ-multiplicity M_γ [1]. In the second method, we use the experimentally obtained response function $w_M(k)$ (the distribution of the numbers of triggered detectors in registration of γ-cascade with a fixed value of M_γ) [2].

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FLUCTUATIONS OF THE INDUCED CHARGE CAUSED BY FLUCTUATIONS OF THE X-RAY QUANTUM ABSORPTION POINT IN A PLANE-PARALLEL SEMICONDUCTOR DETECTOR

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The book [1] provides a formula for fluctuations of the induced charge caused by the trapping of electrons and holes in the volume of a plane-parallel semiconductor detector, obtained in [2]. However, this formula was obtained for the case of a homogeneous distribution of X-ray quantum absorption points in the volume of the detector, and does not take into account the attenuation of the X-ray quantum flux as it penetrates into the detector. In [3], an attempt was made to take into account the attenuation of the X-ray quantum flux, but the formula published by the authors contains errors.

In this paper, formulae are obtained for the fluctuations of the induced charge on the detector electrodes caused by fluctuations in the absorption point of the X-ray quantum, taking into account the law of attenuation of the X-ray quantum flux. The obtained formulae demonstrate the role of covariance of induced charge on the detector electrodes caused by random processes occurring in the detector at the registration of X-rays.

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INTERACTION OF SERUM ALBUMIN AND GRAPHENE OXIDE: INVESTIGATION BY TRITIUM PROBE AND MOLECULAR DOCKING

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Graphene oxide (GO) modification with different compounds for synthesis of new materials with specified properties is the field of interest of modern investigation [1]. Since serum albumin is the main blood protein, it is important to understand the mechanisms of its interaction with medical materials. In present work we propose a novel complex approach of studying interactions between bovine serum albumin (BSA) and GO. The approach includes tritium probe method and computer simulation.

Tritium probe method is based on the application of tritium labeled compounds for the to determine the composition of composite materials, as well as to determine the structural organization of protein molecules on the surface of a solid substrate [2].

BSA was adsorbed on the solid of an aqueous suspension of GO. The composition of such prepared material was determined with the help of tritium labeled protein. We observed that BSA strongly adsorbs on GO. To reveal the structural peculiarities of protein on GO surface, the adsorption composite was subjected to bombardment with atomic tritium following by analysis of label distribution in the amino acid residues. Tritium atoms were formed from molecular tritium on the tungsten filament heated by the electric current up to 1830 K.

The experimental results were compared with molecular docking simulation. Molecular docking was performed using AutoDock Vina 1.2.3, LeDock and Hex8.0.0 softwires. Preliminary preparation of the carbon substrate model, minimization of the free energy of GO structure, as well as preparation of protein files for calculation were carried out using ChemBioDraw/3D Ultra 11.0.2., UCSF Chimera 1.15 respectively. The molecular modeling was performed tooking into account the presence of structural defects in GO, the hydrate shell on the surface of the nanocarbon substrate, as well as the formation of a "protein corona" due to protein-protein interactions.

As a result, we determined the composition of BSA-GO adsorption composites in the wide range of protein concentrations. Moreover, binding sites of BSA and GO have been identified, and the important role of histidine in protein retention on the GO surface will be discussed in the presentation.

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Section 7. Synchrotron and neutron radiation sources and their applications

STUDYING NEUTRON SPECTRUM OF PHOTONEUTRON SOURCE OF INR RAS

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A W–Be photoneutron neutron source IN-LUE based on a linear electron accelerator was created and installed at the Institute for Nuclear Research of RAS [1]. The shape of the neutron spectrum and flux estimation was obtained earlier as a result of simulation [2]. Due to the impossibility of measuring the neutron spectrum in a wide range of energies within the source, various methods of spectrum unfolding based on the solution of the inverse problem are usually used.

In this work, the results of unfolding the neutron spectrum into photoneutron source chamber of the source are presented. As experimental data for unfolding, we used the data of neutron activation analysis of samples irradiated in the source. To unfold the spectrum, a number of well-known Nuclear Energy Agency (NEA) programs were used [3], which implement various algorithms for solving the inverse problem.

This work also presents the results of measurements of the neutron flux by various methods, as well as their comparison.

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SYLA – RUSSIAN 4TH GENERATION SYNCHROTRON

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For more than 40 years synchrotron-based x-ray sources as well as free-electron lasers based on linear accelerators have been widely used in materials science, spectroscopy, crystallography, research of fast processes, medicine, molecular biology and biochemistry, medicine, and other applied and scientific tasks. Nowadays state-of-art technologies make it possible to design and develop specialized synchrotron that is especially aimed to generate SR by means of insertion devises, such as ondulators or wigglers. Such specialized circular electron accelerators have been called SR sources of the 4th generation. Currently, there are already several operating [1–3] and a number of such specialized SR sources are under design [4–6]. A number of 3rd generation light sources are under modernization up to 4th generation nowdaus. In order to advance the development of the research infrastructure of the Russian Federation, by Decree of the President of the Russian Federation No. 356 of 25.06.2019, a storage synchrotron (the 4th generation SR source) with an energy of 6 GeV and an equilibrium value of the horizontal emittance of the electron beam of no more than 70 pm·rad (SYLA, former USSR4) is being developed on the basis of NRC KI [7,8]. This paper presents the results of the development of the machine lattice as well as top-up linac injector.

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ROLE OF POLARIZATION IN THE MULTIPLE IONIZATION BY AN INTENSE RADIATION

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When an atom is irradiated by intense electromagnetic field, the first photoionization act initiates the variety of competitive processes, such as sequential ionization, Auger decay, radiation decay and other [1]. As a result, the sample evolves and its evolution depends on radiation parameters: intensity, pulse duration and polarization. The last is often left behind the scenes, in particular, because accounting for the polarization increases number of degrees of freedom enormously. Here we present an approach based on a system of equations for statistical tensors [2], which are equivalent to a system of rate equations for population, but allows to shorten the number of equations noticeably.

The approach is applied to investigate the sequential multiple ionization of krypton at photon energy range 50–80 eV as an illustrative example. The calculations are performed for the pulse parameters close to modern free-electron laser facilities.

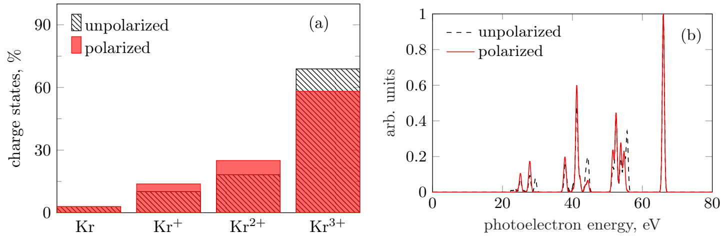

Fig. 1. Ionic yields (a) and photoelectron spectrum (b) for multiple ionization of krypton by the field with energy $\omega = 80$ *eV and fluence 1000 photons/Å²* *calculated for unpolarized and linearly polarized pulse.*

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ATOMIC K-SHELL DOUBLE HOLE CREATION DUE TO ELECTRON CAPTURE AND PHOTOIONIZATION

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Double core hole (DCH) states could be created in two different mechanisms. The first is core subshell electron capture by the nucleus and subsequent shake-process of an electron from the same subshell either to the high unoccupied state (shake-up) or to the continuum (shake-off) mostly due to instant changing of the nucleus charge by unity. Another way is photoionization, when one electron is "knocked out" from the subshell and the residual one undergoes shake-process resulting from changing in screened potential. Physics of the DCH currently attracts interest stimulated by new possibilities of their creation by X-ray free electron lasers and advanced synchrotron sources. Furthermore, DCHs might become a new tool for chemical analysis [1] and plasma diagnostics [2].

In this theoretical contribution we compare the two mechanisms of producing the DCH: *K*-electron capture and *K*-shell photoionization. General theoretical approaches to both problems are known, but we are not aware of such a comparison based on up-to-date models for many-electron atoms. We focus on DCH states in *K*-shell of ^{7}Be and ^{37}Ar (isotopes with natural electron capture radioactivity). The goal is to determine double K-vacancy production probability in both described channels. Also, we analyze shake-off electron spectra and compare the results with different theoretical approaches and experiment.

Our model is based on sudden approximation with the use of fully non-orthogonal sets of electron orbitals in initial and final states, accounting for *j*-splitting of the subshells. Expansions for transition matrix elements are obtained with ZAP_NO package [3]. Radial wave functions are constructed within the multiconfigurational Hartree–Fock method [4]. Photoionization calculations are performed with the use of B-spline R-matrix (BSR) software complex [5].

This research was funded by the Russian Ministry of Science and Education grant No. 075-15-2021-1353. The work of M.D.K. is supported by the Ministry of Science and Higher Education of the Russian Federation (project No. 0818-2020-0005) using resources of the Shared Services “Data Center of the Far-Eastern Branch of the Russian Academy of Sciences”.

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THE PRESSURE EFFECT ON CRYSTAL AND MAGNETIC STRUCTURES OF VAN DER WAALS MATERIALS

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The recent discovery of magnetic ordering in van der Waals (vdW) materials down to the monolayer limit has opened a new direction in the field of two-dimensional materials, allowing researchers to explore magnetism in lower dimensions in simple crystal systems. The advent of long-range 2D ferromagnetism brings about new transport phenomena in two dimensions, like tunneling magnetoresistance and electrical switching of magnetic states promoting 2D ferromagnets as versatile platforms for engineering new quantum states and device functionalities. $CrBr_3$ and Fe_3GeTe_2 are also one of the brightest representatives of this class of materials, which also attract the attention of researchers because of the various observed physical phenomena. The knowledge of relationship between magnetic and crystal structure of such compounds, which can be obtained from high-pressure investigations, is very essential for understanding the nature and mechanism of physical phenomena observed in it.

The present work focuses on the investigations of crystal and magnetic structures of $CrBr_3$ and Fe_3GeTe_2 in wide temperature and pressure ranges. Detailed studies of the crystal structure of the materials were carried out using neutron diffraction on a DN-6 diffractometer of a pulsed high-flux IBR-2 reactor (FLNP, JINR, Dubna, Russia) in temperature range of 6-300 K and at pressure up to 5 GPa. Neutron diffraction investigations of $CrBr_3$ revealed to observe the formation of the long-range ferromagnetic order which leads to the negative thermal volume expansion and anomalous thermal variation of interatomic distances and angles, caused by the spin-lattice coupling. Related effects were found in vibrational spectra of this compound. Noticeable anomalies near the Curie point are observed on the temperature dependences of Raman peak frequencies as well as on their full-width at half-maximum which indicates the strong spin-phonon coupling in $CrBr_3$. The high pressure effect made it possible to identify unusual changes in the diffraction spectra and changes of Raman modes, which may be associated with a phase transition in $CrBr_3$. It was also obtained the evolution of the unit cell parameters, bond lengths under high pressure. The X-ray diffraction of Fe_3GeTe_2 at high pressure revealed anomalies on the baric behavior of structural parameters without clearable structural transition with changing the symmetry. The vanishing of the vibrational modes of Fe_3GeTe_2 at high pressures and low temperature can be caused by the suppression of the long-range magnetic order.

DIFFERENCE BETWEEN DISTRIBUTIONS OF INTERMEDIATE AND SLOW NEUTRON FLUX FROM PHOTONEUTRON SOURCE EXIT CHANNEL

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Distributions of intermediate and slow neutron flux from the output collimated channel of the photoneutron source are measured. A cadmium filter is used to suppress slow neutrons in the measurement of intermediate neutrons. A standard helium counter moved during measurements and the two-coordinate neutron detector based on a thin ^{10}B layer combined with a proportional chamber are used [1]. The significant difference in the experiment is observed in the distribution shape of two neutron groups with energies above and below the cadmium boundary. If the distribution of intermediate neutrons has a symmetrical Gaussian shape, then the distribution shape of slow neutrons is complex. The possible difference of the shapes is discussed.

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NEUTRON TOMOGRAPHY AND DIFFRACTION IN THE STUDY OF THE CULTURAL HERITAGE OF ANTIQUITY AND THE MIDDLE AGES

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The study of cultural heritage by state-of-the-art scientific methods is an important interdisciplinary field. Of interest are archaeological finds made of metal [1, 2]. Such artifacts store valuable information about the technological, economic and social level of ancient states. Corrosion processes occurring in metals also require careful study, because it improves restoration and conservation methodologies. However, research methods traditional in archeology are often unacceptable due to their destructive nature or give incorrect information due to the small depth of penetration. In such cases, neutron tomography and diffraction can be used [3].

In this work, metal artifacts of various ancient states located on the territory of modern Russia (Krasnodar Krai, Republic of Tatarstan, etc.) were studied. Research was carried out at the facilities of the IBR-2 high-flux pulsed reactor: neutron radiography and tomography (NRT), DN-6 and DN-12 diffractometers. Using neutron tomography, spatial variations in the phase composition were visualized, the degree of degradation and the spread of corrosion were determined, and the original appearance of some artifacts was reconstructed. The phase composition was measured by neutron diffraction and Raman spectroscopy. The data obtained made it possible to shed light on aspects of the craft, to identify archaeological objects.

In addition, we have encountered a number of problems, the solution of which requires the use of new algorithms for tomographic reconstruction. This is an improvement in the quality of the resulting models, a decrease in the time spent on routine actions, and a decrease in the time for the experiment. Therefore, modern approaches have been proposed and applied.

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STUDY OF EXTRACTION SYSTEM "N,O-DONOR HETEROCYCLIC AMIDE/EUROPIUM NITRATE" BY EXAFS AND ^{1}H-NMR SPECTROSCOPY

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One of the major problems of nuclear energy is long-term nuclear waste reprocessing and storage. Current technologies are able to partially regenerate nuclear fuel but lead to the accumulation of long-living high-level nuclear waste (HLW). Reducing nuclear waste levels requires the effective and selective separation of minor actinides from HLW possessing high content of lanthanides.

Recently we study derivatives of diamides of 2,2'-bipyridyl-6,6'-dicarboxylic acid, such as **bipy-4Hex** (Fig. 1) as an extraction material. For deeper understanding of extraction process we study the structure of the europium complex of this ligand in crystal and solution, as well as an extraction system with a ligand and europium nitrate.

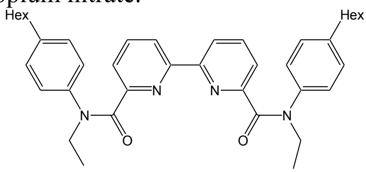

Fig. 1. Ligand bipy-4Hex.

In order to establish the atomic environment of europium we used the experimental EXAFS technique. The absorption spectra of X-ray radiation for crystalline compounds and solutions of europium complexes with nitric acid were measured. Experimental data on X-ray spectroscopy were obtained at the STM station of the Kurchatov Synchrotron Radiation Center. The detection was carried out in the "transmission" mode and by the output of fluorescent radiation. A visual comparison of the XANES spectra confirms the preservation of the degree of oxidation of Eu both in solution and in the crystalline state. Comparison of the Fourier transformed spectra of EXAFS shows the identity of the coordination spheres near Eu ion. In order to clarify the atomic geometry, the EXAFS spectra were adjusted.

In addition, we used ^{1}H-NMR spectroscopy to study extraction systems: the ligand solutions in nitrobenzene-d5 and an aqueous solution of europium nitrate with different concentrations of nitric acid were mixed and the spectrum was obtained from the organic layer. At concentrations of nitric acid 1M and lower only ligand peaks were observed in the spectrum, at higher concentrations of nitric acid, peaks of the complex appeared. For such systems, we calculated the complex-ligand concentration ratio from the spectra and distribution coefficients.

This work was supported by the RSF (project № 21-73-20138).

ACCELERATOR BASED NEUTRON SOURCE VITA

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A compact accelerator-based neutron source VITA has been proposed and created at the Budker Institute of Nuclear Physics in Novosibirsk, Russia. The source comprises an original design tandem accelerator, solid lithium target, and a neutron beam shaping assembly. At present, the facility provides the production of protons or deuterons, the formation of neutron fluxes of almost any energy range: cold, thermal, epithermal, over-epithermal, monoenergetic or fast, as well as the generation of 478 keV, 511 keV or 9.17 MeV photons, α-particles and positrons.

Developed facility became a prototype of neutron sources for the boron neutron capture therapy clinics. The first commercial neutron source is installed at the Xiamen Humanity Hospital in China. The next two neutron sources are made for National Oncological Hadron Therapy Center in Pavia (Italy) and for National Medical Research Center of Oncology in Moscow (Russia).

The facility is used for the development of the boron neutron capture therapy technique, namely: i) to study the effect of neutron radiation on cell cultures and laboratory animals, ii) to treat large pets with spontaneous tumors, iii) to develop dosimetry tools, iv) to test new boron delivery drugs.

The facility is used for a number of other applications, namely: i) for measuring the cross section and the yield of nuclear reactions, ii) for studying radiation blistering of metals under ion implantation, iii) for radiation testing of advanced materials for ITER and CERN, iv) for measuring the thickness of the lithium layer, v) for studying the composition of films by back-scattered protons, vi) for in-depth investigation of the $^{11}B(p,\alpha)\alpha\alpha$ neutronless fusion reaction, etc.

The report will describe the neutron source VITA, present and discuss the results obtained, and declare plans.

This research was supported by Russian Science Foundation, grant No. 19-72-30005.

A LINEAR ELECTRON ACCELERATOR – TOP-UP INJECTOR FOR THE 4TH GENERATION SPECIALIZED SYNCHROTRON RADIATION SOURCE USSR

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The 4th generation synchrotron light source called Ultimate Source of Synchrotron Radiation (USSR-4) is under development at the moment in Russia [1]. Parameters of X-ray radiation of advanced modern Synchrotron Radiation Sources – brightness, coherence and temporal resolution – make it possible to provide experiments to study the structure of the widest range of objects in a variety of disciplines at a qualitatively new level compared to previous generation's sources. New 4th generation source design will be the one of the largest world scientific centers and will require the innovations and evolution in the domestic technologies of magnetic and vacuum systems, the solution of new problems in materials science and instrument engineering.

General facility layout includes 6 GeV main storage ring and a linac for top-up injection. Thus, it is proposed to use the same linac with two RF-guns. First of them will RF photogun and can be used to generate the drive beam for FEL. The second one will RF-gun with thermionic cathode can be used for injection into storage ring. Both injectors will operate with the same regular part of the linac which consists of 110 identical regular sections (see Fig. 1). The planning to have the transverse emittance of 70 pm·rad for the storage ring and less than 1 nm·rad for a FEL.

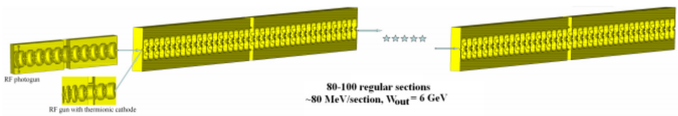

Fig. 1. Layout scheme of the 6 GeV top-up injection linac.

Development of a general layout of the top-up linac with the aim to minimize of the beam energy spread and transverse emittance at the exit, optimization of geometrical and electrodynamical parameters of accelerating structures and analysis of the front-to-end beam dynamics in this linear accelerator will discuss in the report. All results of the beam dynamics simulation carried out using the BEAMDULAC package developed at the Department of Electrophysical Facilities of NRNU MEPhI [2].

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MEPhI's OPTION OF LAB SCALE COMPTON SOURCE

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A development and construction of comparatively cheap and compact (several meters scale) X-ray sources is possible with the help of inverse Compton scattering of laser photons on an electron bunch. Such sources can be used in the field of materials science (new materials, diagnostics of nanostructures at the atomic level), research of nano- and biosystems, medicine and pharmacology (new drugs R&D), physics and chemistry of fast-flowing processes (burning, explosion). It is suggested that compact storage synchrotron will operate with normal conducting S-band top-up linac. Linac will provides bunches with tunable energy in the range of 20-60 MeV to generate the photon flux with tunable energy [1, 2]. The use of a storage ring provides the following advantages: comparatively high average intensity of the generated photon flux, high brightness, photon beam energy tuning in a wide range, high degree of monochromaticity and coherence of the generated photons. There are current results of the design of a compact storage ring for generating the photons in the energy range of 5-30 keV and investigations of the development of relativistic picosecond electron beam dynamics instabilities in the report.

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A LINEAR ELECTRON ACCELERATOR WITH AN ENERGY OF 8-50 MeV WITH INJECTION FROM AN ELECTRON SOURCE BASED ON CLUSTER PLASMA SYSTEMS

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The problem of increasing of the acceleration rate in linear electron accelerators has been one of the key problems for modern accelerator physics for many years. The physical limit of the accelerating field strength for normal (50–100 MV/m) and superconducting accelerating structures (over 200 MV/m) has been practically reached, and therefore various new acceleration schemes are being considered, primarily plasma acceleration and wakefield acceleration [1].

It seems interesting to consider a system in which one can try to bypass the limitations inherent in photoguns (the dominant effect of the space charge in the near-cathode region during injection) and acceleration in the laser-plasma channel (low electron transmission coefficient in the acceleration mode, wide energy spectrum (up to 10%) and low repetition rate pulses, limited by the capabilities of laser systems) [2]. Many works have appeared devoted to the preliminary modulation of the beam in the plasma channel, which makes it possible to improve the spectrum of accelerated electrons by a factor of approximately 3–4 [3].

It is proposed to consider the possibility of using a bunch generated in a laser-plasma channel for injection into a traditional structure based on RF cavities. It is supposed to show that a plasma source of electrons based on cluster plasma can produce a short (from 0.1 to 1.0 ps) bunch of electrons with an energy of several hundred keV [4], which makes it possible to consider such a source as an alternative to the photocathode. Next, the beam must be captured into the acceleration mode in a normally conducting section operating on a standing wave and accelerated to an energy of 50 MeV with adjustable energy.

The features of such a source are considered, including the possible energy spectrum, and features of an electron bunch capturing with the achieved parameters in the acceleration mode will discuss in the report. All results of the beam dynamics simulation carried out using the BEAMDULAC package developed at the Department of Electrophysical Facilities of NRNU MEPhI [5].

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DETERMINATION OF NEUTRON DETECTION EFFICIENCY OF DEMON AND PARIS DETECTORS USING A ^{252}Cf SOURCE

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The results of measuring the energy distribution of neutrons emitted from the ^{252}Cf source by the DEMON and PARIS detectors are presented. DEMON (DEtecteur MOdulaire de Neutrons) is scintillator detector widely used for neutron detection [1]. PARIS (Photon Array for the studies with Radioactive Ion and Stable beams) is new-built detector consisting of $CeBr_3$ - NaI(Tl) phoswich scintillators [2].

The energies of the neutrons were measured by the Time-Of-Flight (TOF) method where a semiconductor detector was used for fission fragment detection and START-pulse generation for the TOF measurements. The STOP pulses for TOF measurements were generated by DEMON and PARIS detectors, respectively.

The energy dependence of the neutron efficiency for DEMON and PARIS detectors at the $E_n = 0.7 \div 7$ MeV neutron energy range were determined by comparing the measured data with standard ^{252}Cf spectrum [3].

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INVESTIGATION OF THE CONDITIONS FOR THE FORMATION OF PARTICLE FLUXES AND HIGH-POWER RADIATION IN A PLASMA WITH A STRONG MAGNETIC FIELD

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Due to the high-energy particles of thermonuclear reactions, the generation of neutron and X-ray radiation is possible, nuclear fusion reactions can occur, in which particles of even higher energies are born (for example, protons with an energy of 14 MeV), the use of which is possible in a number of applied technologies for medicine, safety and disposal nuclear waste.

Plasma maintenance in a highly nonequilibrium state requires a very powerful driver (heating energy source), and therefore one should not count on the fact that such a plasma will provide an energy output that greatly exceeds the driver energy. However, it should be emphasized that the conversion of the energy of the driver into the energy of beams and radiation from the plasma has a very high efficiency compared, for example, with classical accelerator systems.

Also, such a plasma [1-15] that generates neutrons of the megaelectronvolt range can itself be a driver of a subcritical nuclear system, in which (in the chains of transformations triggered by these neutrons) nuclear fuel is produced and waste from the nuclear fuel cycle is simultaneously disposed of. Such a symbiotic "fusion-fission" system achieves a multiple increase in energy output.

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MAGNETIC PHASE DIAGRAM OF Ho FOR FIELD APPLIED ALONG THE [210] DIRECTION DETERMINED BY SINGLE CRYSTAL NEUTRON DIFFRACTION

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Holmium (Ho) is a well-known rare-earth element and its numerous magnetic structures that appear upon application of magnetic field are rather complicated [1,2]. Currently, questions about some details of the true nature of magnetic transitions between them still arise. Ho has the second largest magnetic moment in the lanthanide series, (μ_{eff}=10.61μ_{B}). It also exhibits a significant magnetocrystalline anisotropy and a cascade of magnetic phase transitions below 100K. It also exhibits numerous magnetic phase transitions as magnetic fields applied along different directions vary. Here we report the magnetic phase diagram of Ho in the range temperature of 2 to 100K applying magnetic fields up to 4T along the [210] direction, i.e. perpendicular to the hexagonal axis. Neutron diffraction experiments were performed on a two-axis diffractometer E4 at Helmholtz-Zentrum Berlin (HZB). Comparisons of the phase diagram built from the temperature and field dependences of magnetic Bragg reflections with the magnetic phase diagram obtained from macroscopic magnetothermal properties and calculations within the mean field model show a very good agreement. Preliminary analysis of the data reveal: (i) with increasing the magnetic field up to 4T, the intensity of the (002) nuclear Bragg reflection increases monotonically, indicating the appearance and enhancement of the ferromagnetic component in the basal plane whereas intensities of magnetic reflections significantly dependent on magnetic field and temperature. There seems to be no contribution due to crystal structure modification. (ii) at 4T a small shift of the (002) reflection position indicating a variation in the c-lattice parameter has been observed; (iii) an intriguing observation related to the appearance of the (001) reflection and additional satellite reflections around this position in the L-direction has been made. The existence of such reflections can be related to formation of novel magnetic phases like spin-flip or Fan type.

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URANIUM SPECIATION ON VARIOUS NATURAL SORBENTS: CLAY, GOETHITE, PEAT

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Due to the absolute urgency of the tasks associated with the disposal and storage of radioactive waste, studies of the behavior of actinides in the presence of natural sorbents are currently being intensively conducted. In particular, characteristics of uranium chemistry in natural systems are of considerable interest, since it is the most widely used radionuclide in the nuclear industry. The mobility of uranium in the environment is controlled by the physicochemical species formed under specific conditions. Detailed information about the structure of formed intrinsic phases and surface complexes can be obtained by X–ray absorption spectroscopy (XAS), an element-specific and highly sensitive method implemented on the basis of synchrotron radiation [1]. It is especially important for studying surface complexes and environmental samples, since it is hardly possible to study such systems with extremely low uranium concentration and lack of structure ordering by available laboratory methods [2].

In this work the structures of uranyl cation surface complexes on natural sorbents under various conditions were studied using X-ray absorption spectroscopy. Structural information was obtained from the analysis of EXAFS (extended x-ray absorption fine structure) region of the spectra. It was found that pH weakly affects the speciation of uranium sorbed on goethite and peat, while on clays local parameters of the complexes changed significantly when pH was varied. Structures of uranyl sorption species on clays of different origin are highly dependent on the properties of particular clay studied and pH value. Several types of complexes are formed, the contribution of which changes when the acidity of the solution and the composition of the clay change. In ternary systems with goethite and organic matter, UO_2^{2+} is mainly associated with organic matter, the contribution of direct U-Fe oxide interaction was insignificant.

Obtained data on the local surrounding of UO_2^{2+} in systems with various sorbents would be useful for future investigation of complex environmental samples like contaminated soil, bottom sediments of liquid radioactive waste storage, underground disposals etc.

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THE URANIUM FORMS IN "HOT" PARTICLES USING XANES SPECTROSCOPY

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Chernobyl accident caused a huge radionuclide release into the environment in different forms including so-called “hot” particles. “Hot” particle is the most stable form of technogenic radionuclides in the environment. Fuel “hot” particles mostly consist of uranium oxides with different oxidation state of uranium, also the particles include mobile radionuclides, such as ^{137}Cs, ^{90}Sr, etc. Considering the kinetic stability of “hot” particles, it should be mentioned that this slow radionuclide release continues for many years. The velocity of destruction and dissolution of the “hot” particles strongly depends on uranium forms in it.

XANES spectroscopy is nondestructive method that provides the information on uranium oxidation state. Mixing this method with such non-destructive methods as gamma-spectrometry, scanning electron microscopy, secondary ion mass spectroscopy (SIMS) we are able to establish the dependence of particle stability on its composition and oxidation state.

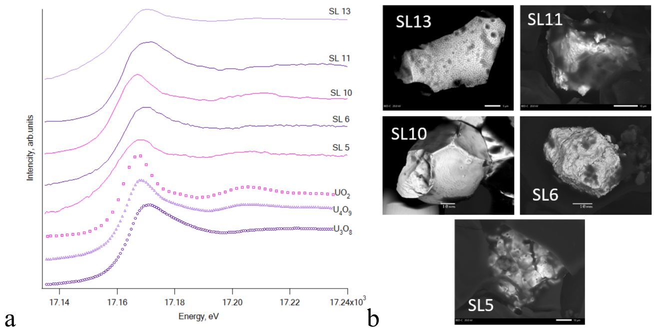

Fig. 1. (a) XANES spectra of Chernobyl "hot" particles (SL) and of standard uranium oxides. (b) SEM images of Chernobyl "hot"particles.

With XANES various forms of uranium in particles were determined, from close to dioxide (SL10) to U_3O_8 (SL 13, 11.6), as well as an intermediate form close to U_4O_9 (SL5) (fig. 1a). The isotope ratios from the SIMS results, as well as the morphological features of the particles from the SEM data (fig. 1b) confirm the XANES data. Therefore, XANES makes it possible to evaluate the kinetic stability of particles based on the oxidation state of uranium.

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PROBING CERIUM AND ACTINIDES PHOSPHATES STRUCTURE BY SYNCHROTRON TECHNIQUES

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Phosphate anion is a crucial component of the life cycle as organophosphate or inorganic phosphate in bone and teeth. Phosphates are ubiquitous in various geologic formations. Besides organic phosphates are often used in different industrial schemes, and the most critical example is nuclear fuel reprocessing (PUREX process). Therefore, the study of actinide (An) phosphates is essential for most of the research fields. Cerium is often presented as a relevant non-radioactive chemical analog of plutonium, neptunium, and thorium due to the closeness of ionic radii. Despite the relatively long history of phosphate-related research, there are still many gaps in the understanding of actinides-phosphates and cerium-phosphate systems. The modern experimental techniques (especially synchrotron based) may help to obtain required information about structural type, oxidation states, chemical resistance etc., and in some cases to revise or expand the previously obtained results. Thus, the purpose of this work was to establish the relationship between the conditions for the synthesis of cerium and actinide phosphates and their structure.

As part of the work, samples of cerium and actinide phosphates were obtained in two different ways. In the first method, phosphates were synthesized by chemical precipitation from 0.1 M Ce(III), Ce(IV), Th(IV), Pu(III), Pu(IV) and Np(IV) solutions. The synthesis was carried out in a NaH_2PO_4 solution taken in excess at pH=1.3. In the second method, phosphates were obtained by hydrothermal treatment of preliminarily synthesized CeO_2 and ThO_2 nanoparticles in a 1M phosphate buffer. Electron microscopy was used to study the morphological characteristics of the obtained phosphates. To decipher the structure of the obtained cerium and thorium phosphates, a set of complementary modern synchrotron methods was used: synchrotron X-ray diffraction, high resolution XANES spectroscopy (HERFD), and EXAFS spectroscopy.

It has been found that, as a result of chemical precipitation from Ce(IV) and Ac(IV), X-ray amorphous gels are formed. Drying of such gel-like precipitates in air leads to their crystallization. The formation of nanocrystalline $Ce^{(III)}PO_4$ with the structure of rhabdophane occurs in the case of precipitation from a Ce(III) salt. Under the conditions of HT treatment in a 1M phosphate buffer medium, the initial CeO_2 and ThO_2 crystallites are reformed into nanocrystalline phosphates with different structures.

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STUDY OF ThO_2 PHASE TRANSFORMATIONS DURING AGING BY SYNCHROTRON-BASED TECHNIQUES

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In recent years, actinide dioxides nanoparticles have attracted significant attention in environmental safety control and the development of new technological schemes. The solubility of actinide dioxides nanoparticles is widely discussed in the literature as it is a substantial process that alters actinide abundance. Thorium dioxide (thoria, ThO_2) could be a model system for studying actinide migration in the environment since it is non-redox sensitive and does not form non-stoichiometric oxides. Prospects for ThO_2 use in the nuclear industry are also widely debated. Well-defined crystalline ThO_2 nanoparticles could form under high temperatures (>100°C). In highly hydrolyzed thorium salts under mild temperature conditions, an ill-defined Th(IV) precipitate is formed (X-ray amorphous ThO_2). The structure of such precipitate and its changes during time-aging remains unclear.

ThO_2(X-ray am) sample was obtained by rapid chemical precipitation method from aqueous solutions of thorium nitrate and aqueous ammonia. To evaluate dissolution and time-related changings in the solid-state, as-prepared ThO_2 sample in form of non-dried suspension were added to 0.01M $NaClO_4$ solution. The pH values of the final suspensions were set to be 2-12. Dissolved thorium concentration was measured by inductively coupled plasma mass spectrometry (ICP-MS) after solid separation. The Th speciation in the solution above the sediment was investigated by the EXAFS method.

The solid phase before and after dissolution experiments has been thoroughly characterized. ThO_2 samples were investigated by synchrotron-based X-ray diffraction (XRD) and X-ray absorption spectroscopy (EXAFS). With the help of synchrotron radiation, it becomes possible to accumulate a large amount of data shortly. Thus, non-dried samples with low crystallinity can be successfully investigated. Transmission electron microscopy (HRTEM), including the cryo-mode, was used to study the morphology of the samples.

The formation of well-defined crystalline ThO_2 nanoparticles from ThO_2 (X-ray am) during time-aging at room temperature was revealed. This transformation depends on the pH value of the solution and on time. The pH value strongly affects the solubility of ThO_2 (X-ray am): the concentration of thorium in the solution decreases from 10^{-3} to 10^{-8} with an increase in pH from 2 to 10. Based on the solubility data the mechanisms of nanoparticle crystallization during time-aging in solution in a wide pH range were proposed.

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STUDY OF THE EXCITATION SPECTRA OF SCANDIUM-YTTRIUM PHOSPHATES DOPED WITH EUROPIUM IONS

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Orthophosphates with zircon structure $REPO_4$ (RE is a rare-earth ion) are well-known due to their excellent electronic, thermal, optical, and luminescent properties. As a result, the phosphates are considered for an application in a large variety of fields. Optimization of phosphates properties for different applications can be achieved by using their solid solutions. By changing the relative concentration of substituted cations, it is possible to influence such characteristics as crystal lattice constants, band gap [1], depth and number of traps [2]. Changing the band gap in solid solutions allows to reduce adverse effect on the luminescent properties of point defects that form discrete energy levels in the band gap.

The studies of the energy transfer processes from the host to RE ions are required to estimate the efficiency of energy conversion into light in case of phosphates application as scintillators or X-ray phosphors. YPO_4 and $ScPO_4$ are wide bandgap compounds with $E_g > 7$ eV [3], and studies of energy transfer process require excitation in the VUV spectral region. Experimental facilities in the channels of synchrotron radiation are most convenient for such purposes.

In this work, we studied the excitation spectra of $Sc_xY_{1-x}PO_4:Eu^{3+}$ (x = 0; 0.2; 0.4; 0.5; 0.6; 0.8; 1) solid solutions of phosphates in the energy range 2.5–10 eV. The values of the optical band gap E_g were estimated by linear interpolation of the excitation spectra onset at the fundamental absorption edge. It was found that the change in E_g in solid solutions is nonlinear and varies from 7.93±0.41 eV to 6.73±0.39 eV, the minimum value of E_g=6.73±0.39 eV for $Sc_{0.2}Y_{0.8}PO_4:Eu^{3+}$. A model for modifying the energy position of the bottom of the conduction band and the top of the valence band is also proposed, which explains the nonlinear change in the optical band gap for the $Sc_xY_{1-x}PO_4:Eu^{3+}$ series.

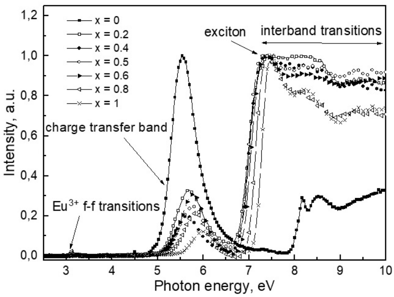

Fig. 1. Luminescence excitation spectra of $Sc_xY_{1-x}PO_4:Eu^{3+}$ in the region 2.5-10 eV, T=300 K.

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Section 8. Nuclear technology and methods in medicine, radioecology

ACTUAL NUCLEAR MEDICINE PROBLEMS IN PEDIATRICS

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The current state and prospects for the development of nuclear medicine in pediatrics was analyzed on the basis of literature data and own experience. The main directions of radionuclide diagnostics and radionuclide therapy in children were considered briefly. There is a quantitative predominance of radionuclide diagnostic studies in pediatric urology compared to studies in oncology. Radionuclide therapy in children are used much less often and mostly for the hyperthyroidism, differentiated thyroid cancer and neuroendocrine tumors.

Currently the most important problem is the exact determination of the individual optimal activity of the radiopharmaceutical administered to a child. The technology is based on body weight and the protocol on a specific device. In the first approximation, this problem is solved by the reference diagnostic levels of activity. At the same time, the impossibility of obtaining an exhaustive solution to the problem of individualization on the basis of the current domestic regulatory documentation was stated, although methods for the refined calculation of the specified activity for the most commonly used diagnostic radiopharmaceuticals in pediatrics have already been proposed and validated by international specialized organizations. In radionuclide therapy for children, optimal activity is determined by the theranostics principles and technologies.

The widespread introduction into clinical practice of hybrid devices for radionuclide research leads to radiation exposure increase to pediatric patients, when internal radiopharmaceutical dose is supplemented by a higher dose of external radiation from X-ray CT. Methods for determining organ and effective doses of diagnostic exposure of children are analyzed. It is noted that the errors in the indicated radiation doses determining on the basis of domestic regulatory documentation and international recommendations reach several tens of percent, what is significantly worse than the other radiation therapy methods accuracy.

When compiling the list of clinical indications for nuclear medical procedures in children, there is the need of taking into account the risk of radiation-induced carcinogenesis. In the case of radionuclide therapy its probability in children is significantly higher. The possibility and expediency of risk assessment based on the concept of effective radiation risk instead of the concept of effective dose is discussed. It also requires the development of appropriate methodological recommendations, including the international level.

The technological and psychological features of nuclear medical procedures in children are discussed together with a higher complexity of their implementation. Practical recommendations for such cases are presented.

ADVANCED HADRON THERAPY TECHNOLOGIES BASED ON THE BINARY NUCLEARPHYSICS METHODS

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The program of development and implementation of new diagnostic and therapy technologies based on the Proton Therapy Complex (PTC) "Prometheus" is presented. The tasks will be implemented with the close integration of the LPI, MEPhI, Center of Radiology of RF, as well as their Russian and foreign partners.

Modernization of Russian-made proton synchrotron complexes of the Prometheus system is envisaged in order to develop and implement new technologies based on them and improve existing technologies for proton and ion therapy and diagnostics. Prometheus is a unique PTC. It is a compact (outer diameter - 5 m, weight – 15 tons) synchrotron for protons with low energy consumption (up to 100 kW), which allows one to place such PTCs directly in medical centers.

It is supposed to develop proton radiography and tomography technologies using the maximum proton energy. Technologies of combined action of various types of radiation (protons-neutrons, protons-carbon ions, multi-ion therapy); targeted proton therapy technologies using promising nanoparticles and systems based on them as therapy sensitizers and active agents for diagnostics.

The latter direction involves a significant expansion of the field of modern nuclear medicine through integration with nanomedicine, which uses nanoparticles for the diagnosis and therapy of cancer, using their unique properties. The introduction of non-radioactive materials that can be activated from the outside using various external sources of nuclear particles to produce radioactivity in situ is one of the new directions of activation of nano-drugs at the site of a cancerous tumor, which can be considered as in situ production of radiopharmaceuticals [1].

Modernization of Prometheus PTC based on the developed nuclear physics technologies, their production for Russian nuclear medicine centers opens the way for solving the issue of development and introduction of new effective technologies for proton and ion diagnostics and therapy.

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ANALYSIS OF CELL RESPONSE TO ULTRAHIGH DOSE-RATE PROTON IRRADIATION

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As is known, the flash effect in radiotherapy with a dose rate of more than 40 Gy/s makes it possible to destroy tumor cells much stronger than normal cells. Additional prospects for flash therapy are associated with irradiation with protons, since protons and ions make it possible to increase the conformality of irradiation compared to irradiation with light particles. A unique feature of the proton beam facility at the Institute of Nuclear Research [1], is that it makes it possible to deliver the total irradiation dose in one pulse with a duration of less than 100 μs. Such a single-pulse flash mode (splash) of radiotherapy may open up additional prospects.

We have carried out a series of several runs of the INR proton accelerator in a wide range of modes: from the conventional mode with an average dose rate $\dot{D} < 3$ Gy/s to the splash mode with $\dot{D} > 10^4$ Gy/s. Two types of tumor cells were irradiated in these experiments: human colon adenocarcinoma (HT-29) and human colon cancer (HCT116). Human adipose tissue mesenchymal stem cells (ADSC) – fibroblasts – were taken as normal cells. Cell cultures were irradiated in the region of the Bragg peak (SOBP) and on the plateau up to the Bragg peak. The task is to carry out a comprehensive analysis of the cell response to various modes of proton irradiation, both using flow cytometry and using another method – real-time PCR. Quantitative PCR was used to analyze the genetic control of apoptosis initiation (BAX, PUMA genes), cell cycle control (CDKN1A gene), and genome integrity control (p53 gene).

According to preliminary results, the levels of expression of genes involved in apoptosis and genome integrity control under flash/splash irradiation differ from those under conventional irradiation both in the studied tumor lines and in normal fibroblasts.

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DEVELOPMENT OF THE SPECIALTY "MEDICAL PHYSICS" IN THE REPUBLIC OF BELARUS

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The main principles and requirements for the introduction of medical physics into medicine in the CIS countries were developed by the organizer of the Association of Medical Physicists of Russia and its first president, Professor Valery Aleksandrovich Kostylev, back in the last century. Now there are medical physicists in the Republic of Belarus.

By the Decree of the Ministry of Labor and Social Protection of the Republic of Belarus dated May 31, 2013 No. 49 "On Amendments and Additions to the Decree of the Ministry of Labor of the Republic of Belarus dated December 30, 1999 No. 159", the position of "Medical Physicist" was introduced in the republic.

The Republican Institute of Higher Education, by changing No. 9 of the National Classifier of the Republic of Belarus 011-2009 "Specialties and Qualifications", approved a new specialty of higher education of the first stage "Medical Physics".

By the Decree of the Ministry of Health of the Republic of Belarus No. 55 dated April 12, 2016 "On approximate staffing standards for the oncological service", the position of "Medical Physicist" was introduced in the republic.

The training of medical physicists in the Republic of Belarus is carried out at the International Sakharov Environmental Institute of Belarusian State University (ISEU BSU, since 2013. In 2017, a master's program in medical physics was organized at the ISEU named after A.D. Sakharov BSU. Master students underwent an in-depth study of all sections of medical radiology. Graduates of the institute work in most oncological institutions of the country, as well as in other institutions of the republic related to dosimetry, radiation safety, processing of information obtained in the diagnosis and treatment of patients, sanitary supervision, metrology, etc. In 2022, more than 80 medical physicists work in Belarus, and their number will increase every year for 10-15 people In addition to practical work in clinics, medical physicists actively participate in scientific research, including projects supported by the IAEA.

In 2018, a postgraduate course for medical physicists was opened at ISEU

BSU. Unfortunately, the specialty "Medical physics" is not yet available in the Higher Attestation Commission of Belarus, and graduate students are preparing to defend dissertations in other specialties of technical sciences.

RADIOACTIVE PARTICLES TRANSPORT AND ABSORBED DOSES DISTRIBUTION IN THE RATS' GASTROINTESTINAL TRACT

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The radioactive ("hot") particles (HP) production can occur in different nuclear accidents. To date, a large amount of scientific data on radiation exposure of humans and other mammals has been accumulated, but information on radiative effect on the gastrointestinal tract (GIT) by HP is not enough.

The aim of the study was to simulate the HP transfer in the gastrointestinal tract (GIT) of laboratory rodents (namely, rats) and estimate doses of internal irradiation. It should be noted that monogastric rodents are widespread in nature and can be used as reference organisms to evaluate the radiative effect on the environment. Besides, their GIT is morphologically similar to the human one.

To study the HP radiative effect on laboratory rodents, the rats of Wistar breed weighing from 200 to 300 g were used. In the experiments the silicate fused radioactive particles gage 80–160 μm got by "uranium", "three-component" and "rhenium" models were used because their radiation characteristics are similar to ones of instantaneous fission products of 10–15 hours age. At the time of the HP intake in animals, the HP specific activity ranged from 3.7 to 7.4 GBk/g (100–200 MCi/g). Figure 1 shows the experimental data on time-depended radiation for all kinds of HP.

The one-compartmental model of HP transfer was applied to estimate time-dependent activity in rat's stomach. Then, dose rates in stomach and intestines were evaluated by two calculation techniques:

a) traditional, using simple semiempirical model;

b) more precise one, based on RADAR rat phantom [1].

Dose rates and accumulated doses were received in 1) source localization, i.e. fundus ventriculi; 2) small intestine; 3) thick intestine. In General, the best consistency of accurate and semi-empirical results is achieved at the source localization point. On the periphery, as you would expect, the discrepancy of results is greater. Here doses are many times less.

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DIAGNOSTIC REFERENCE LEVELS IN NUCLEAR MEDICINE IN RUSSIAN FEDERATION

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Implementation of novel radiopharmaceuticals and methods of diagnostics leads to a corresponding increase in the collective dose of the population and radiation risks from this diagnostic modality. Development of nuclear medicine, especially diagnostic modalities, requires developing and improving radiation protection methods. Radiation protection of the patients from medical exposure is based on the system of diagnostic reference levels (DRLs). DRLs are defined as a specific (usually 75%) percentile of a selected dose quantity distribution for a certain examination. A common approach to the establishment of DRLs in nuclear medicine is to use administered activity (MBq). Additionally, in Russia the effective dose is used as a DRL quantity as well. Despite the fact that DRLs were implemented in Russian radiation protection legislation in 2010 no DRLs were established in nuclear medicine yet. The aim of the study was to establish DRLs for most common nuclear medicine examinations in Russia.

Dose survey was performed in 55 nuclear medicine departments, including 18 positron emission tomography (PET) departments in 14 representative Russian regions in 2013–2018. Data was collected on most common diagnostic nuclear medicine examinations. Data on the examination, radiopharmaceutical and administered activity was collected for at least 10 standard adult patients for each type of examinations for each unit. Typical administered activities were estimated as an average for the standard patient sample for each unit. The effective dose was calculated using conversion coefficients from administered activity of radiopharmaceutical and does not accounts for dose from external exposure (i.e. from the computed tomography scan in hybrid imaging). DRLs were established as 75%-percentiles of administered activities and effective dose distribution samples for 14 examinations: whole body scan with ^{123}I-MIBG (325 MBq, 4.2 mSv), thyroid scan with ^{99m}Tc-pertechnetate (150 MBq, 2 mSv), parathyroid scan with ^{99m}Tc-MIBI (600 MBq, 5.4 mSv), bone scan with ^{99m}Tc- phosphates and phosphonates (600 MBq, 3.4 mSv), renal scan with ^{99m}Tc-MAG3 (150 MBq, 1 mSv), renal scan with ^{99m}Tc-DMSA (120 MBq, 1 mSv), renal scan with ^{99m}Tc-DTPA (200 MBq, 1 mSv), lung scan with ^{99m}Tc-MAA (185 MBq, 2 mSv), liver scan with ^{99m}Tc-IDA (130 MBq, 2.2 mSv), liver scan with ^{99m}Tc-colloids (140 MBq, 1.3 mSv), myocardial perfusion^{99m}Tc-MIBI (500 MBq, 4.5 mSv), whole body PET/CT with ^{18}F-FDG (350 MBq, 6.6 mSv), brain with ^{18}F-FDG (200 MBq, 3.8 mSv), brain with ^{11}C-methionine (500 MBq, 4.2 mSv). Presented DRLs were approved by the Russian radiation protection regulator in 2021.

THE PIPLAN2021 PROTON AND CARBON ION RADIATION THERAPY TREATMENT PLANNING SYSTEM

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This paper describes the main features of newest version of the PIPLAN Proton-Carbon Ion Radiation Therapy Treatment Planning System. The PIPLAN 2021 code [1] was assigned for precise Monte Carlo treatment planning for heterogeneous areas, including lung, head and neck location. Three various computer methods are used to modeling the interactions between the proton and carbon ion beam and the patient's anatomy to determine the spatial distribution of the radiation physical and biological dose. The first algorithm is based on the use of the RTS&T 2021 precision radiation transport code system. The RTS&T [1] code (Radiation Transport Simulation and Isotopes Transmutation Calculation) was assigned for detailed Monte Carlo simulation of many particle types (γ, $e^{\pm}$, p, n, $\pi^{\pm}$,$K^{\pm}$, K_0^L, antinucleons, muons, ions and etc.) transport in a complex 3D geometry's with composite materials in the energy range from a fraction eV to 20 TeV and calculation of particle fluences, radiation field functionals and isotopes transmutation problem as well. A direct using of evaluated nuclear data libraries (data-driven model) (ENDF/B, ROSFOND, JENDL, BROND, TENDL etc. - total 14 libraries) to N, d, t,^{3}He,^{4}He particles transport and isotopes transmutation modeling in low and intermediate (E<200 MeV) energy regions is the general idea low-energy part of the RTS&T code. In general, this approach is limited by the available evaluated data to particle kinetic energies up to 20 MeV, with extensions up to 30 MeV or 200 MeV. To generate the output characteristics of secondary particles in NA-interactions in the energy region exceeding 200 MeV, as well as to model acts of inelastic hA- and AA interactions in the entire range of energies under consideration, software implementations of the JQMD model (JAERI Quantum Molecular Dynamics) were used and the cascade-exciton model (CASCADE), including the generation of nuclear fragments in both the post-cascade and fast stages of the reaction (up to the complete break-up of the nucleus). In the process of transport simulation, the decay processes of metastable fragments with the subsequent transport of decay products were considered.The second and third algorithms are based on the original Bortfeld's [2] and Ulmer's [3] methods for primary proton beam and adapted these algorithms for primary carbon ion beam.

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NEW APPROACHES TO THE MODERNIZATION OF TECHNOLOGIES FOR RADIATION STERILIZATION OF BIOIMPLANTS

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Modern requirements for the quality of bioimplants combine the need to ensure not only the necessary osteoinductive potential, adequate structure and mechanical strength, but also guarantees the safety of the recipient due to the high level of sterility of the plastic material.

Among the currently used technologies for the sterilization of biomaterials, radiation exposures occupy an increasing volume [1]. However, the presence of pronounced dose-dependent side effects that can lead to deterioration of all of the above vital properties and characteristics of bone implants determines the need for further improvement of radiation technologies.

One of the promising solutions is the development of combined technologies that combine, along with radiation treatment, other types of physico-chemical effects with a pronounced resultant synergism of sterilization action. As the author's research has shown, one of such promising combinations is two-stage treatment (ozone + radiation) [2]. Further development and improvement of the new technology is carried out in several directions. Firstly, the optimization of the impact parameters at each of the stages. Secondly, the choice of optimal sources (ozone, radiation) effects to ensure the quality of manufactured bone implants, including the characteristics of the surface layer of bone samples [3,4] (relief, microarchitectonics, mechanical characteristics, elemental composition, etc.).

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DEVELOPMENT OF FAST NEUTRON THERAPY TPS

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NIITFA is participating in development of new fast neutron machine for external beam therapy. It's based on C-arm gantry and D-T neutron generator. So overall design is very close to conventional x-ray LINACs and rises similar problems of dose calculation. Due to unavailability of commercial treatment planning systems (TPS) for fast neutron dose calculation, development of new TPS has been started recently. The TPS architecture is based on brachytherapy PlanB (RT7 LLC) system [1]. Planning tab graphical user interface can be seen on Figure 1.

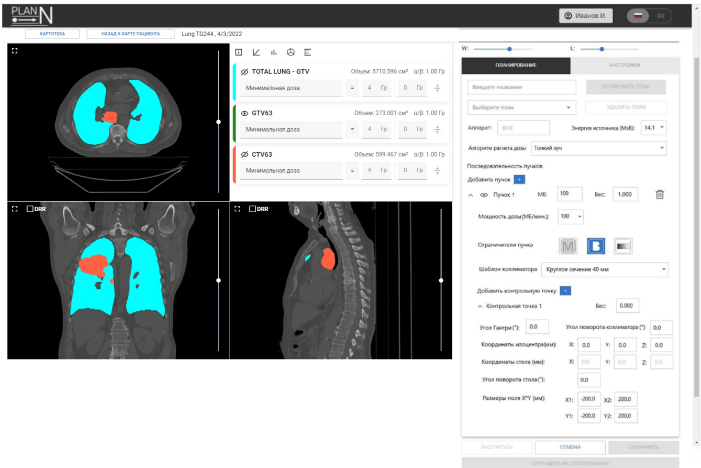

Fig. 1. Dose planning tab in developing TPS.

Dose calculation engine will be based on pencil beam (first step) and Monte-Carlo simulation (second step). Pencil beam algorithm is currently under implementation in system. Monte-Carlo calculations will use external general-purpose radiation transport code with dose calculation broker/pipeline, controlled by TPS server.

Developing TPS also can include numerous modern approaches for dose calculation, radiobiology models, dose optimization, etc. as it Russian-based and open for collaboration. But the main goal is clinic-ready TPS for external beam fast neutron therapy and we believe it will be available in close future.

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DEVELOPMENT OF SIMPLE TREATMENT PLANNING SYSTEM BASED ON TOPAS MC GEANT4 CODE FOR FAST NEUTRON IRRADIATION

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At present, NIITFA is developing a new medical device for fast-neutron radiotherapy based on the 14.1 MeV neutron source NG-24[1].

The neutron source NG-24 was simulated in the Topas MC Geant4 environment. The simulation result was compared with the previously obtained result from the MCNP code[2].

A Python console program for running multiple Topas simulations has been developed. The developed program supports the following functions: setting several irradiation fields (SDS, gantry rotation angle), loading the patient's CT and HU-ED curve for Geant4 simulation, viewing the received dose distributions in transverse coronar and siggital projections

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THE DOSIMETRY OF FLASH PROTON BEAMS

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Proton flash therapy with high dose rates is at the forefront of cancer treatment. The phenomenon of flash effect is to reduce the damage to normal cells with an extreme dose rate increase of over 40 Gy/s.

Radiobiological experiments aimed at studying this phenomenon may require a special dosimetry equipment [1].

Our work consisted of the formation system settings [2] including the spread-out Bragg peak (SOBP) localization and measuring the absolute values of the absorbed dose in the SOBP region in the water phantom PTW MP3-P T41029.

We used PTW Advanced Markus Chamber Type 34045 ionization chambers (IC) in pair with Scanditronix IC-10 connected to a PTW MULTIDOSE electrometer for relative dosimetry.

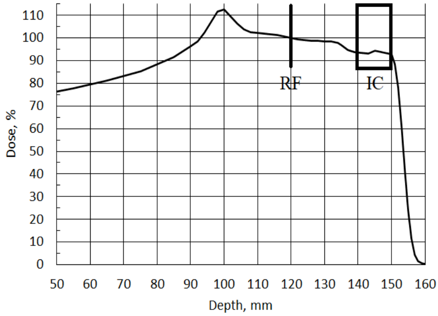

Fig. 1. Depth dose distribution and the corresponding location of radiochromic film (RF) and Ion Camber (IC) for absolute dosimetry.

For absolute dosimetry, we used a PTW 31010 IC and GafChromic EBT-XD films. The measured SOBP and the detectors' location is shown in Figure 1. The result corresponds to a decrease of IC dose referred to film values by 15% in the conventional dose rate. At a dose rate above 50 Gy/s, the response of the films is an order of magnitude greater than the corresponding radiochromic film data. It indicates the impropriety of using ionization chambers in radiobiological experiments with proton beams at high and ultrahigh dose rates.

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SIMULATION THE EFFECT OF ^{11}B ISOTOPE ON THE PROTON AND ALPHA PARTICLE DOSE DISTRIBUTIONS USING MONTE CARLO METHOD

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The advantages of proton therapy make it useful for treating tumors located in the regions that surround radiosensitive tissues and, in the tissues, where surgical access is limited [1]. Recent studies [2-3] have indicated that Proton-Boron Capture Therapy (PBCT) induces tumor cell death through three alpha particles via the reaction between proton and ^{11}B. When a proton reacts with boron (^{11}B) based on the following equation, the ^{11}B changes to ^{12}C in an excited state. Then, the excited carbon nucleus splits into an alpha particle with the energy of 3.76 MeV and ^{8}Be. Finally, ^{8}Be splits into two alpha particles each with the energy of 2.74 MeV.

$$^{11}B + p \rightarrow {}^{12}C \rightarrow {}^{8}Be + \alpha \rightarrow 3\alpha + 8.7\ MeV \quad (1)$$

The therapy results can be more effective than proton therapy if the energy deposition due to the alpha particles and the proton's Bragg-peak in the tumor regions could be matched. Of course, further studies are needed to evaluate the use of PBCT in clinical practices. It is also important to investigate secondary particles in radiotherapy. Secondary particles such as neutrons and photons can be produced by the Coulomb interaction of protons with atomic electrons, elastic nuclear scattering, and the passing of protons through tissues. The main aim of this study was to determine the dose of protons and alpha particles for boron different concentrations, investigate the role of secondary particles in the PBCT treatment method as compared to the conventional proton beam therapy using Monte-Carlo simulation package FLUKA. To do so, first, the variation of the Bragg-peak dose and the depth of protons were examined depending on the boron concentration and the proton energy. The doses of these particles were calculated for boron concentrations in the range of 1; 1,5; …; and 5% and different proton energies including, 60; 90; 120; and 150 MeV.

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SIMULATION OF THE PROTON BEAM FACILITY AT INR RAS USING THE TOPAS PROGRAM

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Proton therapy is currently attracting additional interest from specialists due to the possibility of using some proton accelerators in the FLASH mode with a dose rate of more than 40 Gy/s. The FLASH effect opens up new advantages for radiation therapy due to the predominant destruction of tumors. The proton beam facility at the INR of RAS makes it possible to achieve a record mean dose rate for proton accelerators, up to 10^6 Gy/s [1]. The calculation of the characteristics of a proton beam facility in extreme conditions is a necessary step in the experiments carried out on it. As is known, the Monte Carlo method is one of the most accurate and widespread methods for calculating the interactions of radiation with matter. Previously, we compared some options for using this method [2]. In this work, the beam-forming system of the INR beam facility is modeled using the TOPAS software package. Among the features of this program, one can single out the possibility of calculating the linear energy transfer (LET), which in proton therapy affects the relative biological effectiveness (RBE) of irradiation. Examples of calculation of LET for a real modified Bragg peak (Fig. 1) and effective dose for various models [3] of the dependence of RBE on LET (Fig.2) are presented and compared with the absorbed dose $D(z)$.

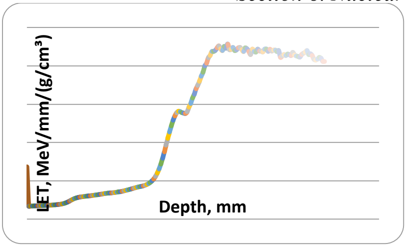

Fig. 1. Dependence of LET on depth in a water phantom.

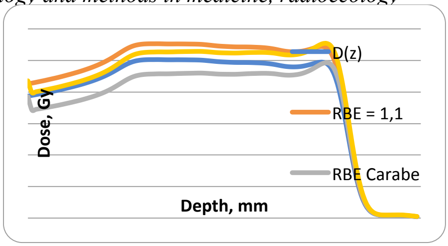

Fig 2. Biological effective dose for the HT29 cell line.

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ADAPTIVE RADIATION THERAPY METHOD USING CONE BEAM COMPUTED TOMOGRAPHY

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There are situations at prolonged treatment when patient loses weight, tumor changes its size or new lesions appear. In this case adaptive radiation therapy (ART) is necessary. This concept takes into account the changes of patients' parameters and involves the recalculation of the treatment plans using new set of images. In this phantom study the ART method with using cone-beam computed tomography (CBCT) was developed.

CBCT doses for head and neck, chest and pelvis sites were calculated for small and big size of the heterogenic phantoms [1]. Deviation between the calculated CBCT doses and the reference doses was determined. The long-term stability of the ratio between Hounsfield Units and Relative Electron Density (HU-RED) for CBCT was investigated [2].

The deviation of the average dose in the target, for the plans on the CBCT with HU-RED for corresponding size and protocol, from the reference dose was less than 0.5% and 1.5% for pelvis and head and neck, respectively. For lung the deviation of the average dose in the target is 2% from the reference dose only using the methods of the HU-RED correction.

HU-RED curves for XVI *Elekta Synergy* have good long-term stability.

The ART method using the CBCT was developed using X-Ray Volume Imaging (XVI) *Elekta Synergy*. This method allows to estimate consequences of pediatric patients' anatomy changes and to recalculate new radiotherapy plans without additional scanning on the computed tomography (CT).

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DETERMINATION OF TREATMENT EFFICIENCY OF HEAD-AND-NECK CANCER BASED ON TCP MODEL

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External beam radiotherapy based on volumetric modulated arc radiotherapy technic delivery is widely used for the treatment of the locally advanced head-and-neck cancer (LAHNC). There are some approaches of irradiation of LAHNC, for example, simultaneous integrated boost (SIB) and sequential boost (SEQ) [1]. Analysis of the developed treatment plans based on tumour control probability (TCP) models (Niemierko's TCP model [2]) could help to estimate expected efficiency of the developed plans and to find optimal treatment schemes with respect to total dose value, fractional dose and overall treatment time (OTT).

In this study, the simultaneous integrated boost VMAT (SIB-VMAT) plans and sequential boost VMAT (SEQ-VMAT) plans were developed and obtained values of TCP based on the anatomical data of 11 patients.

The anatomical data of 11 patients with LAHNC (larynx, oropharynx and oral cavity) were used. For each patient two treatment plans were developed, SIB-VMAT (70 Gy to tumour, 50 Gy to lymph nodes, 25 fractions) and SEQ-VMAT (70 Gy to tumour, 50 Gy to lymph nodes, 35 fractions). The developed plans were analyzed using the Niemierko's TCP model with Maciejewski's parameters (TCD50 = 70.26 Gy) taking into account dose-volume histograms and OTT.

The developed SIB-VMAT and SEQ-VMAT plans had the physical coverage of the CTV tumours more than 97% of prescribed dose delivered to more than 97% of the volume, except one. The average TCP value of SIB-VMAT was equal to 99.9% due to short OTT. The average value of TCP for SEQ-VMAT was equal to 61.0%. For one patient, the both SIB-VMAT and SEQ-VMAT plans showed zero expected efficiency due to CTV coverage 95%–95%.

According to the Niemierko TCP model using Maciejewski's parameters, the 50% efficiency of the treatment could be reached at EUD equal to EUD = 70.26 Gy, when the prescription dose values higher than 71–72 Gy or 70 Gy delivered in less than 35 fractions. The analysis of selected clinical trials showed that the reported results of treatment efficiency rather well correspond to the model predictions. However, the results of DVHs calculated for real patients' anatomical data showed that even small volumes of the tumour that were irradiated to doses less than 70 Gy in 35 fractions could significantly decrease the expected TCP value. The results of simulation and analysis of clinical practice show that the DVH of each patient should be analyzed on the expected TCP.

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VERIFICATION PHANTOMS FOR DYNAMIC RADIOTHERAPY PLANS

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Currently, verification phantoms for the verification of radiation therapy plans represents a rectangular or cylindrical solid body made of water-equivalent material with a rectangular hole for inserting a matrix detector. The most famous examples are the MULTICube phantom [1], which is a rectangular solid body made of plastic water (water equivalent with an error of ≤ 0.5%), which has several configurations, which allows you to install the MatriXX matrix detector [2] in the phantom body in a position corresponding to the region of interest; ArcCheck phantom [3], which is a cylindrical solid body made of polymethyl methacrylate with a built-in spiral grid of detectors, and having a cavity for inserts made of tissue-equivalent materials; Octavius 4D phantom which is a solid cylindrical body made of polystyrene (water equivalent with an error of ≤ 2%) with a rectangular hole in the center of the cylindrical phantom for inserting a matrix detector.

The analysis showed that a significant drawback of these devices is that their use for the verification of the patient's treatment plan does not give an accurate idea of the absolute dose values in the phantom volume (patient's body), since they use the cross-calibration coefficient and thus neglect a number of quantities that can affect the delivered absorbed dose.

The authors consider it expedient to develop a method for verifying radiation therapy plans, which makes it possible to improve the quality of verification of radiation therapy plans through the use of a cross-calibration coefficient determined taking into account the value of the radiation output of a medical linear accelerator immediately at the time of this procedure.

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COMPARATIVE ANALYSIS OF DOSIMETRIC PLANS WITH SIMULTANEOUS DOSE ESCALATION FOR PROSTATE TUMORS IN THE APPLICATION OF BIOLOGICAL AND PHYSICAL OPTIMIZATION FUNCTIONS

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Purpose of the work. a comparative analysis of radiation therapy (RT) plans with simultaneous dose escalation for prostate tumors in the application of biological and physical optimization functions.

Research methods. In this research, dosimetric plans with volumetric modulated arc therapy (VMAT) were developed for nine patients diagnosed with prostate cancer in the Simultaneous integrated boost (SIB) mode. RT was conducted in the following fractionation mode: the prescribed dose per course of radiotherapy for SIB was 75 Gy, the number of fractions was 25, so that the single focal dose was 3 Gy for PTV1 (prostate region), 2.5 Gy for PTV2 (prostate and seminal vesicles) and 2 Gy for PTV3 (prostate, seminal vesicles and regional lymph nodes) [1].

Dosimetric planning for SIB was performed in the Monaco environment (version 5.51.10) using VMAT. All the dosimetric irradiation plans had the same technical calculation parameters. Several therapeutic plans with different optimization functions were created for comparative analysis: physical; biological; a combination of physical and biological optimization functions. The acceptable level of prescribed dose was greater than 95% of the volume of each treatment site. A maximum dose of 107% of the prescribed dose was allowed for <2% of PTV1. Dose volume limits for OAR: for rectum: $V_{74}\leq15\%$; $V_{69}\leq20\%$; $V_{64}\leq25\%$; $V_{59}\leq35\%$; for bladder: $V_{74}\leq25\%$; $V_{69}\leq35\%$; $V_{64}\leq50\%$; for femoral heads: $V_{45}<10\%$ [2].

Results. The dose distribution in the clinical target volume for all VMAT-SIB plans was in the range of at least 95% of the prescribed dose covering at least 95% of the target volume. Radiation exposure levels to OAR did not exceed tolerated levels. A comparison of dosimetric plans showed that the best optimization of the PTV1 is achieved when only the physical functions are used. However, OAR receive less dose when only biological optimization functions are used.

Conclusion. The dose distribution results have shown that it is possible to create clinically acceptable dosimetric plans when only biological or physical optimization functions are used separately. Comparison of the obtained results shows that the most optimal dosimetric plan is achieved when using a combination of biological and physical optimization functions.

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MEASURING THE RADIATION YIELD COEFFICIENTS OF SMALL FIELDS WITH IBA DETECTORS

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The objectives of this work are: measurement of the data set of coefficients of radiative output (Output Factors - OF) using five detectors and data validation; determine how OF changes when using two types of field formation, namely, collimator shutters and a multileaf collimator (MLC); investigate the dependence of the output factors on the source-to-surface distance (SSD) and measurement depth, as well as on the type of detector used in the measurements.

The measurements were carried out in 6 MV photon beams with a smoothing filter on a TrueBeam linear accelerator. Five IBA detectors were used: two diode detectors (PFD and SFD) and three ionization chambers (CC 01, CC 04 and CC 13). Margins varied from 10cm x 10cm to 1cm x 1cm. Measurements were made with various combinations: SSD = 100cm and depth = 10cm, SSD = 95cm and depth = 5cm. The fields were formed by collimator shutters and MLC.

The radiation yield coefficient increases with decreasing SSD and measurement depth. An unshielded SFD diode detector has an insufficient response at low fields, a shielded PFD diode, on the contrary, has an excessive response. Ionization chambers have insufficient response at a field size of 1 cm x 1 cm due to their finite volume. At a field size of 1 cm x 1 cm, for any given SSD and depth, there is a large scatter in measured output factors between detectors. A particularly weak response in this field is observed in the CC13 ionization chamber with a volume of 0.13 cm3, which is largely due to the effect of volume averaging; this chamber is not suitable for measurements in such low fields.

To correct the output factors, it is necessary to use correction factors or calculate the coefficients based on the measurement results [1].

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THE METHOD FOR VISUALIZATION QUALITY ASSESSING FOR THE OBJECTS IN POSITRON EMISSION TOMOGRAPHY IMAGES

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Dosimetric planning of radiation treatment using positron emission tomography (PET) images is a promising area that has received special attention in recent years [1]. The PET/CT method makes it possible to improve the accuracy of determining the boundaries of the irradiation volume. However, the use of PET images for radiotherapy planning complicates the low spatial resolution (compared to CT and MRI), as well as respiratory movements, which affect the formation of contours and volumes of pathological foci of radiopharmaceutical accumulation [2]. The technological process in conditions of high throughput of the PET department does not allow performing each examination using synchronization with the respiratory gating system.

To assess the effect of respiratory movements on image characteristics, the authors developed a device consisting of a movable platform and a water-filled phantom installed on it with six spheres installed inside with diameters of 37 mm, 28, 22, 17, 13, 10 mm. The phantom and spheres were filled with ^{18}F - FDG in a ratio of 1/6 (background volume activity/volume activity in the spheres). 8 cycles of phantom scanning (4 in static, 4 in dynamic states) were performed on PET/CT DISCOVERY IQ. Each of the spheres was competed in static and dynamic positions of the phantom according to PET images. Contouring was performed using a color gradient at levels of 80%, 70%, 50% of the maximum value of volumetric activity (kBq/ml).

Calculation of contoured volumes by PET image and comparison with nominal volumes were performed. The minimum error in calculating the volume for a sphere of 10 mm was achieved with contouring at the level of 50% of the maximum value of volumetric activity. However, the volume of spheres with a diameter of more than 10 mm was overestimated both in images obtained in static and dynamic positions.

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EVALUATION OF IMPACT OF INJECTED ACTIVITY OF 18F-FDG ON THE PET IMAGE QUALITY

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Positron emission tomography (PET) is a modern radionuclide method of medical imaging which allows to quantitative estimate of radiopharmaceuticals distribution in vivo. PET is based on the injection of radiopharmaceuticals labeled with ultrashort-lived positron-emitted radionuclides.

Image quality in PET depends on physical characteristics of radionuclide, technique parameters of scanner, acquisition protocol and reconstruction algorithm. Injected activity is one of the main examination parameters. It should guarantee good image quality and provide low patient dose. In order to determine the optimal activity of radiopharmaceutical, several factors should be considered: patient related factors (weight, body mass), and scanner related factors (detector material, acquisition mode, acquisition time per bed) [1].

Quality control (QC) of PET images of the patients could be based on the quantitative parameters [2] or image evaluation by the expert. The aim of this study was to perform QC of the PET images of the patients obtained with different PET injected activity.

The study was based on the different PET/CT units with different practice and protocol parameters. Fifteen series of PET images of the patients were collected from three PET/CT scanners (Siemens Biograph mCT 128). All patients underwent PET/CT study with ^{18}F-FDG. Injected activity of ^{18}F-FDG was 100 MBq per body surface area (BSA) on 1st scanner (2.5 min per bed); 110 MBq per BSA on 2nd scanner (2.3 min); 130 MBq per BSA on 3rd scanner (1 min). For all scanners the distributions of patient BSA were the same (Kruskal-Wallis: $p=0.5$).

Both methods demonstrated the same quality level for each PET/CT scanner. It means that decrease of injected activity in general and increase time per bed lead to reduce patient dose without loss of image quality. At the same time, increase of injected activity and decrease of time per bed lead to comparable quality.

In that case, in process of optimization of PET examination protocols it is necessary to consider relations between examination parameters.

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DIFFUSION DATA OF MAGNETIC RESONANCE TOMOGRAPHY FOR DIAGNOSTICS AND STEREOTACTIC RADIOTHERAPY OF INTRACRANIAL PATHOLOGY

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In clinical practice, and especially in stereotactic radiosurgery planning, the significance of diffusion-weighted imaging (DWI) [1] is growing. This makes the existence of software capable of quickly processing and reliably visualizing diffusion data, as well as equipped with tools for their analysis in terms of different tasks.

We are developing the «MRDiffusionImaging» software on the standard C++ language. The subject part has been moved to separate class libraries and can be used on various platforms. The user interface is Windows WPF (Windows Presentation Foundation), which is a technology for managed Windows applications with access to all components of the .NET 5 or .NET Framework platform ecosystem. One of the important features is the use of a declarative markup language XAML (eXtensible Application Markup Language), with which you can conveniently create, initialize and set properties of objects with hierarchical relationships. Graphics are generated using the DirecX environment.

The «MRDiffusionImaging» software was implemented, equipped with a unique set of tools for working with diffusion images. An algorithm for "masking" diffusion MRI series based on T2-wieghted images was developed using a deformable surface model to exclude tissues that are not related to the area of interest from the analysis. A tool for calculating the various diffusion coefficients [2] has been created, on the basis of which it is possible to build quantitative maps for solving various clinical tasks. Clustering and segmenting images functionality based on the k-means clustering method has been created to individualize the clinical target volume and further assessment of response to the treatment [3]. White matter tracts [4] of the brain were visualized using two algorithms: deterministic (fiber assignment by continuous tracking) and probabilistic using the Hough transform [5]. The proposed algorithms tests candidate curves in the voxel, assigning to each one a score computed from the diffusion data, and then selects the curves with the highest scores as the potential anatomical connections. Tractography data can be used to optimize the dose received by critical structures in irradiated areas.

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ASSESSMENT OF THE EFFECT OF DISTORTION OF MAGNETIC RESONANCE IMAGING IMAGES ON THE PLANNING OF RADIATION THERAPY

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MRI images have been increasingly used in radiotherapy planning in recent years. They have better soft tissues contamination in comparison with CT scans. This is used effectively in the irradiation of soft tissue tumors and especially brain tumors. However, geometric distortions have an impact on dose delivery accuracy when MRI is used in LT. MRI distortion is a particularly acute problem when planning stereotactic radiosurgery. In this case high dose (from 12 Gy) is delivered in 1-3 fractions with high accuracy of the beam hitting the target region. The aim of the present work is to measure distortions of MRI-images using a special phantom and subsequent quantitative assessment of their influence of distortion on stereotactic radiosurgery plan formation.

CT scanning of the phantom was performed on a Phillips Brilliance iCT. The thickness of the slices was 1 mm and the resolution of the image was 0.5 mm.

The detected distortion is minimal in the central part of the magnetic field and increases significantly at the periphery of the examined phantom. The maximum displacement found is 3.1 mm and is located at 6.6 cm from the central axis of the phantom. At distances less than 5 cm from the center, the effect of distortion is not clinically significant and averages 0.01 cm.

The main conclusion of this work is that the measurement of distortion is essential to guarantee the accuracy of the planning process and further treatment of patients. It can be concluded from this study that for the practical application of MRI in radiotherapy planning, special protocols for outlining structures on MRI images should be applied considering the distortion. Otherwise, there is a possibility that covering the target with a dose will be unacceptable

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DEVELOPMENT OF A METHOD FOR MONITORING THE ABSORBED DOSE IN PHOTON RADIATION THERAPY

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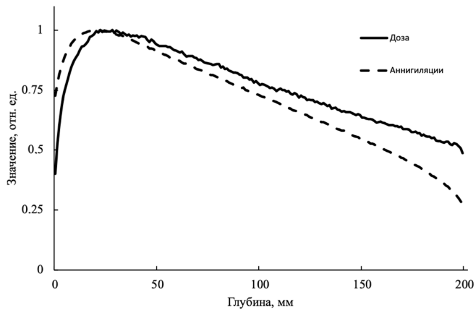
New results of a study aimed at developing a method for upgrading existing medical electron accelerators, which can become a real-time method for assessing the dose distribution in the patient's body during irradiation, are presented [1,2]. The paper presents the idea of creating a mathematical model that makes it possible to estimate the distribution of the absorbed dose in the studied tissue area by the distribution of annihilation photons arising in the process of



irradiation.

Fig. 1. Depth distribution of the absorbed dose and the number of annihilation events.

To study the proposed method, a computer experiment was performed using the GEANT4 package based on the Monte Carlo method. As part of the work performed, the correlation between the distribution of the absorbed dose of photon radiation and the distribution of positron annihilation coordinates was estimated, and the energy spectra of bremsstrahlung and annihilation photons were analyzed.

The study was supported by the Interdisciplinary Scientific and Educational School of Moscow University “Photonic and Quantum Technologies. Digital Medicine.

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INVESTIGATION OF THE FEATURES OF BONE IMPLANTS SURFACE CONDITION DURING COMBINED RADIATION STERILIZATION

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The relevance of research on the creation of new, effective and safe approaches to the sterilization of bioimplants is beyond doubt due to the high prevalence of diseases and the growth of traumatic injuries of the bone and joint apparatus. The maximum reduction of the radiation dose, elimination of the side effects of radiation, as well as ensuring absolute sterility of the transplant is an important interdisciplinary task. A promising solution is the use of combined technologies combining ozone-oxygen mixture treatment at the first stage with subsequent radiation exposure at the second stage [1].

The material for the study was samples of native bovine bone tissue made and processed on the basis of the joint Laboratory of Biomedical Technologies (Lomonosov Moscow State University – VILAR). The surface structure of bone fragments was studied by scanning electron microscopy (SEM) using JSM-7800F (Japanese Electron Optics Laboratory, Japan). Morphofunctional characteristics of the surface of bone implants, including its relief and porosity, play an essential role in the implementation of bone grafting.

The results of changes in some of these characteristics obtained earlier during radiation exposure are known [2]. The effects of ozone have not been sufficiently investigated to date. In our first works, it was shown that ozone treatment does not lead to significant morphological changes in the surface of bone samples [3], as well as microhardness parameters [4]. Of particular interest are new data on the elemental composition of bone implants [3]. This research was performed at the NEFU Radiation Technologies Laboratory within the framework of the state assignment of the Ministry of Science and Higher Education of the Russian Federation No. FSRG-2021-0014 and has been supported by the Interdisciplinary Scientific and Educational School of Moscow University «Photonic and Quantum technologies. Digital medicine».

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STUDY OF DOSE TRANSMISSION FROM A MULTIPLE COLLIMATOR ON VARIAN HALCYON AND VARIAN TRUEBEAM STX LINEAR ACCELERATORS

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The study of dose leakage is a vital topic because the number of patients who have developed delayed radiation injuries is increasing every year [1].

The linear accelerator Varian Halcyon V1.0 (Varian Medical Systems, Palo Alto, California, USA) [2] without collimation shutters has recently been put into operation and is now gaining popularity in oncology clinics. The Halcyon MLC system features a unique stepped two-layer design consisting of a distal and proximal lobe layer. The primary and secondary collimators are fixed, there is no flattering filter [3-4].

Similar studies were carried out on the Varian TrueBeam STx accelerator, which combines the capabilities of radiation therapy and radiosurgery with millimeter precision. The TrueBeam STx accelerator is equipped with a high resolution multi-leaf collimator (HD120 MLC), which has two blocks of 60 wolfram leaves each [5].

The aim of this study is to experimentally measure dose leakage from the Varian Halcyon multileaf collimator and HD120 MLC. To achieve this goal, the following experiments were carried out on the Varian Halcyon and Varian TrueBeam STx linear accelerator with an energy of boundary photons of 6 MeV:

1. Study of the influence of the field size on dose leakage. IMRT plans were created to irradiate the phantom with fields of various sizes in the Eclipse planning system. The dose profile was measured with an IC Profiler SunNuclear array detector and an SNC125c ionization chamber. A Solid Water GAMMEX water equivalent phantom and a 3D Scanner SunNeclear water phantom were used.

2. Measurement of dose leakage at a small field size. In this experiment, an irradiation plan for the 3D Scanner SunNuclear water phantom was created. The multi-leaf collimator was positioned in such a way as to create a rectangular beam with a size of 1×2 cm^2. An ionization chamber of the SNC125c type was used.

The experiment showed that despite the fact that the same dose of 200 monitor units was applied in all experiments, the dose leakage in the collimator becomes larger with increasing field size. For the Varian Halcyon collimator at a distance of 16 cm from the central axis, doses of 0.003, 0.012, 0.029, 0.052, 0.092, 0.128 Gy are observed for fields with dimensions of 5x5, 10x10, 15x15, 20x20, 25x25, and 28x28 cm^2, respectively. For the HD120 MLC collimator at a distance of 16 cm from the central axis, doses of 0.014, 0.33, 0.62, 0.96% of the maximum dose are observed for fields with dimensions of 10x10, 16x16, 20x20 and 24x24 cm^2, respectively.

The results of the current study are important for understanding how field size affects dose leakage.

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ESTIMATION OF THE CONTRIBUTION OF SECONDARY NEUTRONS TO THE ABSORBED DOSE DURING THE OPERATION OF MEDICAL LINAC

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Bremsstrahlung obtained during the operation of medical linac is used in the treatment of various types of cancer. At photon energies above 8 MeV, secondary neutrons are produced as a result of photonuclear reactions. This radiation is able to cause additional dose load on the patient, as well as unacceptable working conditions for personnel.

The contribution to the dose due to secondary neutrons is not estimated and is not taken into account in modern planning systems. The relatively small contribution of photoneutrons to the radiation flux leads to a large increase in the dose in the irradiated tissues, which is unacceptable in the treatment of oncology.

The head of a medical linear accelerator is modeled in order to estimate the contribution of secondary particles to the dose. The model is validated based on the depth dose distribution in water.

As the result of the study, the spectra of secondary neutrons were obtained, their average energy was estimated, and the contribution of photoneutron radiation to the dose was calculated.

INCREASING THE UNIFORMITY OF RADIATION TREATMENT UNIFORMITY OF OBJECTS USING MODIFIER PLATES

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Today more than 70 countries around the world have radiation processing centers for treatment of food and medical products [1]. Such radiation processing centers increasingly use electron accelerators, due to the higher dose rate received by the facility compared to authorized radioactive sources and, as a consequence, a higher rate of food processing [1].

During treatment with accelerated electrons, heterogeneity of irradiation of objects is inevitable [2]. For most medical products uniformity of irradiation of about *50%* is sufficient. But for other categories of irradiated objects, such as transplantation equipment, pharmaceuticals, chilled meat and fish products, it is necessary to ensure the uniformity of irradiation of at least *80%* [1-3].

It is possible to use electron energy variation over several irradiation sessions to increase the uniformity of dose distribution over the volume of treated objects [4]. However, a repeated irradiation increases treatment time and cost. In addition, for some treated objects it is not recommended to stay outside the cooling chambers for a long time. Therefore, it is ~~an~~ important to develop a method that would allow to increase radiation treatment uniformity in one irradiation session, which is the subject of this study.

This paper proposes a method for modifying beam spectrum using aluminum modifier plates, which allows to increase the irradiation uniformity up to 0.97 for the radiation treatment of parallelepiped-shaped objects with a mass thickness up to 3.125 g/cm^2 by accelerated electrons with energies up to 10 MeV. The possibility of applying the method to the irradiation of spherical and cylindrical objects is shown. The experiment showed that the proposed method of electron beam modification is applicable to radiation treatment of objects at industrial electron accelerators UELR 10-15-C-60 [6] and ILU-14 [7] to increase the uniformity of irradiation.

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IMPACT OF ACCELERATED ELECTRONS ON THE CHEMICAL PARAMETERS OF CHILLED MEAT OVER LONG-TERM STORAGE

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Radiation treatment of food products with properly chosen physical and technical characteristics of radiation (type of radiation, dose, dose rate, etc.) effectively increases the microbiological safety of products, preserving their taste and nutritional properties.

Changes in organoleptic properties of chilled meat products after radiation treatment are related to the degree to which ionizing radiation affects fatty acids, which may decompose into volatile compounds such as alcohols, aldehydes and ketones as a result of hydroxyl radicals and oxidation. The role of aldehydes as markers of food radiation treatment has been discussed in the literature [1].

The aim of this work was to obtain dependences of concentrations of volatile organic compounds in turkey meat on irradiation dose after exposure of 1 MeV electron beam.

Chilled turkey meat was chosen as an object of research. The samples were irradiated using continuous electron accelerator UELR-1-25-T-001 with the energy of 1 MeV. The samples were irradiated at doses of 0.25 kGy, 0.5 kGy, 1 kGy, 2 kGy, 5 kGy, 10 kGy and 20 kGy. The estimation of chemical changes was carried out using Shimadzu GCMS-QP2010 Ultra gas chromatography-mass spectrometer.

Within 13 days after irradiation the changes in concentrations of volatile organic compounds in samples irradiated at different doses were monitored.

The dependence of aldehyde concentrations on time after irradiation could be divided into 3 periods: the first 4 days, then from the 4th to the 8th day, and then from the 8th to the 13th day of observation. During the first period, relative fluctuations in the concentrations of this group of compounds were observed; the second period was characterized by a decline and approach of aldehyde concentration values in the irradiated samples to the reference values. During the third period, the dependence of pentanal concentration in all irradiated samples was close to the reference values. Concentrations of acetaldehyde and heptanal on the 13th day of observation were higher in all irradiated samples compared to the reference values.

Analytical relationships describing changes in the concentration of various volatile compounds in turkey samples as a function of irradiation dose and time after treatment were proposed, based on the fact that two competing processes take place in all the samples studied: decomposition of a chemical compound and formation of molecules of this compound due to the decomposition of other compounds.

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ADVANTAGES AND DISADVANTAGES OF TIMEPIX DETECTOR FOR SPECT/CT

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The report presents the advantages and disadvantages of using the Timepix family detectors [1] as a registration system for SPECT and CT scanners. The possibilities of using pixel detectors for creating multimodal SPECT/CT systems are demonstrated. The possibilities of using pixel detectors for creating multimodal SPECT/CT systems are demonstrated. Much attention is paid to microtomography systems. The perpectives for using CdTe as a sensor are considered.

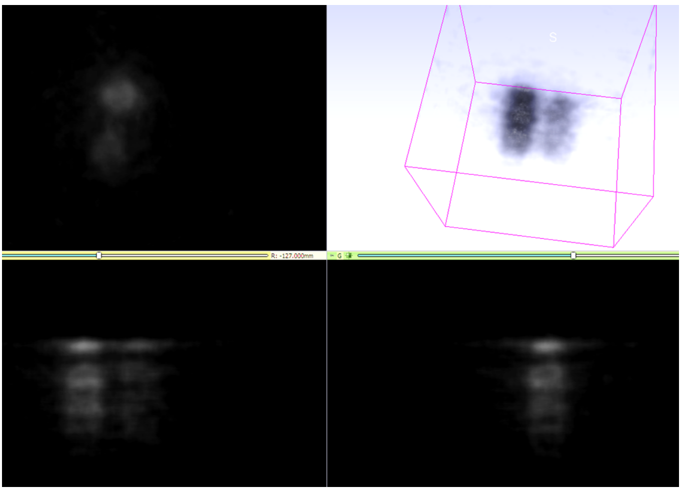

Fig.1. SPECT phantom image with Tc-99m.

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SIMULATION OF ELECTRON DOSE DISTRIBUTION IN TISSUE EQUIVALENT LAYERS OF MULTILAYER IONIZATION CHAMBER

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Depth distribution of ionization losses by electron beam from the output channel at angle of 270° of LUE-8 accelerator is measured. A four-layer ionization chamber in current mode is used for measurements [1]. Ionization chamber air layers imitates layers which equivalent to biological tissue if taking into account correction factor. Method for testing of various radiation-protective material elements of at LUE-8 accelerator up to 8 MeV is proposed and studied. Depth-dose distribution is obtained.

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SOFTWARE FOR PROCESSING AND ANALYZING DATA FOR DETECTORS OF THE MEDIPIX FAMILY

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This report describes the current stage of developing a new multi-energy X-ray tomograph, which based on hybrid semiconductor pixel detector Widepix. The Widepix analyser software was written for processing the data of the detector during this work.

The Widepix detector is one of Medipix series detectors, which are hybrid semiconductor pixel detectors developed by the Medipix collaboration. They consist of two parts: a sensor and a readout chip. In sensor substance a hitting charged particle cause appearing of a signal. The signal is digitized and compared with adjustable threshold in the pixels of the chip part. By this way, Medipix series detectors are able to register radiation in different energy diapasons [1, 2].

The developed software operates only with raw detector's data. The software provides possibilities to construct different types of spectra, frames and distributions. It can make a lot of operations with the data like as flat field correction, pixel filtering, arithmetic operation with spectra. The software is possible to calculate statistical parameters of frames data. The result of the program operations can be saved in different types of files.

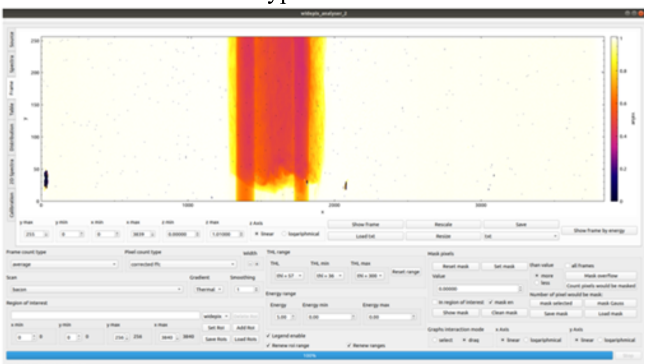

Fig. 1. General view of the program in the frame display mode.

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$MAPbBr_3$-BASED RADIATION DETECTOR

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Recently the opportunity of using metalloorganic perovskites as a basic material for semiconductor detectors of ionizing radiation was demonstrated [1]. Presence of lead atoms make possible appearance of small size devices intended for personal dosimetry purposes. Crystal growing from solutions provides low cost of these devices [2]. Chlorine substituted methilammonium lead bromide perovskites $MAPbBr_{3-x}Cl_x$ was investigated in 2017 [3], and it was demonstrated by authors that the ratio of chlorine to bromine atoms has an impact on the energy resolution of $MAPbBr_{3-x}Cl_x$-based detectors. At the present time $MAPbBr_{3-x}Cl_x$-based detectors becomes comparable by practical characteristics to widespread stintillator-based detectors, whereas pure $MAPbBr_3$ doesn't allow obtaining energy resolution at all. Such a behavior demands investigation of the influence of structural and topological defects on electric properties and band structure of metalloorganic semiconductors. Electrical transport properties may be investigated by dielectric spectroscopy, which can provide information about impurity levels [4].

The purpose of this work was to obtain $MAPbBr_{3-x}Cl_x$ crystals by an original method, to study their transport properties using impedance and optical spectroscopy, to find out the possibility of their application in semiconductor detectors of ionizing radiation.

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STUDY OF DOSE DELIVERY FOR TOTAL BODY IRRADIATION ON TOMOTHERAPY USING EXIT DETECTOR DATA

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Optimized Conformal Total Body Irradiation (OC-TBI) is very complex and unique method of radiotherapy. It include irradiation of the whole body with dose of 12 Gy, except organs at risk: lungs, kidneys, liver and lenses. Because of its complicity, we need to pay attention to dose delivery in this method.

The evaluation of the delivered dose for patient received OC-TBI on TomoTherapy can be done using MVCT images and raw data from exit detectors. Exit detectors are an important part of TomoTherapy that needed to visualize patient anatomy right before the treatment. Also they store a huge amount of information about the beam characteristics throughout the procedure, that achieved by 640 xenon ionization chambers.

We used CIRS ATOM anthropomorphic phantom to find correlation between fluence of radioation that collects in detectors and the dose in each area of irradiation. 12 additional plans with different shifts were calculated and then performed on Tomotherapy. Signal from exit detectors was collected and analyzed with Gamma 0.5%/0.5 mm criteria.

Data from exit detectors during irradiation of patients were also used for analysis. We took 24 data from procedure of OC-TBI and analyzed them in our hand-made software in MatLab. MVCT images were taken before treatment for each fractions and then were exported in MIM software that has the opportunity to recalculate dose. For each fraction the patient CT was deformed using MVCT images, creating an synthetic CT (sCT). Dose recalculation was performed on the sCT. Planned and delivered doses were compared using Gamma 3%/1 mm criteria.

We found that coefficient of determination between fluence and dose for anthropomorphic phantom is bigger than 80% in all areas of irradiation: mean coefficient of determination is 87.9 ± 7.2%. For patients coefficients of determination decrease due to micro movements and breathing. Mean gamma index in the area with minimum moving (head) is 96.0 ± 4.2%, when in the area of breathing (chest) it decrease to 69.9 ± 12.6%. It shows that signal from detectors very sensitive to any movement, which should be taken into account in further research.

The study showed that fluence and dose in OC-TBI procedures have a high correlation. That can lead to dose evaluation only from data from detectors.

SPATIAL DISTRIBUTION OF ATMOSPHERIC AEROSOL DEPOSITION MEASURED WITH ^{7}Be AS A TRACER AND MOSSES AS A SAMPLING MEDIUM

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Cosmogenic radionuclide ^{7}Be is frequently used as an atmospheric tracer. Air concentrations or deposition rate of ^{7}Be are usually measured at limited number of locations equipped with air samplers or depositional collectors. Mosses that do not have root system but receives and retains nutrients from the atmosphere can be used as natural filters that provide very good spatial resolution of sampling. Deposition rate at some selected location is governed by a number of factors, among which the most important are meteorological conditions and the characteristics of the relief.

The spatial distribution of ^{7}Be atmospheric deposition was measured once using terrestrial mosses on the territory of the Republic of Serbia [1]. In order to assess whether there are some areas with preferentially higher or lower atmospheric deposition, a three-year project has been started. The moss samples will be periodically taken in the northern part of Serbia and ^{7}Be concentrations will be measured.

In the first campaign, moss sampling was performed at 70 locations in the northern part of Serbia. Dried samples, compressed into 200 ml plastic containers were measured in an anti-Compton NaI detector adapted for this purpose to serve as a high efficiency well-counter.

In this work, the results of the first sampling campaign are presented and compared with results of previous study. An analysis was made to establish to which extent the deposition patterns in two existing measurements coincide.

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STUDY OF VOLUMETRIC ACTIVITY OF RADON IN AQUATIC MEDIUM BY METHOD LIQUID-SCINTILLATION SPECTROMETRY

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Currently, an indirect method of measuring the volumetric activity of ^{222}Rn in an aqueous medium, which is measured in liquids by depositing its daughter decay products or by bubbling liquid, is used to analyze samples of water bodies of regions with a naturally elevated level of radiation and its effect on the human body. These methods have a number of disadvantages, such as low particle detection sensitivity, since ^{222}Rn concentration measurements are made not on a straight line, but indirectly through the determination of the concentration of daughter elements. Measuring the volumetric activity of radon and calculating the equivalent equilibrium volumetric activity (EEVA) with model weighing coefficients consists of several stages and is carried out using solid-state standards of ^{226}Ra, ionization chambers, semiconductor gamma spectrometers with detectors from particularly pure germanium and other devices. In this regard, the development and implementation of a new method for measuring radon in water are relevant.

This paper proposes a new method of experimental measurement of the ratios of the current activity of radon and EEVA in a liquid, based on the effect of the total alpha-beta radiation of radon decay products by liquid scintillation spectrometry - a modern highly sensitive means for measuring alpha-beta radionuclides in a liquid medium. During the study, the radon concentration in the rock sample from the uranium deposit in the Aldan region of the Republic of Sakha (Yakutia) was determined by calculating the ratio of instantaneous and equivalent equilibrium volumetric activities of radon in the water tincture of crushed uranium ore. The experiment was carried out using a scheme for the decay of ^{226}Ra, developed at the Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University. To measure the concentration of radon and its daughter decay products, a low-phonic liquid scintillation alpha and beta spectrometer of Hidex SL-300 (Finland) was used, which allows measuring the tritium content in water up to 1 Bq/l. During the experiment, values of the activity of the daughter decay products of radon corresponding to its EEVA were obtained, taking into account the formation of α- and β-particles during the decay of the radon itself and its daughter elements, such as ^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po, ^{210}Pb, and using the law of radioactive decay of ^{222}Rn.

This method of analysis of radon concentration can be used more effectively in studies of the degree of radioactivity of samples from various media compared to existing methods of measuring radon concentration, which require high time and other resource costs.

DOSIMETRIC INDICATORS OF ULCERATIVE-NECROTIC LESIONS OF THE DIGESTIVE TRACT OF MONOGASTRIC ANIMALS WITH INCORPORATED "HOT" RADIOACTIVE PARTICLES

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The analysis of the dosimetric pattern and experimentally established biological effects of internal irradiation of monogastric animals (rats, guinea pigs, piglets) is presented "hot" radioactive particles (RP) that cause ulcerative necrotic lesions of the gastrointestinal tract (GIT). Mathematical models of RP transport (in the GIT) and the formation of absorbed doses of β-radiation on the mucous membrane of the digestive tract have been developed. The features of the deep distribution of absorbed doses in the mucous membrane depending on the spectral characteristics of β-radiation are given. Calculations were performed using a multifunctional interactive computing system PTC Mathcad Prime 4.0. and a specialized dosimetric program VarSkin 4.0. The main factors in the formation of ulcerative lesions of the digestive tract are the extremely uneven distribution of particles in the contents and on the surface of the mucous membrane of the GIT, the concentration of particles in areas of the mucous membrane capable of depositing RP with the subsequent formation of high local levels of beta radiation. A dosimetric scale of extremely severe, severe, medium and mild degrees manifestations of acute radiation ulcerative gastroenterocolitis is proposed, which allows extrapolating the results of model experiments on scenarios of radioactive contamination of the environment by particles of various genesis. The data obtained can be taken into account in radiation safety tasks.

STUDY OF TIKHONOV REGULARIZATION IN SPECTRA RECONSTRUCTION

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The electron energy spectrum is one of the important parameters in electron beam radiation treatment planning for accurate calculation of the dose-volume distribution of the irradiated object. Existing methods such as Monte-Carlo modeling of the radiation source and radiation geometry and direct measurement of the energy spectrum using special equipment are time consuming and expensive, respectively. The most universal method is the indirect method based on the reconstruction electron beam spectrum from experimentally measured data.

In this work, the authors reconstructed electron energy spectra from the depth dose distributions in aluminum using the standard least squares method, supplemented with Tikhonov's regularization. As the reference spectra for estimating the reconstruction accuracy the spectra of the UELR-10-15S accelerator for four different operating modes with maximum energies of 5 MeV, 6.5 MeV, 8 MeV, and 10 MeV have been selected.

The aim of the work was to study the influence of different types of Tikhonov regularization parameters calculated with the absolute and relative correction methods, the quasi-optimal method and the residual method [1-3], on the accuracy of reconstructing the electron beam spectra from the depth dose distributions in aluminum.

The accuracy of reconstructed with Tikhonov's regularization the electron spectra from depth dose distributions was established depending on the choice of the regularization parameter, as well as the energy mode of the accelerator and the experimental error in measuring depth dose distributions.

It was found that the error in the reconstruction of the spectra in the case of the regularization parameter calculated with the residual method is on average 10% lower compared to other methods.

It was also shown that the accuracy of the reconstruction of depth dose distributions from the reconstructed energy spectra is about 85–95%, depending on the maximum energy of the electron beam of the accelerator and the choice of the regularization parameter.

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INCREASING IRRADIATION UNIFORMITY AT INDUSTRIAL ELECTRON ACCELERATORS

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These days radiation treatment of objects and materials has been increasingly used in various areas of the national economy. For a number of categories of objects narrow radiation dose ranges are prescribed. Exceeding the upper limits of this range has a negative effect on physical and chemical properties of the object. Going beyond the lower limits does not reach the desired treatment objective. Therefore, it's important to ensure the best possible dose distribution homogeneity over the entire volume of the object. An increase in the uniformity of irradiation is achieved by placing aluminium plates between electron accelerator exit window and the irradiated object [1]. The presence of the plates modifies the electron beam spectrum by blurring the peak of the initial electron spectrum towards lower values. Thus, the dose in the surface layers increases, resulting in a greater irradiation uniformity. But at the same time the limiting size of objects that can be treated decreases.

In this work we propose a method of increasing irradiation uniformity based on placing a combination of aluminum modifier plates of different thicknesses at the electrons beam way during radiation treatment. Methods like this are used in proton radiation therapy to form a modified Bragg peak of a given thickness at a given depth [2]. The key task is to determine absorbed dose distributions weights in such a way that the superposition of dose distributions is as close as possible to the desired form. In other words, $\sum_{j=1}^{M}\left(\sum_{i=1}^{N}\omega_i D\left(x_j,d_i\right)-\hat{D}\left(x_j\right)\right)^2\rightarrow Min$, where $D\left(x_j,d_i\right)$ - is the absorbed dose generated at point of x_j depth when using a d_i thickness modifier, ω_i - weight coefficients, of the dose distributions in the presence of the plate d_i , $\hat{D}\left(x_j\right)$ - the desired dose at point x_j . The summation is performed on i from 1 to N, where N is the number of different thickness modifiers and on j from 1 to M, where M is the number of points at which the absorbed dose is determined.

In this work, the absorbed dose distributions over the depth of cubic water phantoms with a depth up to 155 mm during one-sided irradiation with monoenergetic electrons with energies 1 - 10 MeV were obtained by computer simulation using the Geant4 toolkit. Aluminum plates with the thickness of 0 - 6 mm were placed in the beam path.

Based on the results of the work for each phantom, weighting coefficients were selected by using the non-negative least squares method [3] to obtain combinations of dose distributions that provide maximum possible radiation treatment homogeneity.

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PHOTONUCLEAR METHOD OF ^{161}TB PRODUCTION

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^{161}Tb is a medical isotope that is considered in therapy as an alternative to the widely used ^{177}Lu. Currently, the main way of production of this radionuclide is the reactor method based on the neutron capture reaction followed by β-decay: ^{160}Gd(n,γ)^{161}Gd→^{161}Tb. However, in this case it is necessary to use expensive enriched targets. This disadvantage is the reason why the development of alternative methods for production of the radioisotope ^{161}Tb is an important issue.

Theoretical analysis of the possibility of producing the radioisotope ^{161}Tb by the photonuclear method was performed. Using cross sections calculated on the basis of a combined model of photonuclear reactions, the yields and activities of reactions ^{162}Dy(γ,p) and ^{163}Dy(γ,pn) on electron beam at energies up to 70 MeV were estimated. The side reaction activities of ^{161}Dy(γ,p), ^{162}Dy(γ,pn), ^{163}Dy(γ,p2n) and ^{163}Dy(γ,p) were also analyzed. The optimal conditions for the production of ^{161}Tb were chosen on the assumption that the activity of the main reaction should be more than 1MBq, and the activity of the side reactions should be 4 orders of magnitude less than it. The obtained results indicate the possibility of using the monoisotopes ^{162}Dy and ^{163}Dy at energies of 19-21 MeV and 25–27 MeV, respectively, to produce ^{161}Tb radionuclide.

PRODUCTION OF MEDICAL RADIONUCLIDE ^{82}RB USING PHOTONUCLEAR REACTIONS

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The ^{82}Rb isotope has found application in medicine, where it is used to diagnose diseases of the heart and blood vessels. Being a biological analogue of kalium, rubidium is absorbed by tissues, after which the absorption pattern is visualized by positron emission tomography. A very short lifetime forces the use of mobile ^{82}Rb generators, in which the isotope is produced during the decay of ^{82}Sr and is isolated chemically immediately before the procedure.

The method of induced activity was used to study photonuclear reactions on a natural mixture of strontium isotopes. The experiment was performed on a bremsstrahlung of an RM-55 electron accelerator at an electron energy of 55 MeV. The study examined the possibility of producing ^{82}Sr isotope in photonuclear reactions on a natural mixture of strontium isotopes. ^{82}Sr has no gamma lines; therefore, it is not possible to experimentally determine the yield of this isotope by the usual method from the peak in the residual activity spectrum. Due to the large difference in the half-lives of ^{82}Sr and ^{82}Rb, which decays this isotope (25.55 days and 1.27 minutes, respectively), it is possible to determine the experimental yield of ^{82}Sr from the ^{82}Rb gamma lines in the last spectra, using the secular equilibrium formula. Experimentally determine the yield of ^{82}Rb impossible due to the fact that the target transfer time from the accelerator to the detector is several times the half-life of ^{82}Rb.

Experimental data on the cross-sections of photoproton reactions on Sr isotopes are not available in the literature. The yields of the formation of ^{83,85,85m,87m}Sr isotopes as a result of ^{nat}Sr(γ, i*n*) reactions, the target nuclide ^{82}Rb and the side nuclides ^{81,82m,83,84,86,86m}Rb as a result of ^{nat}Sr(γ, i*n*1*p*) reactions were measured. The experimentally obtained yields of photonuclear reactions are compared with the yields calculated using theoretical cross-sections of photonuclear reactions from and the TALYS program.

^{212}Pb: PRODUCTION AND APPLICATIONS

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Over the last twenty years targeted alpha therapy has demonstrated its high efficiency in treating various oncological diseases. ^{212}Pb, with its convenient half-life of 10.64 h, and its daughter alpha-emitter short-lived ^{212}Bi ($T_{1/2}$ = 1 h), provides the possibility for the synthesis and purification of radiopharmaceuticals with minimum loss of radioactivity during preparation. It can be milked from a radionuclide generator via various techniques.

The main approaches applied for this purpose are considered and described, including chromatographic and other methods to separate ^{212}Pb from its parent radionuclide. The results of preclinical studies with an estimation of therapeutic and tolerant doses as well as recently initiated clinical trials are presented.

LABORATORY GENERATOR FOR ^{212}Pb PRODUCTION

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^{212}Pb radionuclide generator with ^{228}Th as a parent radionuclide has been developed. The generator principle is based on diffusion of gaseous ^{220}Rn emanating from strong anion exchange resin containing ^{228}Th into a separate collector where post-decay ^{212}Pb is deposited on the collector walls. After a 48-hour operation cycle of the generator, sampling of ^{212}Pb in the form of solution in 0.1 M HCl is executed with approximately 40% yield of ^{212}Pb.

Another ^{212}Pb generator design was also realized via ion exchange technique with ^{224}Ra as parent source ($T_{1/2}$ = 3,6 d). Actual implementation involves an ion exchange separation of ^{224}Ra from ^{228}Th with subsequent absorption of ^{224}Ra in strong cation exchange column. ^{212}Pb could be then eluted with 1 M HCl.

The generators are supposed to be reloaded once in a few years because of long-lived parent ^{228}Th ($T_{1/2}$ = 1,9 y). The generators is developed for biological and radiochemical investigations in the field of obtaining radiopharmaceuticals for targeted therapy.

NASOLACRIMAL DUCTS PHARMACOSAFETY OF 131-IODINE

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Secondary obliteration of the lacrimal duct obstruction (SALDO) is one of radioiodine therapy complications in differentiated thyroid cancer observed in 9% of cases [1]. Development of methods for the prevention of SALDO one of the urgent tasks facing radiology and ophthalmology [2].

We analyzed the frequency of 131-iodine uptake nasolacrimal ducts in 203 patients on 72 h. after 131-iodine administration. Patients were divided in two groups according type of preparation to the radioiodine therapy: 103 used classic levothyroxine withdrawal for 3 weeks, 100 used recombinant human thyroid stimulating hormone to increase TSH level.

Image segmentation method was developed for static 131-iodine scintigraphy of head and neck (Figure 1).

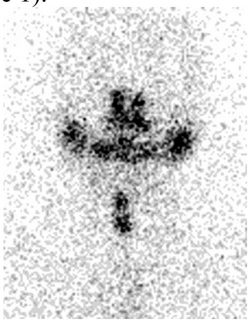

Fig. 1. Static 131-iodine scintigraphy of head and neck with bilateral lacrimal duct uptake.

Additionally, we made an attempt to highlight several groups of risk to develop SALDO in patients undergoing 131-iodine therapy.

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RADIATION SOURCE CHARACTERISTICS ANALYSIS DURING BRACHYTHERAPY WITH THE RING APPLICATOR FOR DIFFERENT IRRADIATION PLANS

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Inaccuracies in brachytherapy treatment occur due to two reasons mainly: anatomical misalignment or as a result of errors that are usually associated with incorrect positioning of the applicator or radiation source during treatment. The purpose of this work is to test the degree of inconsistency in the positioning of the radiation source at the most distant position of the ring applicator when different dosimetric exposure plans are used. An IBU-Digital X-ray machine was used to check the quality of the source positioning. The ring applicator was secured with an applicator clamp with a base plate and placed on the patient table perpendicular to the direction of the x-ray beam. Dosimetric exposure plans were created on the planning system Oncentra Brachy v4.5.2 for microSelectron HDR v3 Digital, Elekta, Sweden. The plans included one distal active position as well as several active positions in the annular part of the applicator. After the source moved to the distal position, planar X-ray images of the applicator with the source were obtained, as well as lateral images at an angle of 90 degrees for reconstruction. The coordinates of the points of the center of the radiation source capsule for the respective treatment plan were used to measure the distance between the distal position of the source on the reference plan (plan with one distal active position) and the distal position on the remaining plans. The maximum deviation of the source location in the distal position was observed during the implementation of the dosimetric plan, in which the last 2 positions were deactivated and amounted to 1.7 mm. The number of inactive positions in front of the outermost active position in the ring applicator did not affect the positioning accuracy of the source. The observed differences in the accuracy of positioning the source in the distal position when implementing different irradiation plans lead to uncertainty in dose delivery on brachytherapy devices. The results obtained indicate the need for quality control procedures when putting applicators into clinical operation, as well as the need to develop an additional device for dose delivery quality checking for various applicators in brachytherapy.

ESTIMATES OF THE EXPECTED AVERAGE ANNUAL EFFECTIVE DOSE OF NATURAL RADIATION BACKGROUND OF EMPLOYEES IN THE ADMINISTRATIVE BUILDING, TAKING INTO ACCOUNT THE DISTRIBUTION OF RADON AND ITS DECAY PRODUCTS

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Radium is the most radiotoxic natural radionuclide, since small amounts of it can accumulate in bone tissue, damaging the bone marrow and mutating bone cells [1]. Radon is a decay product of radium and is ubiquitous in the biosphere and present in soils and building materials. Most people are most exposed to radon in residential and industrial buildings. It accounts for about half of the total human exposure dose from natural sources. Radon can damage the DNA of the respiratory epithelium, and radon exposure is suspected to be the cause of lung cancer [2]. Significant health effects have been observed among uranium mine workers exposed to high levels of radon. They found a link between exposure to radon and its decay products and an increased risk of developing lung cancer. Despite this, it remains unclear what impact household exposure to radon has on the development of lung cancer.

The purpose of this work was to estimate the dose load from natural sources of radiation based on monitoring measurements of the topology of the distribution of radon isotopes in a building located near a tectonic fault. The measurement was carried out using a radon radiometer “Ramon-02” in an administrative building located near a tectonic fault from February 2021 to February 2022 in Almaty. The experiments were carried out in rooms with a volume of 128.38 m^3 with a ceiling height of 2.6 m and located in the basement, on the third and fifth floors. During the experiment, the concentration of radon activity averaged 189.59 $Bq{\bullet}m^{-3}$ for the basement, 23.78 $Bq{\bullet}m^{-3}$ for the third floor and 35.01 $Bq{\bullet}m^{-3}$ for the fifth floor. In addition, fluctuations were observed in the range from 59.9 to 568.9 $Bq{\bullet}m^{-3}$ for the basement, from 12.2 to 33.6 $Bq{\bullet}m^{-3}$ for the third floor and from 16.2 to 71.8 $Bq{\bullet}m^{-3}$ for the fifth floor.

Based on the data obtained, the doses from radon and its decay products received by students and faculty members who are in classrooms during the day, month and year were calculated. Calculations showed that the annual effective dose in this administrative building (working time-2000 hours/year) ranged from 0.5 mSv/year (for the fifth floor) to 2.2 mSv/year (for the basement).

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STUDY OF GENETIC EFFECTS IN BIOASSAYS ARISING FROM RADIATION THERAPY USING A LINEAR ACCELERATOR ELEKTA AXESSE

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Currently, gamma radiation is widely used in the treatment of cancer. In particular, in the treatment of oncological diseases, the ELEKTA AXESSE medical linear accelerator is used, which forms beams of gamma rays with energies of 10 MeV and 15 MeV. Gamma radiation of such energies is highly penetrating and thus capable of being absorbed in a sufficiently large volume of biological material. Thus, in this work, the aim is to study the appearance of radiation defects from various doses of irradiation with gamma rays with energies of 10 MeV and 15 MeV. Such a study is of interest in studying the prolonged effect of gamma therapy on body cells.

This paper presents the results on the frequency of mutations induced by beams of gamma rays with energies of 10 and 15 MeV. The relative exposure doses were 2Gy, 5Gy, 10Gy, 15Gy, 20Gy and 30Gy. The electronic accelerator Elekta Axesse of the oncological center "Sunkar" (Almaty) was used as a source of gamma quanta. A study of the genotoxic effects of gamma radiation was carried out using Drosophilamelanogaster. A series of fly larvae after irradiation were placed in test tubes with a medium for crossing irradiated adults. Each tube in the tests was subjected to visual analysis after the complete departure of the generation to identify mutations. Morphoses were chosen as the main criterion for assessing the mutagenic and teratogenic effects of gamma radiation on Drosophila. The formation of morphoses is one of the properties of conditional mutations that are not associated with the primary structure of DNA and occur in regulatory genes responsible for the formation of traits of intraspecific similarity. In this case, the stress factor was gamma radiation, and the appearance of morphoses demonstrated teratogenic effects or disturbances in the genetic development program. In addition to morphoses, cases of sterility or a decrease in the fertility of adults were found, which is evidence of the mutagenic effect of irradiation, since such a phenomenon was not observed in the control. The teratogenic properties of gamma radiation were revealed, expressed in the appearance of morphoses or asymmetric ugly disorders of the soma morphology. The data obtained indicate that gamma quanta have pronounced mutagenic and teratogenic properties, i.e. is genotoxic. As a result of the experiments, the types of induced mutations were determined, and the significance of genetic effects for various energies of gamma rays was assessed.

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STUDYING THE DOSE LOAD ON THE RESPIRATORY SYSTEM FROM HEAVY NATURAL RADIONUCLIDES DURING TOBACCO SMOKING

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According to the ICRP (publications No. 50 and No. 65), radon and its decay products (Rn-DP) contribute more than 50% to the total radiation background. In Kazakhstan, cancer incidence rates remain among the highest among the CIS countries [1-2] and 28831 new cases were detected in 2020 [3]. Currently, it has been proven that the main cause of lung cancer is smoking [4]. However, despite the fact that the first place as a cause of lung cancer is occupied by tobacco smoking, the second place is occupied by the inhalation of radon and Rn-DP. Toxic chemicals in tobacco smoke are one reason why cigarettes cause cancer, but radioactive heavy elements also play a significant role in them. They accumulate in tobacco leaves at the time of their vegetation due to absorption from the soil and air, and the rate of absorption depends on the pH of the soil. The decay product of radon, Pb-210, plays an important role in human radiation exposure, since it has a long residence time in the body [5]. This contributes to an increase in the dose of internal radiation and increases risk of lung cancer. For this reason, conducting studies on the quantitative assessment of the concentration of natural beta-radionuclides in the lungs due to smoking as one of the causes of the carcinogenic effect is an urgent task.

In this work, the authors performed a quantitative assessment of the concentration of natural beta-radionuclides in six samples of the most popular tobacco products in the Kazakhstan. The beta activity concentrations of the samples were measured by beta spectrometry using a scintillation detector. The results of the preliminary analysis of this work show that the lower threshold for the activity of beta-radionuclides in the tobacco of one cigarette is 60 mBq. A person who smokes one pack a day (20 cigarettes) inhales an average of 120 mBq. The annual effective doses were calculated based on the intake of Pb-210, as having the greatest danger among other beta radionuclides, and amounted to 39 μSv/year for a person who smokes one pack per day.

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STUDIES OF RADON CONCENTRATION IN RESIDENTIAL AND PUBLIC BUILDINGS LOCATED IN THE TIEN SHAN FOOTHILLS AND THE NEVA LOWLAND AREAS

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The large territories of the Republic of Kazakhstan and the Russian Federation are characterized by a different radiation environment due to the mining (coal, gas, non-ferrous metals and uranium), the geological conditions, seismic activities and mountainous areas. In this case, the radiation environment is influenced by radioactive gases (radon, thoron), together with their decay products, and radioactive aerosols formed in natural chains of uranium and thorium series. Thus, one of the most important tasks of radioecological research is the analysis of radon concentration in residential and public buildings. Radon enters the building from the ground, through foundations and floors, or directly from building materials. As a result, a rather high radiation background can be registered in the building. Especially if the house has the high concentration of uranium-thorium series radionuclides, or if materials with a high uranium concentration were used in its construction. Also, if there is a positive temperature difference inside and outside the building, a pressure gradient arises and an additional mechanism appears that contributes to the entry of radon. This mechanism is usually much more important than the diffusion transfer of radon [1].

Therefore, it seems to be interesting to study the concentrations of radon and its decay products in residential and administrative buildings, and especially in newenergy-efficient buildings [2]. In present work, the objects of research were buildings located in the foothill regions of the Tien Shan (Almaty region), because tectonic faults and the rocks are additional sources of radon. On the other hand, it would be interesting to compare experimental data on radon concentration obtained in buildings located in mountainous areas with data obtained in buildings built in the Prinevskaya lowland area (with the corresponding geological structure) at the zero mark of the height and depth reference system (region of St. Petersburg).

In this work, data on radon volume activity were obtained and analyzed in the period from February 2021 to February 2022 in housing and public buildings of Almaty and St. Petersburg. As a result, the radon concentration distributions were obtained at all levels of administrative and residential buildings. The dependences of radon volume activity on temperature, humidity and pressure were analyzed. Also, in some local places the high radon volume activity was detected. Such radon «jets» can add an additional radiation load to the total exposure dose for the population from natural radiation sources.

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APPLICATION OF SRI$_2$(EU) CRYSTAL IN PROBLEMS OF GAMMA-RADIATION SPECTROMETRY

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According to the requirements of international standards, the energy resolution of spectrometric equipment for radiation monitoring systems should be less than 4.5%. The Rosenergoatom standard STO 1.1.1.01.001.0875-2017 requires a spectrometric detection unit with a resolution of not above 4.5% for ^{137}Cs radionuclide to be used at the radiation monitoring station ASCRO. Also, the ANSI N42.34-2015 standard introduces a requirement for the energy resolution of the spectrometric channel of radionuclide composition identifiers to be no more than 4%.

ATOMTEX SPE has developed a spectrometric detection unit based on the SrI$_2$(Eu) scintillation detector with dimensions Ø38×38 mm. According to the results of the spectrometric studies of the detection unit, the typical resolution was 3.3% for the 662 keV line of the ^{137}Cs radionuclide.

To minimize the influence of external factors on the characteristics of the spectrometric path, classical LED stabilization is used. To correct superimposed pulses from the ADC, pulse superposition rejection is used.

Detection unit		BDKG-05S	BDKG-205A
Detector		Scintillator SrI$_2$(Eu) Ø38×38 mm	Scintillator LaBr$_3$(Ce) Ø38×38 mm
Energy range		20 keV – 3 MeV	30 keV – 10 MeV
Measurement range of ambient dose equivalent rate		30 nSv/h – 150 μSv/h	30 nSv/h – 300 μSv/h
Energy dependence relative to 662 keV (^{137}Cs) when using the hardware correction method		±20% (50 keV – 3 MeV)	±20% (30 keV – 10 MeV)
Typical resolution at 662 keV (^{137}Cs)		3,2%	3,3%
Typical sensitivity to gamma radiation	^{41}Am	5500 cps/(μSv/h)	5400 cps/(μSv/h)
	^{37}Cs	850 cps/(μSv/h)	750 cps/(μSv/h)
	^{0}Co	450 cps/(μSv/h)	380 cps/(μSv/h)

The developed spectrometric detection unit based on the SrI$_2$(Eu) scintillator can be widely used both in stationary radiation monitoring systems and in mobile devices with the radionuclide identification function.

THE DOSE CALCULATION BASED ON CBCT IMAGES FOR LONG TARGET CASES: A PHANTOM STUDY

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Cone-Beam Computed Tomography (CBCT) images have different normalization of the Hounsfield Units (HU), artifacts and a limited field of view. That is all creates difficulties for the CBCT dose recalculation. In this study we assess the possibility of using several CBCT sets for replanning or further dose evaluation for long target cases.

Doses were calculated in the anthropomorphic phantom CIRS ATOM® using Monte-Carlo algorithm in MIM SureCalc® MonteCarlo (Cleveland, USA). Planned dose at the CT images (rCT) was considered as reference, doses at different CBCT images were considered as evaluated. The phantom was scanned with the standard CT mode (120 kV); the targets (Brain and Spinal Cord) were contoured and treatment plan was created.

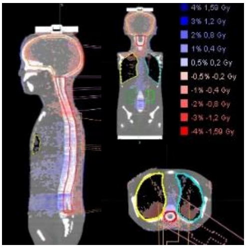

Fig. 1. Dose difference between rCT and cCBCT with imbedded HUs correction

Obtained CBCTs for four different regions of the phantom (head, chest, abdomen, and pelvis) were united into one combined series (cCBCT) for futher dose calculation. Also all areas were scanned using the only low-dose CBCT protocol to get another low-dose cCBCT. HU to electron density correction was applied for both cCBCT and low-dose cCBCT, assigning density to bones and lungs was applied only for low-dose cCBCT. Reference and evaluated dose distributions were compared using gamma criteria of 2% 1 mm. The number of points that satisfy this gamma-criterion is 87.38% between rCT and low-dose cCBCT; 94.08% between rCT and low-dose cCBCT with assign lungs and bones densities; 96.78% between rCT and low-dose cCBCT with imbedded correction HUs; 98.72% between rCT and cCBCT captured on different protocols corresponding scan areas with imbedded HUs correction. Plans recalculation using several CBCTs for long targets is difficult but feasible task and provide possibilities for adaptive radiotherapy.

AGILITY MULTILEAF COLLIMATOR PARAMETERS OPTIMIZATION IN THE INDEPENDENT DOSE CALCULATION SYSTEM

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The MIM SureCalc® is MonteCarlo Plan verification system (MIM Software Inc. Clevland, OH, USA) used to provide an independent dose calculation calculation check of radiotherapy treatment plans. These module include a voxel based Monte Carlo engine to calculate the dose in the patient. The input data are DICOM RT Image, RT Structure and RT dose derived from treatment planning system. The algorithm uses virtual source models, which are analytically expressed phase space models generated from BEAMnrs [1]. The model of the linac is created by the software manufacturer based on the data provided by the users (depth dose distributions, beam profiles, and radiation output factors)

The aim of this study was to assess the MIM SureCalc® MonteCarlo Plan verification module and optimize the calculation parameters according the measured data obtained using Elekta linear accelerator equipped with Agility™ multileaf collimator (MLC).

The modeling accuracy of MLC was assessed by comparing the calculated and measured dose distributions in L-shaped test radiation fields (four bordering segments in the form of the letter “L”). The measurements were performed with the massive of ionization chambers MatriXX (IBA Dosimetry). The modeling of the MLC offsets (the difference between the given leaf position and its actual value), as well as the leaf groove values (characteristic of the field edge formed by the side surfaces of the MLC leaf) was evaluated using Gamma analysis [2].

The optimization began with all parameters set to their default value. Comparison of the calculated test fields with the measurements showed that correction of the leaf groove leakage and offset values are required. The offset value of 0.1 mm was selected that best replicated measurements with the Agility™ MLC. Correction of leakage values was possible only by changing the virtual source model and required additional actions from the manufacturer.

The adjustment of the above parameters resulted in improved 2D Gamma of 2% 1 mm analysis passing rates up to 98.0% when applying the global and 95.2% when applying the local normalization.

The appropriate optimization of MLC parameters responsible for the properties of a particular device makes it possible to achieve high accuracy in MIM SureCalc® MonteCarlo Plan calculation.

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REFERENCE FIELDS FORMED AT THE DOSIMETRIC BETA-RADIATION FACILITY

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To reproduce absorbed dose units, directional and individual dose equivalents of beta radiation in tissue-equivalent matter, and to transfer the obtained units to working standards and dosimeters of beta radiation, beta radiation dosimetry units are used, which form the reference fields from radionuclide beta radiation sources.

ATOMTEX SPE has developed a beta-radiation dosimetric facility AT200, which allows the formation of reference beta-radiation fields using the following radionuclide sources:

Parameters	Radionuclide			
	^{147}Pm	^{85}Kr	^{90}Sr + ^{90}Y	
Type	BIP-50	KAC.D3	BIS-50	
Activity, GBq	9,32	14,8	1,14	20,7
Half-life, days	958	3915	10523	
Average energy beta-particle energy, MeV	0,06	0,24	0,8	
Maximum energy of beta particles, MeV	0,225	0,687	2,274	

Sources are placed in special holders made of materials that provide radiation protection from beta particles, as well as braking radiation arising in the elements of source construction. The sources are used together with equalizing filters made of polyethylene terephthalate, which provide uniformity of the field across the beam section at the location of the dosimeter to be calibrated.

The report presents the results of studies of the characteristics of beta-particle radiation fields obtained experimentally and by numerical simulation. The data on estimation of dose characteristics formed by a set of sources in the installation are given.

PHOTONUCLEAR METHOD FOR THE PRODUCTION OF MEDICAL RADIOISOTOPE ^{72}AS

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The method of induced activity was used to study photonuclear reactions on a natural mixture of selenium isotopes. The experiment was performed on a bremsstrahlung of an RM-55 electron accelerator at an electron energy of 55 MeV. The study examined the possibility of producing ^{72}As isotope in photonuclear reactions on a natural mixture of selenium isotopes. Experimental data on the cross-sections of photoproton reactions on Se isotopes are not available in the literature. The yields of the formation of ^{73,74,75,76,81,81m}Se isotopes as a result of ^{nat}Se(γ, in) reactions, the target nuclide ^{72}As and the side nuclides ^{71,74,76,77,78,79}As as a result of ^{nat}Se(γ, in1p) reactions were measured. The experimentally obtained yields of photonuclear reactions are compared with the yields calculated using theoretical cross-sections of photonuclear reactions from and the TALYS program.

APPLICATION OF LITHIUM-DOPED CRYSTALS IN TASKS OF SEPARATE DETECTION OF GAMMA-RAYS AND NEUTRONS

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Modern trends of radiation control instruments development require creation of highly efficient high autonomy detection devices with minimal dimensions, which allows radiation safety services to perform inspection of various objects in the most efficient way.

Currently, ^{3}He counters are used in most of the neutron detection devices. An alternative is the use of lithium-doped crystal scintillators, which combine the functions of gamma spectrometry and neutron detection. The main representatives of detectors of this class are CLYC [Cs_2LiYCl_6(Ce)], NaIL [NaI (Li+Tl)] and CLLB [$Cs_2LiLaBr_6$(Ce)].

The ATOMTEX SPE is developing probes for separate detection of neutron and gamma radiation on the basis of CLYC and NaI(Li+Tl) detectors. According to the results of the studies, NaI(Li+Tl) scintillator is more promising for use in the absence of strict requirements to the resolution capability due to simpler discrimination of radiation types and lower cost of the detector.

The use of the CLYC scintillator is associated with the need to solve the problem of optimal light collection, because this scintillator has light output twice less than NaI(Li+Tl) and its emission spectrum is shifted to UV region. Also the process of classification of the registered radiation is more complicated and requires the use of digital signal processing methods.

The report presents the analysis of pulses of CLYC, NaI(Li+Tl) detectors obtained from the photomultiplier tube and considers methods of pulse processing for separate detection of gamma-radiation and neutrons on these scintillators. The prospects of application of separate gamma-radiation and neutron detection units for various tasks are considered.

THE STATUS OF FOOD IRRADIATION RESEARCH IN LOMONOSOV MOSCOW STATE UNIVERSITY

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Radiation technologies are commonly used in different areas, such as medicine, in treatment of tumors, radioecology, to ensure radiation safety of the natural environment, and agriculture, to combat with pests and stimulate the growth of crops. Moscow State University (MSU) is currently focusing on five aspects of research in food irradiation. Our researchers are particularly involved in the development of irradiation technology with accelerated electrons. Such a focus is determined by economic demand in view of the fact that electron accelerators have proved to be more efficient in terms of dose rate and processing speed, and much safer compared to radioisotopes. Moreover, it is possible to determine the irradiation depth by varying electron beam energy. However, it is still unclear how to achieve a consistent dose uniformity in objects of different geometry and texture. To solve this problem we have developed and tested a dose uniformity method using aluminium modifiers placed between the accelerator output and the treated object. Researchers of MSU are now improving this method to ensure the 100% irradiation dose uniformity in objects with the linear dimension of up to 8 cm. Another area of MSU research is the reconstruction of electron beam spectrum using experimental depth dose distributions in phantoms developed specifically for simulation and measuring dose values. Knowing the spectrum of industrial accelerator allows to calculate depth dose distribution in the objects of different geometry and precisely estimate the dose uniformity throughout the treated food item. In search of optimal irradiation treatment parameters, our researchers are studying the effect of the dose value and rate, as well as type of irradiation on microbiological and chemical composition of a range of foods. The data obtained during the research can be used for the development of state irradiation guidelines. One more area of the research is detecting the fact of foodstuff irradiation by means of gas chromatography to identify organic volatile compounds, which show that some irradiation treatment has been performed on the item. Also the fluorescent fingerprinting express method is being assessed as a potential strategy to prove the fact of irradiation treatment. To address the needs of agriculture our university is studying the impact of pre-seeding irradiation treatment on crops infected with different fungi to increase the yield and its phytosanitary safety.

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Наши спонсоры

VOLNOE DELO
OLEG DERIPASKA FOUNDATION

Фонд поддержки социальных инноваций «Вольное Дело» основан выпускником физического факультета МГУ Олегом Дерипаска в 2008 году. Сегодня это одна из крупнейших в России организаций, работающих в сфере благотворительности, меценатства и волонтёрства. Фонд поддерживает отечественное образование и науку, решает социально значимые проблемы и содействует сохранению культурно-исторического наследия России.

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