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Fundamental problems and applications

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BOOK OF ABSTRACTS

Dubna 2024

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PLENARY TALKS

MANIFESTATION OF CHAOS IN NUCLEAR STRUCTURE PHENOMENA

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The description of giant dipole (GDR) and monopole (GMR) resonance decay widths requires to trace the spreading of the highly excited, collective states along the hierarchy of particle-hole configurations with various degree of complexity. 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. Indeed, our analysis of the dipole and monopole strength distributions in the lead region indicates on the onset of statistical properties close to those of the Gaussian Orthogonal Ensembles (GOE) of the Random Matrix Theory (RMT). We show that employment of the random distribution for the coupling between microscopic one-phonon states and two-phonon states, generated by the GOE distribution, gains a better insight into the description of general properties of the decay widths. Our microscopic calculations (based on the Skyrme forces) demonstrate that Landau damping of the one-phonon states is the basic mechanism of the decay widths of the GDR in heavy nuclei around ^{208}Pb [1]. However, the incorporation of ideas, borrowed from the RMT, providing the effective counting of the two-phonon configurations, contributed additionally to redistribution of the isovector dipole strength distribution. On the other hand, it is found that the main contribution into the decay of the GMR in this nuclear region is determined by a small number of two-phonon states strongly coupled to low-energy surface vibrations [2]. While a vast majority of the coupling matrix elements (that are small in value and following the GOE distribution) are responsible for the fine structure of the GMR decay width. A remarkable agreement between the results of the full microscopic calculations (based on QRPA phonons coupled by means of the microscopic coupling matrix elements with calculated two-phonon states) with those of the developed approach confirms the vitality of the proposed ideas.

1. A.P. Severyukhin, S. Åberg, N.N. Arsenyev, R.G. Nazmitdinov, Phys. Rev. C, 104, 044327 (2021).
2. N.N. Arsenyev, A.P.Severyukhin, R.G. Nazmitdinov, JETP Letters, 118, 718 (2023).

QUANTUM SHELLS IN NUCLEI AND BEYOND

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The present review covers historical aspects and present status of quantum shells (QS) in nuclei and some other quantum systems. The relation of QS with various nuclear features (deformation, pairing, giant resonances etc) is outlined. QS in nuclei and atomic clusters are compared. Supershells in atomic clusters are briefly described. Further, the recent studies related with QS in nuclei are reviewed, first of all, for superheavy (SH) nuclei. The last experimental and theoretical results for K-isomers are briefly discussed. Predictions for magic numbers in SH nuclei, obtained in modern density-functional theory (DFT) (with relativistic, Skyrme and Gogny forces), are outlined. Finally, we present some last Skyrme DFT results of our group for shell effects in low-energy spectra of nobelium isotopes.

PRE-SUPERNOVA (ANTI)NEUTRINO EMISSION VIA WEAK PROCESSES WITH HOT NUCLEI

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(Anti)neutrino luminosities and spectra arising from neutral- and charged-current weak reactions with a hot nucleus ^{56}Fe are computed for pre-supernova conditions and compared with the contribution of thermal processes [1,2]. It is found that thermodynamically consistent consideration of thermal effects within the thermal quasiparticle random phase approximation produces a higher luminosity and a harder spectrum of electron neutrinos, compared to the standard technique based on the large-scale shell model weak-interaction rates. It is shown that in the context of electron antineutrino generation, the neutrino-antineutrino pair emission via nuclear de-excitation (ND) is at least as important as the electron-positron pair annihilation process. We also show that flavor oscillations enhance the high-energy contribution of the ND process to the electron antineutrino flux. This could potentially be important for pre-supernova antineutrino registration by the Earth's detectors.

1. A.A. Dzhioev, A.V.Yudin, N.V. Dunina-Barkovskaya, and A.I. Vdovin, Particles 6 (2023) 682-692
2. A.A. Dzhioev, A.V.Yudin, N.V. Dunina-Barkovskaya, and A.I. Vdovin, Monthly Notices of the Royal Astronomical Society 527 (2024) 7701-7712

AB INITIO РАСЧЕТЫ СТРУКТУРЫ ЛЕГКИХ ЯДЕР И ЯДЕРНО-ФИЗИЧЕСКИЙ ЭКСПЕРИМЕНТ

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Обсуждаются возможности использования современных ab initio подходов для описания различных характеристик легких ядер и ядерных реакций, индуцированных их столкновениями, границы этих возможностей и перспективы расширения этих границ.

Анализируется качество описания: спектров уровней энергии ядер; их размеров; электромагнитных моментов, вероятностей электромагнитных переходов между уровнями как одинаковой, так и разной четности; вероятностей испускания резонансными состояниями нуклонов и кластеров, в частности амплитуд приведенных ширин распада этих состояний; асимптотических нормировочных коэффициентов связанных состояний.

Демонстрируется, что результаты ab initio вычислений перечисленных выше характеристик могут во многих случаях оказаться полезными для описания сечений резонансных и прямых ядерных реакций, предсказания их сечений и анализа результатов их измерений.

MODERN DETECTOR TECHNOLOGIES FOR NUCLEAR PHYSICS EXPERIMENTS AND DIAGNOSTIC STUDIES IN NUCLEAR MEDICINE

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Today, one of the nuclear physics tasks of experiments at high-energy accelerator complexes is the study of the superdense nuclear matter phase diagram. It is assumed that during the formation of such matter there will be an increased yield of particles, which include heavy c- and s-quarks. Due to the short life-time of these particles for precise reconstruction of their decay vertex the new tracking detector systems are needed. In this work a new concept of a vertex detector for the MPD (Multi-Purpose Detector) experiment at the NICA collider is proposed. In this detector, 3 inner layers based on monolithic active pixel sensors are maximally close to the collider beams interaction point and consist of a large area flexible ultra-thin silicon wafers. For the proposed concept the evaluation of the spatial resolution has been done. It was shown that the transition to such thin inner layers with smaller radii allowed reconstructing the decay vertices of D_s^+, D^0 and D^+ mesons.

In this work also an overview of modern detector technologies using silicon pixel sensors is provided for development of proton computed tomography for the diagnostics of tumor in hadron therapy methods. The development of new detector systems for digital track calorimeters will be shown, both for reconstruction of a large number of proton tracks and for proton energy measurements.

The results of experimental work (proton beams of 100 - 200 MeV) on the creation of digital track calorimeters will also be presented, together with the results of properties and characteristics studies of silicon pixel sensors in the context of high accuracy charged particle tracks reconstruction tasks.

The reported study was supported by the Russian Science Foundation, project no. № 23-12-00042, https://rscf.ru/en/project/23-12-00042/

HEAVY-ION PHYSICS RESULTS BY THE CMS EXPERIMENT

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Recent results from the Compact Muon Solenoid (CMS) Collaboration at the LHC (CERN) on heavy-ion physics will be presented.

HEAVY ION LINAC FOR NUCLEAR PHYSICS

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The high intensity heavy ion linac is an attractive instrument for the nuclear investigation. The high energy linac can be effectively used for the rare isotope production (for example – FRIB facility in MSU, USA and SPIRAL2 in GANIL, EU). The low energy linac ($\sim$ 7 MeV/nucleon) can be used for multi-nucleon transfer reactions investigation. In particular, the reactions study is important for understanding the so-called 3rd peak of the distributions of the astrophysical p-process. The project of the room temperature heavy ion cw-linac is based on the technology which is under development in framework of compact accelerator driven neutron source DARIA setup, it could be useful also for the other constructions [1,2]. The talk presents the linac structure and results of the cw RFQ and DTL development.

1. “Дорожная карта” в области ядерной физики, Ред. Л.В. Григоренко, М.: РАН, 2021. ISBN 978-5-907366-33-6.

2. Развитие физики и технологии ускорителей заряженных частиц, Ред.-сост. Б.Ю. Шарков, И.Н. Мешков, М: РАН, 2021. ISBN 978-5-907366-27-5.

HIGH-GRANULAR TIME-OF-FLIGHT NEUTRON DETECTOR HGND FOR THE BM@N EXPERIMENT

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A new high-granular time-of-flight neutron detector HGND (High Granural Neutron Detector) is being developed and constructed in order to measure azimuthal neutron flow in nucleus-nucleus interactions within at the BM@N experiment (JINR). The detector consists of alternating layers of copper absorber plates and matrices of scintillation cells with individual light readout by silicon photomultipliers. The HGND detector will be used in the fixed target BM@N experiment to identify neutrons and to measure their energy in heavy-ion collisions with energies up to 4 GeV per nucleon. The ratios of direct and elliptic azimuthal neutron flow to the corresponding proton flow, which can be measured by the magnetic spectrometer of the BM@N facility, should be sensitive, as shown in a number of models, to the symmetry energy in the equation of state (EoS) of high dense nuclear matter. Measuring these ratios is also important in astrophysics for understanding the structure of neutron stars, processes during supernova explosions and merging of double neutron stars.

The performance studies based on the results of simulations of the new HGND detector at the BM@N experiment will be presented. Results of time resolution measurements of scintillation cells will be shown.

THE JUNO EXPERIMENT: CURRENT STATUS AND PROSPECTS

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The Jiangmen Underground Neutrino Observatory (JUNO) represents a groundbreaking experiment currently under construction in China. Featuring a central detector with a diameter of 35.4 meters and containing 20 kilotons of liquid scintillator, which is read out by 17,612 large and 25,600 small Photomultiplier Tubes (PMTs), JUNO promises to deliver unprecedented statistics, high-energy resolution ($\sigma = 3\%$ @ 1 MeV), and a remarkably low energy threshold (approximately 0.2 MeV), thereby enabling a diverse physics program.

The primary objective of JUNO is to determine the neutrino mass ordering and precisely measure neutrino oscillation parameters. This will be achieved through the observation of over 100,000 reactor electron antineutrinos emitted from the Yangjiang and Taishan nuclear power plants over 6 years. Additionally, JUNO will provide high-statistics data on solar neutrinos, including those from ^{7}Be, and ^{8}B sources, as well as geo-neutrinos with a measurement uncertainty of 8% over a data-taking period of 10 years with a known Th/U ratio. Furthermore, JUNO will capture atmospheric neutrinos in both sub-GeV and GeV ranges, detect the diffuse supernovae neutrino background with a significance of 3σ over a 3-year period, and observe neutrinos from core-collapse supernovae.

In tandem with the central detector, JUNO will be supported by the Taishan Antineutrino Observatory (TAO) detector. TAO's main function will be to measure the antineutrino spectrum from the Taishan nuclear power plant with an energy resolution of $\sigma < 2\%$ @ 1 MeV and a statistical uncertainty of 1%. This satellite detector will aid in mitigating systematic uncertainties associated with the primary antineutrino spectrum from the reactor and facilitate measurements of short-baseline sterile neutrino oscillation, up to differences in squared masses of $\sim$ 8 eV^2. To achieve its unparalleled energy resolution, TAO will utilize Silicon Photomultipliers with a High Photon Detection Efficiency of approximately 50%, operating at a temperature of -50°C.

This presentation will provide an overview of the current status of the JUNO experiment, highlighting its groundbreaking capabilities and prospects.

БАЗА ДАННЫХ И СИСТЕМАТИКА МАГНИТНЫХ МОМЕНТОВ ЯДЕР

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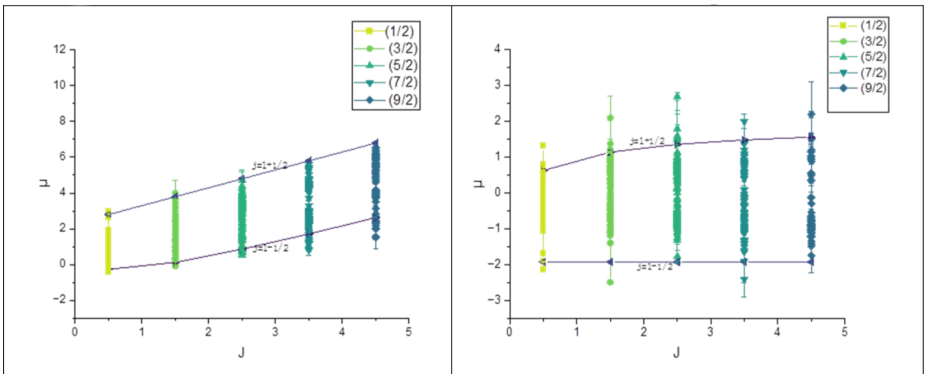
На основе компиляции [1] и файла ENSDF [2] создана новая база данных MagDa свойств ядерных состояний, для которых экспериментально определены магнитные моменты. Программа-интерфейс к этой базе данных позволяет делать выборки спектроскопической информации по различным параметрам, к которым относятся не только спин, энергия возбуждения, время жизни состояния, но и метод измерения и дата публикации результата. Для отобранных состояний можно получить подробную информацию о структуре и распадных свойствах. Программа-интерфейс представляет информацию не только в виде таблиц, которые могут далее использоваться по усмотрению пользователя, но и в виде графиков. Последнее свойство очень полезно при поисковых запросах.

На первом этапе была проведена систематика магнитных моментов ядер в основном состоянии. На рисунке показаны традиционные зависимости наблюдаемых магнитных моментов от спинов в А-нечетных ядрах.



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В приближении сферической симметрии (непрерывные линии на рисунке, «ограничивающие» значения магнитных моментов) проведено описание магнитных моментов легких ($Z < 20$) и околомагических ядер. Значение магнитного момента часто является решающим при определении конфигурации основного состояния нечетно-нечетного ядра.

1. N.J.Stone. Table of recommended nuclear magnetic dipole moments, IAEA Technical Report, INDC(NDS)-0794 (2019).

2. ENSDF: Evaluated Nuclear Structure Data File Search and Retrieval https://www.nndc.bnl.gov/ensdf/

THE TAGGED NEUTRON METHOD AND ITS APPLICATION FOR NUCLEAR PHYSICS STUDIES AND APPLIED RESEARCH

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The Tagged Neutron Method (TNM), sometimes also called Associated Particle Technique consists in irradiating the object of study with fast neutrons with an energy of about 14 MeV, which are formed in the reaction d+t→α+n [1]. Neutron tagging is carried out by registering an alpha particle with a special position sensitive detector built into the neutron generator. The use of TNM in experiments studying nuclear reactions with fast neutrons provides a number of important advantages, in particular, a decrease in the background due to the registration of events coinciding with α-particles. The study of the spectra of gamma rays produced in the reactions of inelastic neutron scattering makes it possible to carry out an elemental analysis of the irradiated object. Currently, TNM technology is widely used in various practical applications for remote non-destructive analysis of the elemental composition of a substance.

The TANGRA (TAgged Neutrons and Gamma Rays) project at JINR is aimed at investigations of the neutron-nuclear reactions using the tagged neutron method. An overview of recent activities in the framework of the project will be presented with an emphasis on the measurements of the gamma-ray emission cross sections and angular distributions from (n,xγ) reactions with 14.1 MeV neutrons using the tagged neutron method, as well as on the development and use of the TNM for non-destructive elemental analysis of various objects [2].

1. V Valkovic. 14 MeV Neutrons. Physics and Applications. — CRC Press, New York. 2015.
2. Yu.N.Kopach, M.G.Sapozhnikov, Physics of Particles and Nuclei, 2024, Vol. 55, No. 1, pp. 55–102.

ELECTROMAGNETIC NEUTRINOS: THE BASIC INTERACTION PROCESSES AND CONSTRAINTS FROM LABORATORY EXPERIMENTS AND ASTROPHYSICS

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We start with an introduction to the theory of neutrino electromagnetic properties [1]. Then we consider experimental constraints on neutrino magnetic $\mu\nu$ and electric dν moments, millicharge qν, charge radii $<$rν2$>$ and anapole aν moments from the terrestrial experiments (the bounds from MUNU, TEXONO, GEMMA, Super-Kamiokande, Borexino, COHERENT, XENON1T, CONUS and the most recent bounds from XENONnT [2] and LUX-ZEPELIN [3]).

Then we focus on the main manifestation of neutrino electromagnetic interactions, such as: 1) the radiative decay in vacuum, in matter and in a magnetic field, 2) the neutrino Cherenkov radiation, 3) the plasmon decay to neutrino-antineutrino pair, 4) the neutrino spin light in matter, and 5) the neutrino spin and spin-flavour precession are discussed. Phenomenological consequences of neutrino electromagnetic interactions (including the spin light of neutrino) in astrophysical environments are also reviewed. The best bounds from laboratory experiments and astrophysical observations on neutrino electromagnetic properties are confronted with the predictions of theories beyond the Standard Model.

1. C.Guinti, A.Studenikin, Neutrino electromagnetic interactions: A window to new physics, Rev.Mod.Phys.87(2015)531.
2. A.Khan, Light new physics and neutrino electromagnetic interactions in XENONnT, Phys.Lett.B837(2023)137650.
3. M.Atzori Corona et al., New constraint on neutrino magnetic moment from LZ dark matter search results,Phys.Rev.D107(2023)053001.
4. S.Jana and Y.Porto, Resonances of supernova neutrinos in twisting magnetic fields, Phys. Rev. Lett. 132 (2024) 101005.

THE MONUMENT (MUON ORDINARY CAPTURE FOR THE NUCLEAR MATRIX ELEMENTS IN $\beta\beta$ DECAYS) PROJECT'S OVERVIEW AND ADVANTAGES

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The main idea of the MONUMENT project is carrying out experimental measurements of muon capture at several daughter candidates for 0n2β decay nuclei. Obtained results are used to check the nuclear matrix elements calculations. In addition, the nuclear structure and the information of the particle's angular correlations of that process could be clarified.

STATUS AND DEVELOPMENT PLAN OF ACCELERATOR COMPLEX FLNR

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The presentation give information about current state of the FLNR accelerator complex, general information and last results work of facilities DC-280 and U-400, first results of U-400M facility modernization, information about New facilities for applied research DC 140 and creation process and Information about project U-400R.

MODERN NUCLEAR PHYSICS RESEARCH IN RADIATION MEDICINE

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Thanks to the studies of the structure of matter at the beginning of the 20th century and subsequent significant discoveries in particle physics, today people have a powerful tool in the form of ionizing radiation both for scientific purposes and for various sectors of the world economy. The development of radiation technologies has allowed nuclear physics methods to become firmly entrenched in human life and become an integral part of many areas of human activity. One of the most important such areas is the application of radiation technologies in medicine. The public's interest in radiation medicine is growing every year, as evidenced by the growth of scientific publications, radiotherapy centers, medical accelerators and other medical equipment based on ionizing radiation. However, with increasing interest, there is also increase number of tasks requiring modern nuclear physics research and new solutions to further improve the effectiveness of radiation technology. For example: in the field of radiation therapy, it is necessary to improve the efficiency of irradiation on electron and photon beams, as well as new methods of dosimetry on medical accelerators, in the field of radiation diagnostics, it is necessary to improve image quality and its automatic processing (removal of artifacts, segmentation, etc.), in the field of medical radioisotopes, research is underway in terms of obtaining radioisotopes in new ways. The question of the effect of ionizing radiation on structural changes in the blood is no less important. It is also necessary to study the biophysical aspects of radiation treatment of food products, since human health directly depends on the quality of food consumed. Currently, all of the above-mentioned studies are conducted all over the world, including in the Department of Nuclear Physics Methods in Medicine and Industry of the Moscow State University Research Institute of Nuclear Physics.

Thus, this report is devoted to modern nuclear physics research in radiation medicine, which is a key aspect of the successful application and development of this field.

HEAVY ION COLLISIONS AT INTERMEDIATE AND HIGH ENERGIES

UNSTABLE NUCLEI ^{8}Be AND ^{9}B AND THE HOYLE STATE IN RELATIVISTIC NUCLEAR FRAGMENTATION

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The BECQUEREL experiment is aimed at solving topical problems in nuclear clustering physics. The used method of nuclear track emulsion (NTE) makes it possible, due to its unique sensitivity and spatial resolution, to study in a unified approach multiple final states arising in dissociation of relativistic nuclei. Currently, a research focus is on the theoretical concept of α-particle Bose-Einstein condensate (αBEC) - the ultra cold state of several S-wave α-particles near coupling thresholds. The unstable ^{8}Be nucleus is described as 2αBEC, and the ^{12}C(0+2) excitation or Hoyle state (HS) as 3αBEC. Decays $^{8}\mathrm{Be} \to 2\alpha$ and $^{12}\mathrm{C}(0+2) \to {}^{8}\mathrm{Be}\alpha$ can serve as signatures for more complex αBEC decays. Thus, the 0+6 state of the ^{16}O nucleus at 660 keV above the 4α threshold, considered as 4αBEC, can sequentially decay $^{16}\mathrm{O}(0+6) \to \alpha^{12}\mathrm{C}(0+2)$ or $^{16}\mathrm{O}(0+6) \to {}^{28}\mathrm{Be}(0+)$.

The consideration of αBEC as an invariant phenomenon indicates possibility of its search in the relativistic fragmentation. A practical alternative is provided by NTE layers longitudinally exposed to relativistic nuclei. The invariant mass of ensembles of He and H fragments can be determined from emission angles in the approximation of conservation of momentum per nucleon of a parent nucleus. Owing to extremely small energies and widths, the ^{8}Be and HS decays, as well as $^{9}\mathrm{B} \to {}^{8}\mathrm{Be}p$, are identified in fragmentation of light nuclei by an upper constraint on the invariant mass.

Having been tested, 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 probability of detecting ^{8}Be in an event with an increase in number of relativistic α-particles was found. A preliminary conclusion is drawn that contributions of ^{9}B and HS decays also increase. The exotically large sizes and lifetimes of ^{8}Be and HS allowing suggesting possibility of synthesizing αBEC by successively connecting the emerging α-particles.The main task of the forthcoming stage of the project is to clarify the relation between the appearance of ^{8}Be and HS and α-ensemble multiplicities and search on this basis for decays of the ^{16}O(0+6) state. Currently, the BECQUEREL experiment aims to measure multiple channels of ^{84}Kr fragmentation below 1 GeV per nucleon. Searches for αBEC lead to the study of nuclear matter with temperature and density ranging from red giants to supernovae. In this respect NTE layers exposed to heavy nuclei at several GeV per nucleon of the NICA accelerator complex will make it possible to study relativistic ensembles of H and He isotopes of unprecedented multiplicity under optimal conditions.

1. P.I. Zarubin, Lect. Notes in Phys. 875, Clusters in Nuclei, Volume 3. Springer Int. Publ., 51 (2013); arXiv: 1309.4881
2. D.A. Artemenkov et al., Eur. Phys. J. A 56 (2020) 250; arXiv: 2004.10277
3. A.A. Zaitsev et al., Phys. Lett. B 820 (2021) 136460; arXiv: 2102.09541
4. D.A. Artemenkov et al., Phys. At. Nucl. 85, 528 (2022); arXiv: 2206.096

RELATIVISTIC EQUATION FOR FOUR-NUCLEON SYSTEM

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The paper generalizes the four-particle integral Faddeev-Yakubovsky equation to the relativistic case. The obtanied system of integral equations is solved by the iteration method and the binding energy and amplitudes of states of the helium-4 nucleus are found. The rank- one separable Yamaguchi potential is used as the NN interaction potential. In the calculations the only states with zero orbital momentum are considered - S states. The results of the calculation are compared with non-relativistic calculations and experimental value.

STUDY OF CORRELATIONS OF CHARGED PARTICLES IN Xe+W INTERACTIONS AT AN ENERGY OF 3.0 GeV/NUCLEON

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Experimental results on spatial correlations of charged particles in Xe+W interactions at the energy of 3 GeV/nucleon obtained at the Nuclotron internal target station are presented. The simulation of the detectors of the experimental setup has been performed using the Geant4 software package and the PHQMD (Parton-Hadron-Quantum-Molecular Dynamics) event generator.

PROBING OF EXOTIC STATES IN pp AND pA COLLISIONS

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The spectroscopy of higher lying charmonium states together with exotic mesons with masses above the 2mD open charm threshold has been full of surprises and remains poorly understood [1]. It is a good testing tool for the theories of strong interactions, including: QCD in both the perturbative and non-perturbative regimes, LQCD, potential models and phenomenological models. The experiments with antiproton-proton annihilation, proton-proton and proton-nuclei collisions are well suited for a comprehensive spectroscopy program, in particular, the spectroscopy of chamonuim and exotics states.

The currently most compelling theoretical descriptions of the mysterious XYZ mesons attribute them to hybrid structure with a tightly bound diquark [2] or tetraquark core [3 - 5] that strongly couples to S-wave molecular like structures. In this picture, the production of a XYZ states in high energy hadron collisions and its decays into light hadron plus charmonium final states proceed via the core component of the meson, while decays to pairs of open-charmed mesons proceed via the component.

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

In the hybrid scheme, XYZ mesons are produced in high energy proton-nuclei collisions via its compact ($r_{ms} < 1$ fm) charmonium-like structure and this rapidity mixes in a time ($t \sim \hbar/\delta M$) into a huge and fragile, mostly , molecular-like structure. δM is the difference between the XYZ mass and that of the nearest mass pole core state, which we take to be that of the χc1(2P) pure charmonium state which is expected to lie about 20 $\sim$ 30 MeV above MX(3872) [6, 7]. In this case, the mixing time, $c\tau_{mix}$ 5 $\sim$ 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 $\sqrt{s_pN} \sim 8$ GeV energy range with proton-proton and proton-nuclei collisions with $\sqrt{s_pN}$ up to 26 GeV and luminosity up to $10^{32cm^{-2-1}}$ 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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NEGATIVE PION PHOTOPRODUCTION ON THE TENSOR-POLARIZED DEUTERON AT VEPP-3

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The results of measurement of the T20 component tensor analyzing power in incoherent $\pi-$ meson photoproduction on the deuteron in the photon energy range of 300–650 MeV are presented. Experimental statistics of the reaction under study was isolated from the experiment that was designed to investigate photodisintegrathion on deuteron. In this experiment two protons were recorded by the upper and lower arms of the detecting system. The measured asymmetries of the yields with regard to the change in the sign of tensor polarization of deuterons were used to calculate the T20 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 (300-650) 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 2023 using the photon tagging system.

THE HYPERON POLARIZATION AND THE FORWARD-BACKWARD FLOW IN THE Bi+Bi COLLISIONS AT NICA

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The Bi-Bi collisions at $\sqrt{s_{NN}} = 9.0$ GeV are simulated within the PHSD transport model. After spectators separation and fluidization procedure, the velocity and vorticity fields are calculated. Then, the global polarization for different hyperon species is evaluated, and its dependence on the momentum, rapidity, and centrality is analyzed. Finally, the correlations of the polarization and forward-backward flow are shown.

EMISSION OF CUMULATIVE SECONDARY PARTICLES AND FRAGMENTS IN COLLISIONS OF HEAVY IONS OF INTERMEDIATE ENERGIES BASED ON NON-EQUILIBRIUM HYDRODYNAMIC APPROACH

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In development of the nonequilibrium hydrodynamic approach [1,2], we were able to successfully describe [3] the double differential cross sections for the production of cumulative protons, pions, kaons and antiprotons emitted at an angle of 00 for the collision of carbon nuclein the reaction $^{12}C+^{12}C$ at an energy of 19.6 GeV per nucleon on fixed target, obtained at the U-70 accelerator of the Institute of High Energy Physics (Serpukhov) [4]. For collisions of the same nuclei at the same energy, a description was obtained of the cross sections for the yield of protons and light fragments of deuterons and tritons emitted at an angle of 400 and studied in another experiment in [5]. These double differential cross sections reveal scaling for the yields of different fragments depending on their energy.

In continuation of the analysis of experiments at ITEP (Moscow) based on collisions of carbon nuclei with a beryllium target at the FRAGM installation, it was possible to obtain a description of the yields of ^{11}Be and ^{10}B fragments [6], emitted at an angle of 3.5° at an energy of carbon nuclei of 300 MeV per nucleon.

For this description, a nonequilibrium hydrodynamic approach and the Goldhaber statistical model were used. Our description of experimental data appears to be superior to cascade models and the quantum molecular dynamics (QMD) model built into the GEANT4 package. Along with the development of the hydrodynamic approach, the possibility of describing experimental data based on solving of the effective Klein-Gordon equation with dissipation was analyzed [7]. Our approach is applicable to collisions of both light and heavy nuclei, as can be seen from comparisons with experimental data and other theoretical approaches. This can be extended to the energy range of the NICA accelerator complex located at JINR (Dubna).

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THE MPD-ITS PROJECT. STATUS AND PERSPECTIVES

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The Inner Tracking System (ITS) of the Multipurpose Detector (MPD) will be a vertex silicon detector designed for the efficient registration of short-lived products of nucleus–nucleus interactions and it is planned to be built using the novel technology of monolithic active pixel sensors (MAPS) following the corresponding know-how and technological transfer from CERN's ALICE-ITS upgrade project (ALICE-ITS2) to JINR to create a large-area MAPS-only tracker at NICA. The project is being implemented as a collaboration of several institutions from Russia and China lead by JINR and the Central China Normal University (CCNU) respectively. This sophisticated and ambitious project represents equally the possibility of implementing at JINR the latest technology on components and production process, and the necessity of creatively overcoming the many obstacles for getting access to such technologies from Russia the current geopolitical conditions. During the presentation current status of the multiple aspects of the project will be reviewed along with the perspectives for the use of the MAPS technology at NICA.

PRODUCTION OF PROTONS, DEUTERONS, TRITONS IN ARGON-NUCLEUS INTERACTIONS AT 3.2 AGeV

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First physics results of the BM@N experiment at the Nuclotron/NICA complex are presented on studies of proton , deuteron and triton production in interactions of an argon beam with fixed targets of C, Al, Cu, Sn and Pb at 3.2 AGeV. Transverse mass distributions, rapidity spectra and multiplicities of protons, deuterons, tritons are measured. The results are treated within a coalescence approach and compared with predictions of theoretical models and with other measurements.

SEARCH FOR UNSTABLE NUCLEAR STATES IN THE FRAGMENTATION OF Kr NUCLEI AT 950 MeV/NUCLEON

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Since the discovery of the nuclear component of cosmic rays, the nuclear photoemulsion (NTE) method has made it possible to study the composition of relativistic fragmentation of nuclei at high-energy accelerators. The promising potential of the relativistic approach to the analysis of ensembles of fragments manifested itself in layers of NTE exposed by beams at energy of several GeV per nucleon, accelerated at the Synchrophasotron of JINR and Bevalak (USA) in the 1970s. Since the 2000s, the NTE method has been used in the BECQUEREL experiment at the JINR Nuclotron in relation to the cluster structure of nuclei, including radioactive ones, as well as in the search for unstable nuclear-molecular states. Due to its unique sensitivity and spatial resolution, application of the NTE method makes it possible to study in a unified approach many final states that appear while the dissociation of relativistic nuclei. In this aspect, it seems possible to search in α relativistic approach for an α-particle Bose-Einstein condensate (αBEC), an unstable state of S-wave α particles. The extremely short-lived ^{8}Be nucleus is described as 2αBEC, and the ^{12}C(0_2^+) excitation or Hoyle state (HS) is described as 3αBEC. The feasibility of more complex states is important in nuclear astrophysics.

Using NTE layers longitudinally exposed by beams of relativistic nuclei, it is possible to determine the invariant mass of ensembles of He and H fragments from the emission angles in the approximation of conservation of the initial momentum per nucleon. The decays ^{8}Be and HS, as well as the decays ^{9}B $\to$ ^{8}Bep, are identified during the fragmentation of light nuclei according to the upper limit on the invariant mass [1]. This approach was used to identify ^{8}Be and HS and search for more complex αBEC states in the fragmentation of medium and heavy nuclei. Recently, the probability of reconstructed ^{8}Be was found to increase with increasing number of associated α particles [2]. The exotically large sizes and lifetimes of ^{8}Be and HS suggest the possibility of synthesis of αBEC by sequential combination of the resulting α-particles $2\alpha \to {}^8$Be, ^{8}Be$\alpha \to {}^{12}$C(0_2^+), ^{12}C(0_2^+)$\alpha \to {}^{16}$O(0_6^+), 2^{8}Be $\to {}^{16}$O(0_6^+) and further with decreasing probability at each step while the emission of γ-quanta or recoil particles. Ongoing research is aimed at measuring the nα fragmentation channels of ^{84}Kr at energies up to 950 MeV/nucleon to determine the contributions of the 2α decay of ^{8}Be, the 3α Hoyle state and the search for the condensate state of 4α particles [3]. In this report discusses new results on the search for unstable nuclear states in the fragmentation of ^{84}Kr and the prospect of analyzing recent exposure of NTE in beams of Xe nuclei at 3.9 GeV/nucleon at the Nuclotron/NICA accelerator complex.

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STUDY OF Λ-HYPERON PRODUCTION IN COLLISIONS OF HEAVY IONS WITH SOLID TARGETS IN THE BM@N EXPERIMENT

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BM@N (Baryonic Matter at Nuclotron) is the first experiment collecting data at the accelerator complex of NICA-Nuclotron. The BM@N physics program is based on studies of highly compressed nuclear matter in heavy ion beams. The Nuclotron provides heavy ion beams in energy range 2.3 to 4.5 AGeV suitable for strange mesons and multi-strange hyperons production in nucleus-nucleus collisions close to the kinematic threshold.

Data were collected with a carbon beam at 4 and 4.5 AGeV kinetic energy and a set of nuclear fixed targets: Al, C, Cu, Pb.

We present the results on transverse momentum, rapidity spectra, and Λ-hyperon yields. The comparison is done with theoretical model predictions and the experimental C + C results at a beam energy of 2 AGeV (HADES, GSI).

DOUBLE POLARIZED DEUTERON-DEUTERON SCATTERING AND TEST OF T-INVARIANCE

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The total cross section of the interaction of deuterons polarized transversely with respect to the beam direction with the polarization P_y and a tensor-polarized deuteron target with the polarization P_{xz} is a null-test signal of the effect of violation of invariance with respect to time reversal (T) while conserving spatial (P) parity. This effect is very similar to that expected in double polarized pd and ^{3}He-d scattering with vector polarized protons and ^{3}He nuclei and tensor polarized deuterons studied in Refs. [1,2]. Here this effect is studied on the basis of the Glauber theory with account of full spin-dependence of nucleon-nucleon scattering amplitudes. Previously such an extension of the Glauber model was done for pd elastic scattering in Ref. [3]. For dd elastic scattering, the corresponding formalism is developed for the first time in the present work. For simplicity we restrict ourselves by single- and double-scattering mechanisms of dd scattering and keep only the S-component of the deuteron wave function. All types of NN interactions nonvanishing on the mass shell [4] are taken into account. Numerical results for the energy dependence of the expected effect of T-violation under P-parity conservation are obtained at the deuteron beam energies of 150-1000 MeV/nucleon.

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CREATION OF THE THEORETICAL DATA BASE FOR THE RARE CROSS-SECTIONS OF NUCLEAR PROCESSES, CALCULATED IN THE QUARK-LEVEL MODEL FOR NUCLEAR REACTIONS CHIPS

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The CHIPS-TPT program (Rospatent 2014611928) is developed in Dukhov Automatic Research Institute for simulation of neutron-nuclear reactions at relatively low energies under control of the international program Geant4 with the open code. This program has a credit as an alternative for the NeutronHP library, created inside Geant4 in C++ as a copy of the MCNP algorithms written in FORTRAN. But the CHIPS-TPT library includes more powerful algorithms of the CHIPS model, which can simulate high energy nuclear reactions. The CHIPS model is a quark-level model, which can simulate nuclear fragmentation of excited nuclei on the quark level not only at high energies, but at low energies too, e. g. for the pion capture reactions. The essence of the CHIPS algorithm is to capture in nuclear matter the energy and momentum transfer from the projectile and create inside the nucleus the excited hadronic state Quasmon, which dissipates the excitation energy by the quark exchange with the surrounding nuclear clusters. By this model not only the spectra of the pion capture reaction are well fitted, but the photonuclear spectra and the spectra of the antiproton-nucleus annihilation are described too. Even the neutron spectra of the exotic nuclear reaction of muon capture are fitted. The CHIPS model in comparison with the intra-nuclear cascade models generates more appropriate spectra of heavy nuclear fragments. For the neutron-nuclear reactions the non-elastic cross-section is taken from the existing data bases to convert the differential multiplicity of the secondary particles to the inclusive spectra. After the deep-inelastic quark exchange phase of the CHIPS simulation on the relativistic quark-level is finished (the **u** and **d** quarks in CHIPS are massless), the simulation on the nonrelativistic nucleon-level starts, while the neutron evaporation is possible (a neutron can be separated). When the nuclear excitation drops below the neutron separation energy threshold, the gamma-cascade simulation starts. When the virtual nucleus excitation after the last neutron radiation is in the gamma-cascade region, then the closest real excitation level is selected, taking into account the width of the closest excitation levels. After that the last neutron decay is re-simulated with the fixed mass of the residual nucleus, which corresponds to the selected excitation level. Starting with this level the gamma-cascade is simulated. As a future work the level strengths of the competing closest resonance levels will be taken into account. So far a technical difficulty of the CHIPS simulation is lack of the level schemes for some residual nuclei, but for low energies it practically neve happens. Thus, for every energy of the projectile neutron in the e. g. (n,$\alpha\gamma$) reactions, including the elastic scattering, when the residual nucleus is in the ground state, one need to simulate a separate channels of the decay in alpha-particle and the residual nucleus with the all set of levels of excitation. This is a big job, so in the report only one example of ^{16}O(n,$\alpha\gamma$) reaction is considered, where the gamma-level can have different Doppler width for the direct excitation and for the excitation through a decay of the higher excited level. It is planned to create a theoretical CHIPS data base on the basis of the CHIPS model simulation of nuclear reactions the same as the theoretical data base TENDL was created on the basis of the TALYS simulation of nuclear reactions.

ELECTROMAGNETIC DISSOCIATION OF NUCLEI: FROM LHC TO NICA

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In ultraperipheral collisions (UPC) of relativistic nuclei without overlap of their nuclear density distributions the collision partners are mutually impacted by Lorentz-contracted Coulomb fields [1]. This leads to a variety of processes induced by equivalent Weizsäcker-Williams photons. In particular, large neutron emission cross sections ($\sim$ 200 b) were measured in the ALICE experiment at the LHC for the electromagnetic dissociation (EMD) of ^{208}Pb nuclei at $\sqrt{s_{\rm NN}} = 5.02$ TeV [2], leading to the production of lead isotopes as secondary nuclei. As follows from calculations [3], Tl, Hg, Au, Pt, Ir, Os, Re, W, Ta and Hf are also produced in EMD of ^{208}Pb at the LHC with the cross sections of 1-30 b exceeding or comparable to the total ^{208}Pb-^{208}Pb hadronic cross section of 7.67 b. The cross sections of neutron and proton emission in the EMD are expected to be smaller for nucleus-nucleus collisions at NICA. However, it is important to calculate these cross sections in order to evaluate a possible contamination of the detected hadronic events by EMD events, which can affect the detector performance.

By means of RELDIS model [1], we have simulated the EMD of ^{209}Bi and ^{124}Xe in ^{209}Bi-^{209}Bi and ^{124}Xe-^{184}W collisions in the MPD experiment at NICA in collider and fixed target modes, respectively. The cross sections of the production of given numbers of forward neutrons and protons, their energy and angular distributions have been calculated. Mutual EMD events in ^{209}Bi-^{209}Bi collisions were also modeled, since such events can in principle mimic very peripheral hadronic events. EMD of ^{124}Xe was also modeled in UPC with CsI target in the BM@N experiment. In such collisions, the emission of a single neutron from electromagnetically excited ^{124}Xe dominates, providing a unique well-collimated monoenergetic neutron beam that can be used for detector calibration or applied research, e.g. to study unexplored radiobiological effects of high energy neutrons.

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ANALYSIS OF NUCLEAR TRACK EMULSION EXPOSED BY RELATIVISTIC HADRONS

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The recent results of exposure of a nuclear track emulsion (NTE) in a mixed hadron beam is discussed. The purpose of this work is to search and measure the length of short-range tracks of alpha particles produced in the interactions of hadrons and nuclei from the composition of a NTE. Modeling the ionization losses of alpha particles in the substance of a NTE in the SRIM program made it possible to reconstruct their kinetic energies in each found event. Reconstruction of tracks in full 4π-geometry makes it possible to reconstruct the emission angles of alpha particles with high accuracy. In this way, combinatorial spectra of invariant masses of systems of (2-3) alpha particles in the event have been obtained. The angular and energy correlation of the produced alpha particles is presented.

SPLITTING EFFECT OF LIGHT NUCLEI MOMENTUM DISTRIBUTIONS AT FRAGMENTATION OF IRON IONS WITH ENERGY OF 230 MeV/NUCLEON

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The results of iron fragmentation on different targets at energy 230 MeV/nucleon are presented. Experimental data were obtained with the FRAGM experiment and TWA heavy ion facility, which has a unique opportunity to measure the momentum distribution of fragments with high resolution at small angles [1,2]. In contrast to the typical fragmentation, where the momentum spectra have Gaussian-like shapes, the emission of light fragments has a double-humped structure. This splitting effect is most clearly manifested in proton spectra. An attempt to describe the effect by asymmetric fission and multifragmentation is discussed. Experimental data are compared with the results of the FRS-GSI measurements [3] and with the predictions of various models of nucleus-nuclear collisions.

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MEASUREMENT OF NEUTRON ENERGY SPECTRA IN THE REGION OF LARGE ANGLES IN Xe + Csl COLLISIONS AT ENERGY OF 3.8 A GeV

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Neutron production double-differential cross section was measured for ^{124}Xe + CsI collisions at energy 3.8 A GeV with a compact TOF spectrometer as a part of BM@N setup at external beam channel of the Nuclotron. The aim of this study is to obtain new experimental results on neutron emission from excited spectators of the target nuclei. The measurement was performed at angles $\theta > 90°$ and it covers an energy interval of emitted neutrons from 2 to 200 MeV. Neutron detectors based on stilbene with pulse shape discrimination of gamma-rays and a time resolution of 110 ps allow to use short flight distances of $\sim$30 cm and by these to get small contribution from gamma-ray and neutron background. The preliminary results of data analysis are presented and discussed.

COVARIANCE AND NONCOVARIANCE OF RELATIVISTIC SPIN EQUATIONS

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To solve difficult problems of nuclear spin physics like the proton spin crisis physicists should perfectly understand what spin is. There are a few correct definitions of the relativistic spin operators [1]: Dirac spin definition and two Foldy-Wouthuysen spin definitions coupled with the center-of-charge and center-of-mass position operators. The conventional definition explicitly or implicitly uses the Foldy-Wouthuysen representation and presents the total angular momentum as a sum of the orbital angular momentum defined in the laboratory frame and the spin defined in the particle rest frame. It has been proven [2] that this definition leads to noncovariant spin equations. Two other definitions result in covariant spin equations but are not convenient.

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PERFORMANCE STUDY OF THE ANISOTROPIC FLOW MEASUREMENTS WITH FIXED-TARGET MODE OF THE MPD EXPERIMENT AT NICA

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The study of the high-density equation of state (EoS) and the search for a possible phase transition in dense baryonic matter are one of the main goals of beam energy scan programs with relativistic heavy ion collisions at energies $\sqrt{s_{NN}}$=2-5 GeV.

The results of performance study for the differential anisotropic flow measurements of identified charged hadrons at energies $\sqrt{s_{NN}}$=2.5-3.5 GeV will be presented, using a realistic procedure for data simulation and reconstruction in the MPD experiment at NICA working in a fixed-target mode (MPD-FXT).

CUMULATIVE PRODUCTION AT CENTRAL RAPIDITIES DUE TO INTERACTIONS INVOLVING FLUCTONS

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We study the yields of pions and protons with large transverse momenta at mid-rapidities in the region that is kinematically inaccessible for single nucleon-nucleon interactions (the so-called cumulative region), which may be observed in nuclear collisions by MPD and SPD detectors of the NICA complex. We assume that particles in this kinematic region are formed as a result of scattering from the so-called nuclear “fluctons”, which from a modern point of view can be considered as clusters of cold quark-gluon matter with a high baryon density. We generalize the microscopic quark-parton approach developed in [1-4] for describing the production of cumulative particles in the fragmentation region of one of the colliding nuclei to the case of particle production in this new cumulative region.

For the case of nucleon-flucton interaction, we found that there is a change in the ratio of the proton to pion yield in the region of central rapidities and high transverse momenta compared to the cumulative production in the fragmentation region of one of the nuclei. The reason for this is that in the case of cumulative proton production, the mechanism of coherent coalescence (recombination) of three flucton quarks into a proton dominates, while in the case of cumulative pion production, the fragmentation of a single flucton quark into a pion dominates [3,4,9]. We compare the obtained theoretical results with the results of our preliminary estimates of particle yields in this region based on a more phenomenological approach [5-7].

We show that the study of cumulative phenomena in this new region of central rapidities and large transverse momenta also opens up the possibility of experimentally studying a new interesting process of flucton-flucton interaction in MPD and SPD experiments at NICA, which cannot be studied in the region of fragmentation of one of the nuclei. Note that the study of this process in dd collisions at future NICA SPD has some advantages over MPD. There is no contribution from additional nucleon-nucleon collisions when both deuterons are in the state of 6-quark bags at the moment of collision. This reduces the background and simplifies the registration of a cumulative particle in correlation with particles formed from fragmentation of a flucton residue [8]. An important role in recording rare cumulative processes is also played by the much higher frequency of collisions that the SPD installation can record compared to the MPD.

It is important that studies of particle production in this new cumulative region are available for experimental study only at relatively low initial energies of colliding nuclei of the NICA collider facility and are not available for experimental study at the RHIC and LHC colliders.

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RECONSTRUCTION OF STRANGE PARTICLE DECAYS FROM Xe+CsI INTERACTIONS WITH THE BM@N SPECTROMETER

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In December, 2022 – January, 2023 the BM@N experiment performed its first physics run with full configuration. Over 400 million events of Xe+CsI interactions with the Xe beam kinetic energy of 3.8A GeV were collected. Since then, the collaboration put strong efforts to reconstruct and analyze collected data. The current status of this activity will be presented with the emphasis given to the ability of the experiment to reconstruct strange particles via their weak decays to charged hadrons.

EVENT-BY-EVENT DETERMINATION OF THERMODYNAMIC QUANTITIES AT NICA ENERGIES

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Currently, studies of the properties of a strongly interacting medium in collisions of hadrons and nuclei are actively being carried out in experiments at accelerator complexes at BNL, CERN, and JINR. The NICA collider (Dubna) and the multipurpose detector MPD are expected to be put into operation soon. One of the primary research directions for these experiments involves scanning the phase diagram of strongly interacting matter, investigating the phase transition between hadronic gas and quark-gluon plasma, and searching for the critical point. For these purposes, various fluctuation and correlation observable quantities are used.

The process of nuclear collisions and the evolution of the quark-gluon medium created in them in the energy range of the NICA collider is quite complex, and the thermodynamic equilibrium achieved is only local. All thermodynamic characteristics of the medium undergo unavoidable event-by-event fluctuations. In this regard, it is quite relevant to develop a method for estimating the temperature and baryon chemical potential in each event.

To extract thermodynamic parameters from the particle yields and spectra, the Thermal-FIST package was applied. The average values of temperature (T) and baryon chemical potential (μ_B) were extracted from the experimental data of NA61/SHINE and STAR experiments, and the fluctuations of these values were established. Then, it was checked to what extent it is possible to extract event-by-event thermodynamic characteristics, and the method resolution was estimated. The results showed the fundamental applicability of this method in a wide range of (T, μ_B).

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CHARGED FRAGMENTS-SPECTATORS MEASUREMENTS WITH SCINTILLATION WALL IN THE BM@N EXPERIMENT Xe+CsI@3.8 AGeV

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The report presents the performance of the BM@N Scintillation Wall (ScWall) achieved during the first physics run at the Nuclotron accelerator with Xe+CsI at 3.8 AGeV collisions. The report is devoted to the design of the ScWall and its capability to differentiate charged fragments produced in nucleus-nucleus collisions. The measured charge spectrum and the ability of the ScWall to measure nucleus-nucleus collision geometry are presented. In addition, a comparison between the experimental data and the simulation is provided.

ДИБАРИОНЫ: ПОИСК И ТЕОРЕТИЧЕСКИЕ ОЦЕНКИ

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В работе анализируются нуклон-нуклонные взаимодействия $pn \to d\pi^0\pi^0$, $pn \to d\pi^+\pi^-$ и $pp \to d\pi^+\pi^0$, в которых в конечном состоянии образуется дейтрон и пара пи-мезонов. Им противопоставляются конечные состояния с парой свободных нуклонов.

Получено экспериментальное подтверждение формулы, вляющейся следствием сохранения изоспинов $\sigma(d\pi^+\pi^-)= 2\sigma(d\pi^0\pi^0) + 1/2\sigma(d\pi^+\pi^0)$. Масса 2380 МэВ и ширина 80 МэВ резонансной особенности в сечении подтверждают оценки теории мультиплетов.

Если резонансная структура видна в s-канале для системы протон-нейтрон, то она так же проявляется в поведении некоторых наблюдаемых величин для упругого рассеяния np, например, для анализирующей способности A_y.

PEELING AWAY SURFACE NEUTRONS FROM ^{209}Bi IN ASYMMETRIC COLLISIONS

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The ratio of neutron to proton densities increases toward the periphery of heavy nuclei. While this leads to a subtle difference (∼0.5 fm) in the mean square radii of neutrons and protons, the thickness of such a neutron skin (NS) is very sensitive to the nuclear symmetry energy term in the equation of state (EOS) of nuclear matter important for both nuclear physics and astrophysics [1]. There have been several measurements of the NS thickness in ^{208}Pb, see e.g. [2, 3], but their results diverge. In this respect, the estimation of the NS thickness in a neighboring nucleus such as ^{209}Bi by new methods may help to solve the puzzle.

In this work, by means of Abrasion-Ablation Monte Carlo for Colliders (AAMCC) model [4] with MST-clustering [5] we simulate the emission of free spectator neutrons and protons in ultracentral collisions of ^{209}Bi with target nuclei equal to (Bi) or smaller (Au, W) than ^{209}Bi. It is expected that an excited donut-shaped spectator mater can be produced in such asymmetric ultracentral collisions. Then, an immediate break-up to free spectator neutrons and protons is predicted, and the detection of these neutrons and protons can provide a unique possibility to analyze the n/p ratio at the nuclear periphery.

The multiplicity distributions of spectator neutrons and protons were calculated with and without neutron skin in ^{209}Bi. It was found that the neutron multiplicity distributions are different in Bi-Bi, Bi-Au and Bi-W collisions and they are sensitive to the presence of neutron skin in the projectile nucleus. The average neutron yield was calculated as a function of the volume of spectator matter in the considered ultracentral collisions.

The studies of ultracentral ^{208}Pb–^{208}Pb collisions at the LHC were proposed previously [6] to identify the presence of NS in ^{208}Pb. The ultracentral ^{96}Zr–^{96}Zr and ^{96}Ru–^{96}Ru collisions were also investigated at RHIC [7]. In all these cases the collisions of equal mass nuclei were investigated. In this work the method of Ref. [6] was extended to collisions of ^{209}Bi with lighter projectiles. The yields of spectator nucleons in ultracentral collisions and the n/p-ratio of released spectator nucleons were studied as a probe of NS thickness.

As known, the BM@N experiment is equipped with forward detectors capable of detecting spectator nucleons and fragments from ^{209}Bi projectiles [8]. In view of further upgrades of the BM@N setup one can rely on the possibility to disentangle free spectator neutrons from protons to conduct the measurements proposed in the present work.

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SELF-SIMILARITY APPROACH IN RELATIVISTIC NUCLEAR PHYSICS

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A self-similarity approach to description of interaction of accelerated nuclei in the intermediate energy range is presented. This approach represents a relativistically invariant description of angular, energy, and A-dependences of inclusive hadron production cross sections in nuclear collisions. Special attention is paid to the description of cumulative, subthreshold processes at intermediate energies. Quantitative estimates for secondary particle production in fixed-target experiments at extracted beams of the NICA accelerator complex and heavy meson production in collider experiments with heavy nuclei are considered.

LOBACHEVSKY GEOMETRY IN RELATIVISTIC NUCLEAR PHYSICS. DIRECTED NUCLEAR RADIATION

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Application of the Lobachevsky geometry for solution of some problems in relativistic nuclear physics is discussed. Geometric description of the problem of particle production and the idea of "elementary particle" is considered. The geometric properties of particle distributions in relativistic nuclear reactions and the new regularities based on the properties of the Lobachevsky space are presented. The results of analysis are illustrated by a vast experimental material acquired in the bubble chamber experiments.

PROMPT PHOTON PRODUCTION IN SUB-PROCESSES $qg \to q\gamma$ AND $q\gamma \to q\gamma$ OF COMPTON SCATTERING IN COLLISION OF LONGITUDINALLY POLARIZED PROTONS AT NICA ENERGIES

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Photons are of particular importance in the study of hadronic and nuclear interactions at high energies. The process of prompt photon production plays an important role in determining the distribution of gluons in the proton and testing some aspects of perturbative quantum chromodynamics.

The dependence of the differential cross-section of the production of prompt photons with sub-processes of mixed chromo-electrodynamic $qg \to q\gamma$ and pure electrodynamic $q\gamma \to q\gamma$ Compton scattering in collision of longitudinal polarized protons on the sum of the energies of colliding protons $\sqrt{s}$, the transverse momentum p_T of photons, the cosine of the scattering angle $Cos(\theta)$ and the rapidity of photons y and x_T was investigated.

Investigation of differential cross-section on on the sum of the energies of colliding protons $\sqrt{s}$, the transverse momentum p_T of photons showed that influence of polarization of the initial particles can increase or decrease the differential cross- section depending on the helicity. With different signs of the helicity of the initial particles, the total cross-section decreases, and with the same signs of the helicity, the total cross-section increases compared to the non-polarized case. The polarization of the initial particles strongly influence the subprocess $qg \to q\gamma$ which contribution dominate the contribution of the subprocess $q\gamma \to q\gamma$.

The dependence of the differential cross-section on the cosine of the prompt photon scattering angle for subprocesses $qg \to q\gamma$ and $q\gamma \to q\gamma$ shows that polarization has not changed the character of the dependence. The maximum value of the differential cross-section is achieved at departure angles close to 16 and 164 degrees. This indicates that the probability that the photon will be scattered along the collision axis is highest. As the scattering angle increases, the differential cross-section decreases. The value of the differential cross-section has a maximum value at $y = \pm 1.95$ and decreases with changes in the value of y. The differential cross-section has a minimum value at $y = 0$.

The investigation of double-spin asymmetry of the processes showed that the helicity of the initial particles affects the double-spin asymmetry of the sub-process $qg \to q\gamma$ and $q\gamma \to q\gamma$ in different ways. Thus, we can conclude that it is necessary to take into account the influence of the subprocess $q\gamma \to q\gamma$ when modeling and analyzing experimental data of proton-proton collisions at NICA energies.

FEASIBILITY STUDY FOR DIRECTED FLOW MEASUREMENTS IN THE BM@N EXPERIMENT

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Baryonic Matter at Nuclotron is a fixed target experiment designed to probe the properties of the strongly interacting matter at the region of high baryonic densities. We report a feasibility study for measuring the directed and elliptic flow with respect to spectator symmetry plane for the recent physical run at the BM@N facility. The new results will extend the existing data available from the previous measurements of v_1 and v_2 in heavy ion collisions at the beam energy of several GeV. The system size and passing time dependency of v_1 are discussed.

MAGNETIC MOMENT AND POLARIZABILITY OF THE VECTOR STRANGE MESONS FROM LATTICE QCD

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We explore the ground state energy behaviour of the vector K^* mesons in external abelian magnetic field of QCD scale in SU(3) lattice gauge theory. We calculate the magnetic polarizability of the neutral and magnetic moment of the charged K^* mesons by background field method and investigate the dependence of these physical quantities from the value of m_s/m_d ratio.

О ПРОБЛЕМЕ ПРОИСХОЖДЕНИЯ МАССЫ НУКЛОНА

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Проблема происхождения массы нуклона является одной из наиболее значительных проблем современной физики. Уже в конце прошлого века происхождение этой массы было признано как результат непертурбативного взаимодействия глюонов и токовых кварков при нарушении киральной симметрии. Однако механизм такого взаимодействия остаётся открытым в отличие от механизма возникновения массы лептонов и токовых кварков. Поэтому поиск такого механизма необходим для понимания происхождения основной наблюдаемой массы современного мира, образованного нуклонами. Интенсивность такого поиска в настоящее время несравнимо мала по сравнению с интенсивностью исследований, которые привели к открытию механизма Браута-Энглера-Хиггса и его экспериментальному подтверждению. Тенденция к изменению этой парадоксальной ситуации может возникнуть только на базе изучения процессов с участием конституентных кварков, образующих нуклоны. Экспериментальным подходом для этого может стать изучение неупругих центральных нуклон-нуклонных соударений при сравнительно невысоких энергиях. В этом отношении уникально благоприятны условия, возникшие в настоящее время на экспериментальном комплексе NICA в ОИЯИ.

ANISOTROPIC COLLECTIVE FLOW AT HIGH BARYON DENSITY

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The anisotropic collective flow is one of the important observable sensitive to the equation of state (EOS) and transport properties of the strongly interacting matter created in relativistic heavy-ion collisions. In this work we discuss the recent flow measurements from the Beam Energy Scan programs at SIS, SPS and RHIC and anticipated performance of the BM@N and MPD experiments at Nuclotron-NICA.

RECENT PHENIX RESULTS ON IDENTIFIED CHARGED HADRON PRODUCTION

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Quark gluon plasma (QGP) is a deconfined state of matter, which exists at the temperatures T>170 MeV and energy densities $\epsilon \sim 1$ GeV/fm^3. Initially it was thought that such conditions can be reached only in the relativistic heavy ion collisions (e.g. Au+Au, Cu+Cu, Cu+Au and U+U collisions), while in small collision systems such as p+Al, p/d/^{3}He+Au conditions are not sufficient for QGP formation. Observation of signatures for QGP formation in p/d/^{3}He+Au collisions by the PHENIX experiment in 2019 has renewed interest in small collision systems and hadronic matter phase diagram studies.

One of the probes for studying the phase transition between hadronic and quark-gluon matter is identified charged hadron ($\pi^{\pm}$, $K^{\pm}$, p, $\bar{p}$) production. Enhancement of proton to π-meson yields (p/π) measured in the intermediate p_T range (1.5 GeV/c $\lesssim p_T \lesssim$ 4 GeV/c) in heavy ion collisions in comparison to the ones measured in p+p collisions is usually attributed to the recombination. Recombination implies the formation of hadrons as a result of combining quarks located nearby in phase space. Formation of QGP in the collision significantly increases the probability of recombination. In collisions where QGP is not formed (p+p collisions), hadrons are mainly produced as a result of string breaking, known as fragmentation.

The talk presents latest PHENIX results on $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ measurements in p+Al, ^{3}He+Au, Cu+Au collisions at the energy of $\sqrt{s_{NN}} = 200$ GeV and in U+U collisions at $\sqrt{s_{NN}} = 193$ GeV. It was obtained, that in central Cu+Au, ^{3}He+Au and U+U collisions recombination plays an important role, while in p+Al collisions and peripheral ^{3}He+Au, Cu+Au, and U+U collisions fragmentation dominates over recombination. The conclusions are supported by comparison with theoretical predictions based on the AMPT and PYTHIA models, as well as by comparison with the results of neutral meson production measurements. The possible role of radial flow in particle production at intermediate p_T range will also be highlighted.

PHOTODISINTEGRATION OF POLARIZED DEUTERON. STATUS OF THE EXPERIMENT AT THE VEPP-3 STORAGE RING

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The experiment on photodisintegration of tensor-polarized deuteron is in progress. It is carried out at VEPP-3 storage ring using the internal polarized gas target technique. The component of tensor analyzing power T20 is obtained by measurement of the target polarization asymmetry for deuteron photodisintegration in the photon energy range 400 – 640 MeV. Photon energy is defined by the system for tagging almost-real photons was developed at the BINP. We discuss the results of the last run at VEPP-3 and the future plans to study this physical process.

FRAGMENTATION FEATURES OF Be, B, C NUCLEI IN NUCLEAR TRACK EMULSIONS

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The report will give a brief overview of the experimental results of the relativistic fragmentation of ^{7,9}Be, ^{10}B, ^{10,12}C in the Becquerel project in JINR. The fragmentation of a large variety of light nuclei was investigated using the emulsions exposed to few A GeV nuclear beams at JINR Nuclotron-NICA complex . A nuclear track emulsion is used to explore the fragmentation of the relativistic nuclei. The presented observations serve as an illustration of prospects of the modern accelerators and nuclear track emulsions for nuclear physics researches. Due to a record space resolution the emulsion technique provides unique entirety in studying of light nuclei, especially, neutron-deficient ones. Providing the 3D observation of narrow dissociation vertices this classical technique gives novel possibilities of moving toward more and more complicated nuclear systems. It was studied fragmentation of Be, B, C nuclei with energy 1.2 A GeV in a nuclear track emulsion, derived at the Nuclotron-NICA, JINR. The results of an exclusive study of the interactions of relativistic ^{7,9}Be, B and C nuclei lead to the conclusion that the known features of their structure are clearly manifested in very peripheral dissociations

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IS THERE DIFFRACTION DISSOCIATION OF NUCLEAR NUCLEONS IN NUCLEUS-NUCLEUS INTERACTIONS

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In nucleon-nucleon collisions there are processes: diffraction dissociations of projectile nucleon (PrD), dissociation of target nucleons (TrD), meson exchange processes (ME) and non-diffractive interactions. Correspondently, $\sigma^{in} = \sigma_{PrD}+\sigma_{Trd}+\sigma_{ME}+\sigma_{ND}$. Perhaps there is only one possibility to estimate these cross sections in reggeon approach. According to the approach, σ_{ME} fast decreases with energy grouth. σ_{PrD} and σ_{Trd} grouth logorithmically as the elastic cross section. σ_{ND} has a weak logorithmical grouth. Multiplicities of produced particles in the processes are related as $M_{ME} < M_{PrD}$, $M_{TrD} < M_{ND}$. In nucleus-nucleus (AA) interactions these relations and thier energy dependences can be changed. If one neglects PrD and TrD processes, $\sigma^{in} \simeq \sigma_{nd}$, multiplicities of produced particles will be overestimated. In other case, the multiplicities will be underestimated. These limiting situations are implemented in various Monte Carlo event generators. In the presentewd report, we propose a "soft"scheme of accounting of the diffraction processes in AA interactions. As a result, we have an acceptable description of experimental data of NICA BMN and NA61/SHINE collaborations (at higher energies). Details of the sheme will be considered in the report.

COLD SUPERDENSE BARYONIC COMPONENT OF NUCLEAR MATTER

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Started in the late 1950s at DLNP JINR pioneering experimental studies of proton scattering on nuclei allowed D.I. Blokhintsev assumed the presence in nuclei a lower mass nucleus in a compressed state, i.e. the presence of a cold strongly compressed component in ordinary nuclear matter. The search and study of two- and three-nucleon systems in nuclei continued at DLNP JINR and ITEP (Moscow) and beyond. The investigations were carried out in the kinematic region, outside the kinematic of the nucleon-nucleon interaction. In the future, the processes in this kinematic region were called cumulative processes.

In this report the results of the cumulative processes study outside of the nuclear fragmentation region and with production of particles with the transverse momentum greater than 1 GeV/c is presented. These experiments were carried out with proton and carbon nuclei beams by the IHEP(Protvino) accelerator complex. The data were takeout using the SPIN set up – single-arm magnetic spectrometer. The obtained data showed that the processes of direct knock-out of deuteron and tritium nuclei with momentum up to 6.5 GeV/c are observed. This confirms the presence of deuterons and tritium in the nuclear matter in a highly compressed state, in other words, existing of the cold superdense baryonic component.

STATUS AND PREPARATIONS FOR THE FIRST PHYSICS WITH THE MPD EXPERIMENT AT NICA

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The Multi-Purpose Detector (MPD) is the main heavy-ion experiment of the NICA complex under construction at JINR. With collisions of heavy-ions in the energy range $\sqrt{s_{NN}} = 4 - 11$ GeV, MPD will scan the region of high net baryon density of the QCD phase diagram to look for the critical end point and study the first order phase transition predicted to occur in that region. The commissioning of the MPD and first data taking with Xe-Xe or Bi-Bi collisions at ~ 7 GeV is foreseen to start in 2025. The MPD comprises a rich physics program that includes the study of hadron spectra and hyper-nuclei production, collective flow, correlations and fluctuations, hyperon global polarization, electromagnetic probes, open charm production. In this talk, we present the status of the project, its competitiveness and its physics measurements feasibility with the first beams.

TOWARDS UNDERSTANDING OF K_s^0 MESON PRODUCTION IN HADRONIC INTERACTIONS

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Recently, the NA61/SHINE collaboration has presented experimental data on K_s^0 meson productions in proton-proton interactions at projectile momenta (P_{lab}) of 31, 40 and 80 GeV/c [1]. Earlier, the collaboration obtained the analogous experimental data at P_{lab}=158 GeV/c [2]. As it was shown in [1,2] , there are no Monte Carlo models that can well describe all the experimental data. Only at $Plab$=158 GeV/c, the EPOS model reproduces reasonably well the experimental data.

The description of the experimental data of the NA61/SHINE collaboration by the Geant4 FTF model [3] will be given in our report. According to the FTF model, K^- mesons are mainly produced by the fragmentation of quarks and antiquarks. Productions of K^+ mesons are connected with the fragmentation of di-quarks. The K_s^0 meson yields are coupled with the fragmentation of either quarks/anti-quarks or di-quarks.

Earlier, we have described [4] experimental data on K^+ and K^- meson productions in the proton-proton interactions measured by the NA61/SHINE collaboration. In that study, the main problem that we have identified was the tuning of the fragmentation of di-quarks for K^+ mesons. The experimental data on K_s^0 meson production allowed us to check our tuning. Now, we have reached the best description of K_s^0 yields in the proton-proton collisions.

The mechanism of the K_s^0 meson production can be studied using two-particle transverse-momentum correlations proposed by us in [5]. The correlations between K_s^0 mesons and Λ hyperons, protons, $^-$, π^- mesons produced in proton-proton interactions at center-of-mass energy of NN collisions of 10 GeV have been calculated in the Geant4 FTF and Pythia 6.4 models. The strong P_T correlations between K_s^0 mesons and Λ-hyperons, K^+ mesons, protons have been found. The two-particle P_T correlations can be studied at NICA SPD experiment. The study of the two-particle correlations can help to clarify the mechanism of quark-gluon string fragmentation.

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Low-energy incomplete fusion: a systematic study of entrance channel parameters

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Research into heavy-ion (HI) fusion, a key area of modern nuclear reaction physics, has flourished in recent decades pursuant to developments in accelerator technology. The primary goal of studying HI reactions is to gain knowledge about the underlying processes and how they are affected by entrance channel parameters, such as beam energy, angular momentum, and mass asymmetry. The fusion mechanism of non-α-cluster projectiles, such ^{14}N and ^{19}F, has been studied in the low-energy zone. It has been challenging to analyze the contributing degrees of freedom in such reactions due to the absence of experimental data. The present study reports the measurement of residual cross sections from the ^{19}F induced reaction on ^{93}Nb within the energy range of 3-7 MeV/A. The stack foil activation technique followed by offline γ spectroscopy was employed to measure the cross sections of residues populated in the reaction. The experimental data were compared with theoretical predictions from statistical model code PACE4 to probe the underlying reaction dynamics. The imitation of xn and pxn channel data grossly by model code suggests the production of residues via the complete fusion (CF) mode, while the enhancement observation in α-channel cross sections hints at the signatures of incomplete fusion in addition to the dominant CF. Thus, the ICF strength fraction (FICF) was calculated. Moreover, the estimated incomplete fusion fraction has been used to study the effect of several entrance channel parameters on incomplete fusion reaction dynamics. The present analysis shows the presence of strong clustering in the ^{19}F projectile as α and ^{15}N.

VARIATION OF THE SOURCE VELOCITY IN COLLISIONS 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 superconductind accelerator NUCLOTRON. Source velocities of carbon and lithium fragments were measured (Fig. 1) with the 4π device FAZA [1].

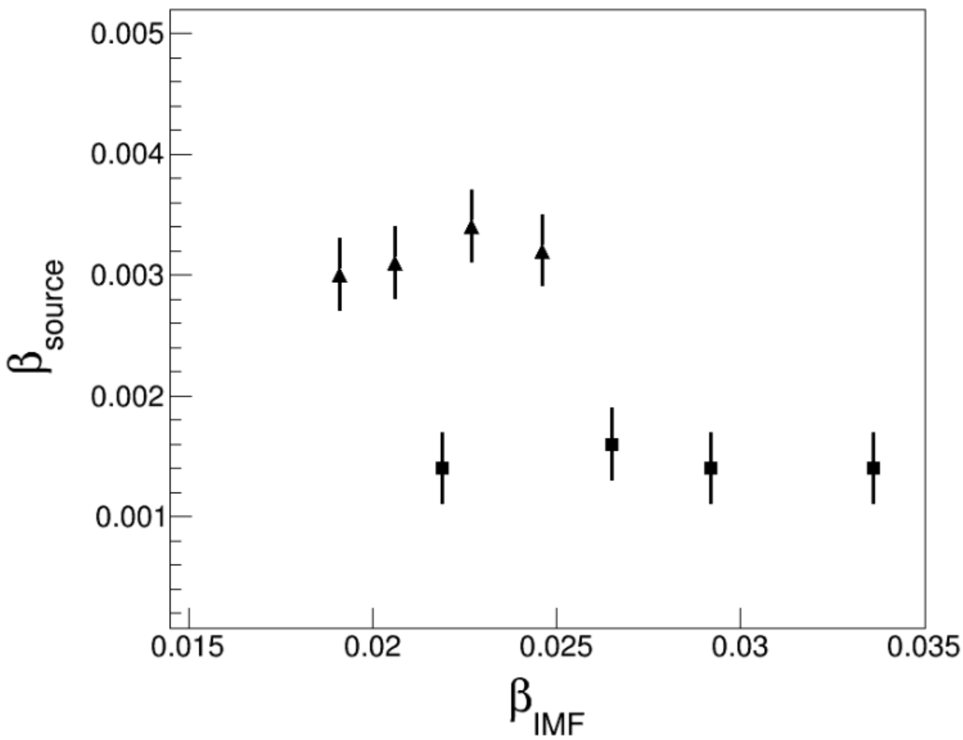

Fig. 1. Source velocities of a target spectator as a function of lithium (boxes) and carbon (triangle) fragment velocity in units of the speed of light.

It was found decreasing source velocities as the charge of fragment is decreasing. Different explanations of this observation are considered.

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DUALITIES IN HEAVY-ION COLLISIONS

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The interplay between different theoretical descriptions of nuclear matter is considered. The statistical approach based on Zubarev density matrix appears to be dual to the geometrical one based on conical singularities for accelerated media. The new phase transition in accelerated media is predicted in both approaches which may explain the hadronization and fast thermalization.

NUCLEAR STRUCTURE: THEORY AND EXPERIMENT

SOME FEATURES OF BETA-DECAY STRENGTH FUNCTION IN HALO NUCLEI

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The probability of the β-transition is proportional to the product of the lepton part described by the Fermi function $f(Q_\beta - E)$ and the nucleon part described by the β-decay strength function $S_\beta(E)$. Until recently, experimental investigations of the $S_\beta(E)$ structure were carried out using total absorption gamma-ray spectrometers ($TAGS$) and total absorption spectroscopy methods, which had low energy resolution. With $TAGS$ spectroscopy, it became possible to demonstrate experimentally the resonance structure of $S_\beta(E)$ for Gamow–Teller (GT) β-transitions [1]. However, $TAGS$ methods have some disadvantages arising from low energy resolution of $TAGS$ spectrometers. Modern experimental instruments allow using nuclear spectroscopy methods with high energy resolution to study the fine structure [2] $S_\beta(E)$.

In this report the fine structure of $S_\beta(E)$ in halo nuclei is analysed. When the parent nuclei has nn Borromean halo structure, than the Gamow-Teller resonance and pygmy resonances in GT β-decay strength function $S_\beta(E)$

in daughter nuclei may have structure corresponding to np tango [3,4] halo. When neutron excess is high enough, resonances in $S_\beta(E)$ may simultaneously have both nn Borromean halo component and np tango halo component and form so-called mixed halo [3,4]. Analysis of the $S_\beta(E)$ structure in halo nuclei allow to determine the most suitable region for the Wigner $SU(4)$ spin-isospin symmetry. Value $Z/N \approx 0.5 - 0.6$ may correspond to the $SU(4)$ spin-isospin symmetry region.

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DYNAMICS OF YRAST BANDS UP TO MAXIMUM KNOWN SPINS IN EVEN THORIUM NUCLEI

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There are only a few works using the boson approach to describe the intersection of the collective band and the band built on a two-quasiparticle mode. The first of these was the work of Gelberg and Zemel [1] based on IBM1. In it, the Hamiltonian term responsible for the interaction of the collective and non-collective bands was replaced by a constant and did not depend on either the spin J of a pair of quasiparticles or the total spin I. The limit val-ue $J^{\pi} = 10^{+}$ is accepted for the case of Xe, Ba, Ce, etc. due to configuration ($h^2_{11/2}$. In [2], collective states were considered in the IBM2 approximation, and the interaction of collective and quasiparticle excitation modes was considered sequentially through a long chain of matrix elements. Thus, to couple a collective mode with a mode con-taining a pair of quasiparticles $J^{\pi} = 10^{+}$, fourth order in perturbation theory is required. As a result, in such a model a very weak interaction of intersecting bands of states is realized. These works did not receive further development. In [3], using IBM1, the space was also ex-panded to include bosons up to $J^{\pi} = 10^{+}$, but the parameters of the interaction terms of collective states and states including quasiparticle pairs were calculated microscopically. How-ever, even in this case, automatic strong mixing of bands with different modes as the leading level could not be fully achieved.

This problem was solved in a series of works, the idea of which was outlined in more detail in [4]. It turned out that it is necessary to take into account the connection between high-spin quasiparticle modes and states that also contain quasiparticles, but which are used when renormalizing the microscopically calculated parameters of the traditional Hamiltonian IBM1. This allowed us to significantly expand the channels of interaction. As a result, strong mixing of states was obtained for several states at once in the band intersection region, which led to large values of $B(E2)$ at the band intersection point, regardless of the position of the energy of the quasiparticle pair. Moving on to heavy and superheavy nuclei, the need arose to expand the two-quasiparticle basis of phonons and, accordingly, bosons to pairs with due to the pair of quasiparticles $(j_{15/2})^2$.

This was done in [5], on the basis of which all even isotopes of Th for which excitation energies were known were analyzed. These are nuclei in the $^{220-236}$Th range. The first of them has an almost ideal vibration spectrum and a first excitation energy of 373 keV. The latter, respectively, has an energy of 48 keV. A preliminary analysis of excitation energies us-ing IBM1 phenomenology showed that it is possible to reproduce energies well up to the max-imum known spins, and this is, for example, up to 30^{+} in ^{232}Th. In this regard, the question arises about the role of high-spin quasiparticle modes and their influence on the spec-trum of observed states. It turned out that in nuclei with A = 220, 222 the crossing of the bands occurs, but very smoothly, so it doesn't significantly affect the smooth dependence of the moment of inertia on the square of the frequency, at least for ^{222}Th. For heavier thorium isotopes, where the band energies are already significantly reduced, the main compo-nent remains collective. The reasons for this are being discussed.

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ВИРТУАЛЬНЫЕ И РЕЗОНАНСНЫЕ СОСТОЯНИЯ В ТРЁХЧАСТИЧНЫХ СИСТЕМАХ $d-\mu^- -t$, $d-\mu^- -d$

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В работе находятся корни однородных уравнений Фаддеева на физическом и нефизическом листах трёхчастичной энергии систем $d-\mu^- -t$, $d-\mu^- -d$ с использованием процедуры прямого численного интегрирования [1] по комплексной плоскости энергий. Осуществлено аналитическое продолжение связанных по каналам упругого рассеяния и термоядерным реакциям двухчастичных уравнений Липпмана-Швингера на нефизический лист энергии [2], решения для которого генерируются зависящими от углов двухчастичными потенциалами МТ-типа. Параметры этих потенциалов подобраны из наилучшего описания оценённых экспериментальных данных по термоядерным dt и dd реакциям. Кулоновское взаимодействие в двухчастичных секторах учитывается в рамках двухпотенциальной модели [3] с введением экранированного кулоновского потенциала. Проведённые численные расчёты показывают наличие нескольких связанных состояний в системах $d-t-\mu^-$, $d-t-e^-$, которые исчезают при выключении короткодействующего dt взаимодействия. На нефизическом листе энергий в области энергий [0;20] кэВ с шагом по энергии 500 эВ расчёты показывают наличие нескольких виртуальных и резонансных состояний в системах $d-\mu^- -t$ и $d-\mu^- -d$. Обсуждается также более реалистичное шестичастичное обобщение данных систем $d\mu^- t - n\mu^-$4He и $d\mu^- d - n\mu^-$3He($p\mu^-$3H), которые возникают уже на трёхчастичных порогах.

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FINDING PARAMETERS OF MULTI-CHANNEL RESONANCES FROM DISCRETIZED SPECTRA

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Recently we have suggested a new method for calculating resonance parameters in multi-channel and three-body systems, using the formalism of the spectral shift and spectral density functions [1]. The method is based on the possibility of reconstructing the spectral and integrated density of states from discretized spectra of the total and asymptotic Hamiltonians found within the variational method. The key point of the approach is combining many discretized spectra of the same dimension, obtained using bases with slightly changed parameters, into one common dense spectral set (union). Analysis of such a dense spectral set for the total Hamiltonian allows one to determine a position and a width of a multi-channel and three-body resonance.

The efficiency of the proposed approach is demonstrated by several multi-channel and three-body examples using a Gaussian basis. The convergence of results when expanding the basis dimension can be justified within the quasi-continuity concept [2] for the case of a multi-channel problem, while for the three-body case it is shown numerically. The developed approach allows one to avoid difficulties associated with the Coulomb interaction and to study problems with charged particles as well, for example, two-proton radioactivity. In particular, the width of the ground state of the ^{6}Be nucleus was calculated within the framework of the three-cluster α-p-p model [1].

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Appearance of superconducting pair correlations in spherical even-even nuclei

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The formation of superconducting pair correlations between like nucleons in the ground state of spherical even-even nuclei is considered within a special Bogoliubov transformation. The influence of the monopole pairing interaction on the energy of single-particle states is taken into account.

It is shown that the emergence of pair correlations depends on the particle number and shell structure.

In open subshell nuclei the correlations exist at any attractive monopole interaction. In this case, nucleon pairs are distributed over all subshells participating in the pairing interaction.

The closed shell nuclei are considered within simplified model with constant pairing interaction. It is confirmed that the superconducting pair correlations appear if the coupling constant G exceeds a certain threshold value. Rough upper and lower estimates are obtained for the threshold value.

SPIN SCISSORS MODE IN ACTINIDES

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The scissors mode is investigated in the actinide region, including even-even superheavy nuclei up to ^{256}No, within the Time Dependent Hartree-Fock-Bogoliubov (TDHFB) approach. The solution of TDHFB equations by the Wigner Function Moments (WFM) method predicts a splitting of the scissors mode into three intermingled branches due to spin degrees of freedom [1]. Both the calculated energy centroid and integrated $M1$ strength in ^{254}No are in good agreement with the results of recent measurements performed by the Oslo method [2]. The energy centroids and summed $B(M1)$ values for other transuranium nuclides are predicted.

The calculations are performed also for ^{232}Th and ^{236,238}U isotopes. The scissors resonance in many actinide region nuclei exhibits a prominent double-hump structure [3,4]. The WFM analysis allows to assume that the observed splitting of scissors resonance can occur due to the separation of conventional scissors and spin-scissors excitations.

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DIPOLE ELECTRIC AND MAGNETIC STRENGTHS IN ^{156}Gd

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In connection with recent NRF experiment for dipole spectra in ^{156}Gd [1], various E1 and M1 excitations in this nucleus are investigated in the framework of the fully self-consistent quasiparticle random phase approximation (QRPA) with Skyrme forces [2]. The low-energy pygmy dipole resonance (PDR), isovector E1 giant dipole resonance (GDR), isovector M1 low-energy orbital scissors resonance (OSR), M1 spin-flip giant resonance (SFGR) are covered. Besides, we consider a toroidal E1 resonance and low-energy M1 spin-flip states. The deformation splitting and dipole-octupole coupling of electric excitations are analyzed. Our calculations show a good agreement with E1 NRF data but disagree with M1 data at 4-6 MeV, where, in contradiction with our calculations and previous (p, p') data, almost no M1 strength was observed.

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NUCLEAR ELECTROMAGNETIC MOMENTS AND RADII NEAR N = 126 NEUTRON SHELL

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Charge radii of Tl, Pb and Bi isotopic chains and magnetic moments of the ground state $J^{\Pi} = 1/2+$ (Tl^g) and $11/2-$ (Tl^m) isomeric states are calculated. The self-consistent Theory of Finite Fermi Systems (TFFS) based on the modified Energy Density Functional DF3-a by Fayans et al. is used. The calculated ground-state charge radii of Tl, Pb and Bi isotopic chains reveal distinctive kink at the N = 126 shell closure which has a similar magnitude, as in the neighboring mercury, lead and bismuth isotopic chains. For Tl isotopic chain, the experimental kink indicators $\xi = \delta < r2 > 128/126/\delta < r2 > 126/124$ [1] are described by the present calculation. Taking into account the meson exchange in the external field operator and in the effective spin dependent NN -interaction, as well as the regular effects of np-nh configurations and non-regular phonon-coupling (PC) corrections enables an improved description of the ground state magnetic moments in the long isotopic chain of thallium isotopes. Calculated magnetic moments agree fairly well with the isotopic trend and qualitatively reproduce the "asymmetric" jump at N = 126 revealed by the experiment [2]. For N = 82-126, "parabolic" N- dependence of the 11/2 - Tl m isomeric state magnetic moments and its value [1] is well reproduced without phonon-coupling (PC) corrections.

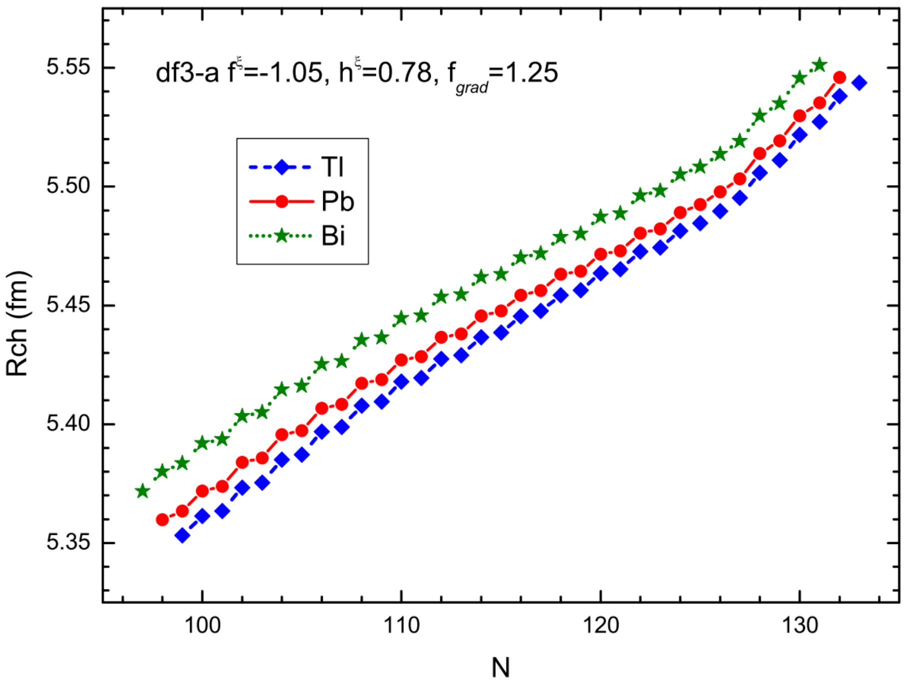

Fig. The ground-state charge radii Rch of Tl, Pb and Bi isotopic chains calculated within DF3-a functional.

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SPIN-DIPOLE STRENGTHS AND NEUTRON SKIN THICKNESS OF ^{90}Zr, ^{132}Sn, ^{208}Pb

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The strength functions of charge exchange spin-dipole (SD) excitations are calculated in the continuum quasiparticle random-phase approximation based on the Fayans density functional DF3-f with modified isovector part [1]. An impact of the isovector parameter h_2^- of the functional on the charge-exchange spin-dipole excitations (0^-, 1^-, 2^-) are studied for ^{208}Pb, ^{132}Sn and ^{90}Zr. The sum rules are calculated using both ground state radii and direct integration of the total SD strength distributions [2]. A comparison with the experimental SD sum rule in ^{90}Zr [3] gives one an additional possibility to check previously estimated h2- values [1] which described well the recent combined estimate for the neutron skin thickness ΔRnp in ^{208}Pb and corresponding parameters of nuclear matter equation of state - symmetry energy J (ρ_0) and a slope parameter L (ρ_0) [4].

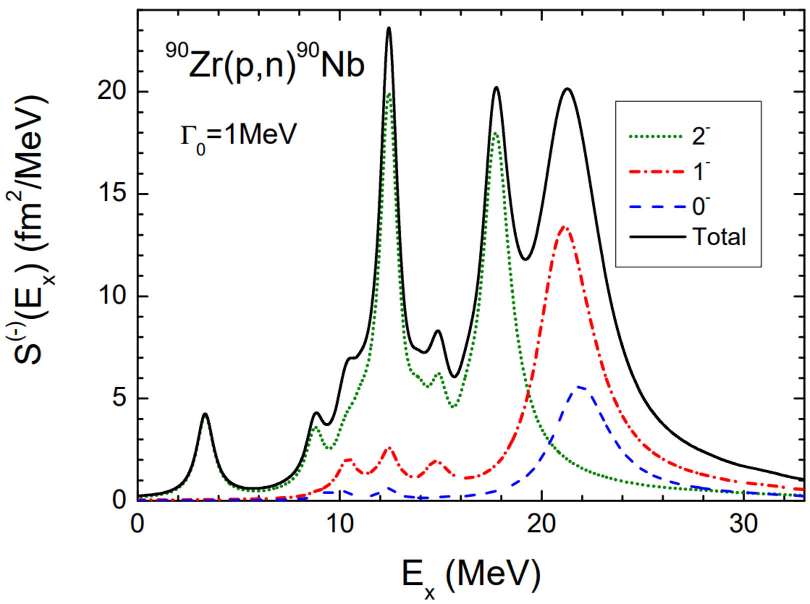

Fig. Strength functions of 0^- (in blue), 1^- (red) and 2^- (green) excitations in ^{90}Zr(p,n)^{90}Nb and total strength function (ful line). Calculation with the DF3-f functional for the h-2 = 1.5.

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INDUCED DIPOLE INTERACTION IN SCATTERING OF POSITRONS AND ELECTRONS OFF LIGHT ATOMIC TARGET

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Induced dipole interaction in scattering of positrons and electrons off light atomic target Scattering of a charged particle with a two-particle target system which is bound by the attractive Coulomb interaction is considered. 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 [1,2]. In this contribution we discuss the role of 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 [3] is used for constructing asymptotic solutions. The derived asymptotics is then intended for the use in electron and positron scattering off the hydrogen (anti hydrogen) atom calculations in the energy region above the thresholds of exited states of the target where the induced dipole interaction produces specific effects in scattering data [4-6]. The Faddeev-Merkuriev set of equations is used for describing the scattering process [7].

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ZEEMAN EFFECT IN NUCLEI

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Wigner Function Moments method is applied to solve Time Dependent Hartree-Fock-Bogoliubov equations. The dynamical equations for the second rank irreducible tensors are derived. Their solution for ^{164}Dy produces fourteen energy levels: ten high lying ones with $E > 10$ MeV (including isoscalar and isovector Giant Quadrupole Resonances) and four low lying $K^\pi = 1^+$ ones with $E < 4$ MeV. Three low lying levels represent three types of nuclear scissors modes: orbital (conventional) one and two spin ones. Fourth level is disposed below all scissors modes and has the electrical (non magnetic) feature. Its nature can be understood after solving dynamical equations for irreducible tensors with $K^\pi = 2^+$ and $K^\pi = 0^+$ and studying the deformation dependence of the found low-lying levels. The results of calculations for ^{164}Dy demonstrate in an obvious way that the lowest 1^+ state is just one of three $(K^\pi = 0^+, 1^+, 2^+)$ branches of $I^\pi = 2^+$ state, which can exist in a spherical nucleus (and which is split due to deformation into these three branches). It is discovered that the antiferromagnetic properties of nuclei predicted in [1], where they were called as "intrinsic angular momenta lead to the splitting of 2^+ states already at the zero deformation. So, we predict the existence inside of nucleus the phenomenon, which is known in atomic physics as the Zeeman effect [2]!

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FINITE ELEMENT SOLVER FOR COLLECTIVE NUCLEAR MODELS

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Computational scheme and solver of the finite element method for solving elliptic multidimensional boundary value problems with variable coefficients given as in analytical, as in tabular form describing collective models of atomic nuclei implemented in Mathematica and C++ are presented.

Benchmark calculations of the spectrum, quadrupole momentum and electric B(2E) transitions of generalized Bohr-Mottelson boundary value problems for the exact solvable and collective model of atomic nuclei including mixed derivative of two dimensional vibrational part of five dimensional Hamiltonian in representation of angular momentum in intrinsic frame are analyzed.

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СРАВНЕНИЕ МЕТОДОВ ДИАГОНАЛИЗАЦИИ ГАМИЛЬТОНИАНА БКШ С ТОЧНЫМ СОХРАНЕНИЕМ ЧИСЛА ЧАСТИЦ

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Традиционным методом определения собственных функций и собственных значений гамильтониана модели Бардина-Купера-Шриффера является квазичастичный подход с приближенным сохранением числа частиц. Однако в ряде случаев этот подход оказывается недостаточно точным. Тогда необходимо воспользоваться методами с точным сохранением количества частиц. Один из таких подходов [1] основывается на представлении основного состояния сферической системы из N частиц (N четное) в виде

$$|N\rangle = \left(S^{+}\right)^{N}|0\rangle\,,$$

где $S^{+} = \sum\limits_{i}\beta_i\left(a_i^{+}a_i^{+}\right)_{J=0}$ — оператор рождения коррелированной пары частиц с моментом J, a_i^{+}— оператор рождения частицы на уровне i. При этом построение возбужденных состояний с четным количеством частиц сводится к замене одного из операторов рождения пары частиц на произвольный двухчастичный оператор. Количество таких двухчастичных операторов можно увеличивать, что ведет к появлению различных возбужденных состояний. Недостатком этого подхода является заданный вид волновой функции, а достоинством — возможность использования удобного формализма симметрических полиномов. Однако по мере увеличения количества неспаренных частиц удобство метода уменьшается.

Другой подход [2] заключается в построении волновых функций четных систем без использования операторов S^{+} на основе N операторов $\left(a_i^{+}a_i^{+}\right)_{J=0}$, распределенных в основном состоянии по одночастичным уровням согласно вариационному принципу. Построение возбужденных состояний сводится или к изменению распределения этих операторов, или к появлению состояний с ненулевым сениорити s. Для низколежащих состояний этот метод требует больше вычислительного времени, однако по мере перехода к высоколежащим состояниям трудоемкость обоих методов сближается, но второй точнее, так как не использует заранее заданного вида волновой функции $|N\rangle$.

Проведены расчеты перекрытия волновых функций, полученных в рассматриваемых подходах в зависимости от количества и положения одночастичных уровней, количества частиц, константы парного взаимодействия и величины s, а также сравнение вычислительного времени.

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АНАЛИЗ МЕЖПОЛОСНЫХ И ВНУТРИПОЛОСНЫХ ПЕРЕХОДОВ СОСТОЯНИЙ ПОЛОЖИТЕЛЬНОЙ ЧЕТНОСТИ ИЗОТОПОВ ^{182,184}W

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Изотопы ^{182,184}W многократно изучались в распаде ^{182,184}Ta и многочисленных ядерных реакциях [1-5]. Наиболее полные результаты по этим ядрам представлены в работе [1,2]. Энергии коллективних уровней низколежащих полос близки к рассчитанным по сверхтекучей модели [6].

Экспериментальные данные энергии, вероятностей внутриполосных и межполосных электрических переходов, также отношения вероятностей переходов для ^{182,184}W указывают на наличие отклонения от правила Алаги [1-5].

В настоящей работе исследованы структура, энергетические и электрические свойства состояний положительной четности ядер ^{182,184}W в рамках феноменологической модели [7-9], учитывающей кориолисово смешивание состояний низколежащих ротационных полос. Вычислены спектр энергии, структура состояний ротационных полос, вероятности внутриполосных и междуполосных $E2$-переходов и отношения вероятностей $E2$-переходов из уровней γ - вибрационной полосы, также статические матричные элементы основной и γ - полос. Вычисленные значения энергии, вероятностей $E2$-переходов и их отношений сравниваются с существующими экспериментальными данными, которые дают хорошие согласия с экспериментом.

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RESONANT STATES OF THE 3n SYSTEM IN THE SS-HORSE–NCSM APPROACH

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The SS-HORSE–NCSM method [1] is generalized to the case of democratic decay into an odd number of fragments. This method is applied to the search for resonances in three-neutron system (trineutron) using *ab initio* No-Core Shell Model [2] calculations with realistic nucleon-nucleon potentials [3-5].

We predict two overlapping trineutron resonances with spin-parities $3/2^-$ and $1/2^-$ which energies E_r and widths Γ are nearly the same. For the Daejeon16 interaction [3], we obtain $E_r = 0.5$ MeV and $\Gamma = 1$ MeV; for JISP16 [4] and the chiral interaction of the effective field theory N3LO [5], regularized by the SRG transformation [6] with the parameter $\Lambda = 2$ fm^{-1} these values are smaller: $E_r = 0.35$ MeV and $\Gamma = 0.7$ MeV, respectively. On the other hand, these resonances are not supported by NN interactions of chiral effective field theory without SRG modification.

Our results are in line with the conclusions of Ref. [7] predicting the trineutron resonance at lower energy than the tetraneutron resonance [8, 9].

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QUANTUM CONTROL OF MOLECULAR ALIGNMENT AND ORIENTATION BY TWO-COLOR TRAPEZOIDAL LASER PULSES

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The alignment and orientation of the linear molecule by the two-color trapezoidal laser pulses were theoretically investigated. The use of the trapezoidal shape of a laser pulse enhances the maximum alignment degree for the same intensity and duration comparing to the Gaussian laser pulse. Influence of pulse duration on the maximum degrees of molecule alignment and orientation was investigated. The influence of temperature effects is shown. It is shown that the use of additional preimpulse increases the maximum degree of orientation, and the application of two-color rather than monochromatic preimpulse leads to a higher maximum degree of orientation. The influence of change of relative phase between fundamental and second harmonics on orientation of molecules in the case of one and two impulses was also studied.

LATTICE SYSTEM OF TWO FERMIONS WITH FIRST AND SECOND NEAREST-NEIGHBORING-SITE INTERACTIONS

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A system of two identical spinless fermions on the two-dimensional lattice is studied [1] under the assumption that the first and second nearest-neighboring-site interactions between the fermions are only nontrivial and that these interactions are of magnitudes λ and μ, respectively. A partition of the (λ,μ) plane is established such that, in each its connected component, the two-fermion Schroedinger operator corresponding to the zero quasi-momentum of the center of mass has definite (fixed) numbers of eigenvalues that are located below the bottom of the essential spectrum and above its top. Furthermore, for each connected component, a sharp lower bound is established on the number of isolated eigenvalues for the two-fermion Schroedinger operator corresponding to any admissible nonzero value of the center-of-mass quasimomentum. The results obtained help one to clarify the mechanism of emergence of eigenvalues of a two-fermion lattice Schroedinger operator from the essential spectrum as λ and μ vary as well as to understand the inverse process, the absorption of eigenvalues by the essential spectrum.

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MACHINE LEARNING IN THE PROBLEM OF EXTRAPOLATION OF NO-CORE SHELL MODEL RESULTS

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We modify the method of extrapolating the variational calculation results to the case of the infinite model space using machine learning of neural networks suggested in Ref. [1]. The main idea of the modified method is to train an ensemble of artificial neural networks using a preliminary selection of training data, a subsequent selection of the trained neural networks according to some criteria, and a statistical processing of the selected network predictions. We propose a new neural network topology with an appropriate set of learning parameters. The suggested modified method provides stable results, does not require a division of data into the training and test sets, ensures the convergence of predictions with increasing the learning data set by including the results from larger model spaces as well as a high statistical confidence of the final results.

We extrapolate results obtained within the no-core shell model [2] with NN interaction Daejeon16 [3] for ground state energies and root-mean-square radii of ^{6}Li, ^{6}He and ^{6}Be nuclei. We obtain the ^{6}Li ground state with the same accuracy but higher in energy than the predictions of Ref. [1]. However, our approach has a higher statistical confidence.

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SINGLE IONIZATION OF HELIUM ATOM BY PROTONS IN THE PARABOLIC QUASI-STURMIAN APPROACH

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Singly ionizing ion-atom collisions are investigated theoretically. A parabolic quasi-Sturmian approach [1,2] is applied to the single ionization of helium atom by intermediate- and high-energy protons. The fully differential cross sections (FDCSs) are calculated for 1 MeV and for 75 keV protons.

In the framework of the approach, the transition amplitude is extracted directly from the asymptotic behavior of the solution of an inhomogeneous driven Schrödinger equation for the Coulomb three-body system (e^-,He$^+$,p^+). This equation is solved numerically by expanding the wave-function in terms of convolutions of the parabolic quasi-Sturmians for the two-body subsystems (p^+,He$^+$) and (e^-,He$^+$). This basis is referred to as the convoluted quasi-Sturmian (CQS) basis.

CQS calculations showed that at high energies of the incident proton (0.5, 1 and 2 MeV), the pe-potential can be treated as perturbation. Switching-on this interaction slightly influences the angular distribution of electrons, scarcely affecting the magnitude of the FDCSs. On the other hand, with a decrease in the energy of incident protons (up to 75 keV), the role of the pe-potential expectedly increases. For example, the capture *ep* - channel becomes important especially when the velocities of the ejected electron and scattered proton are comparable (capture into continuum).

The results for the cross sections obtained within the CQS model are shown in Fig.1 in comparison with experiment [3]. Taking into account the importance of the pe-potential, we plan to modify the CQS approach in such a way that the electron capture into continuum is treated properly.

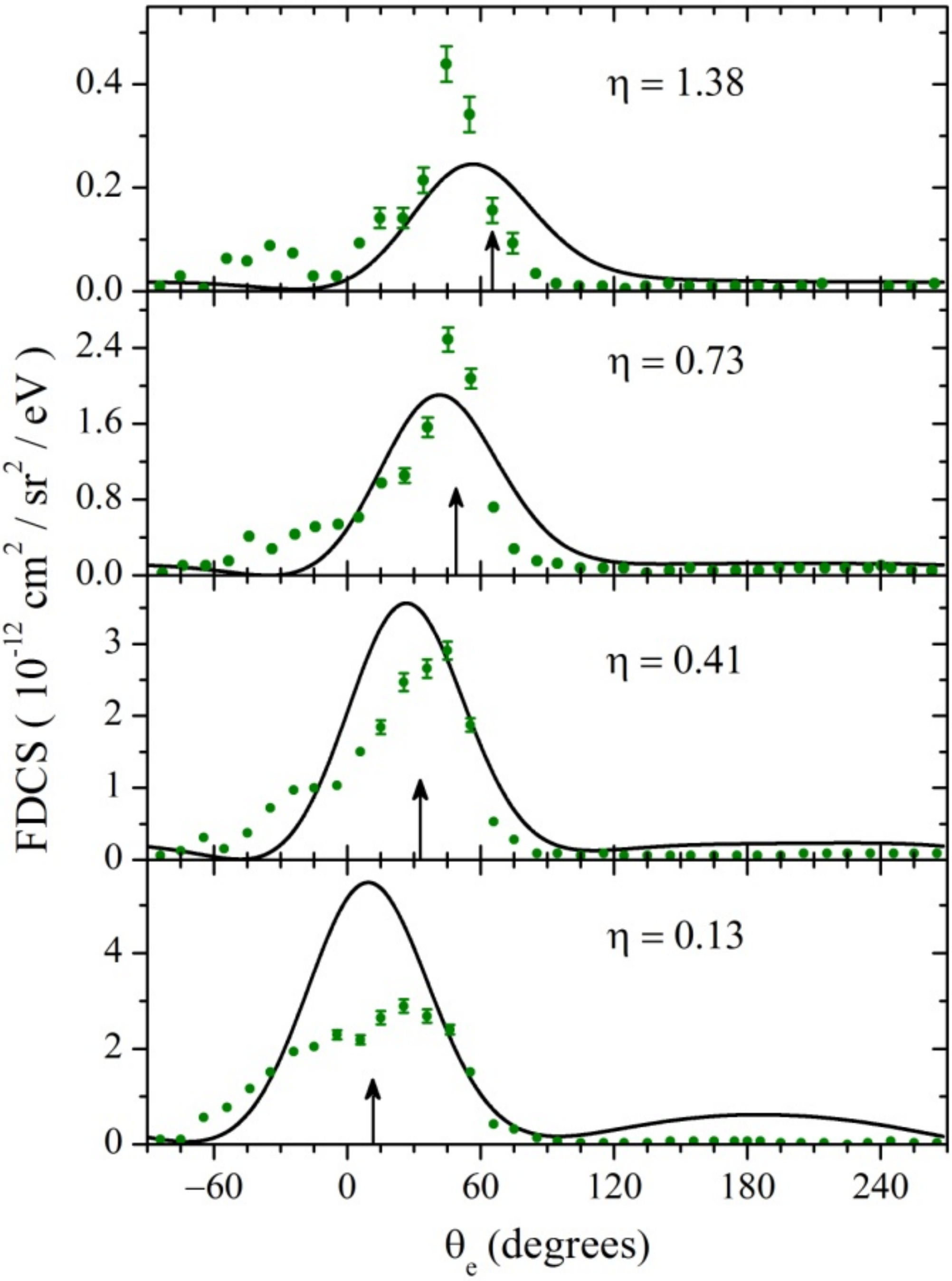

Figure 1. Our calculated FDCSs [2] (solid line) are compared to experimental data [3] for single ionization of helium by 75 keV protons in the collision plane, for different transverse momenta η. The ejected electron energy is $E_e = 5.4$ eV.

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EVOLUTION OF NEUTRON SHELL STRUCTURE OF $N = 14, 16$ ISOTONES

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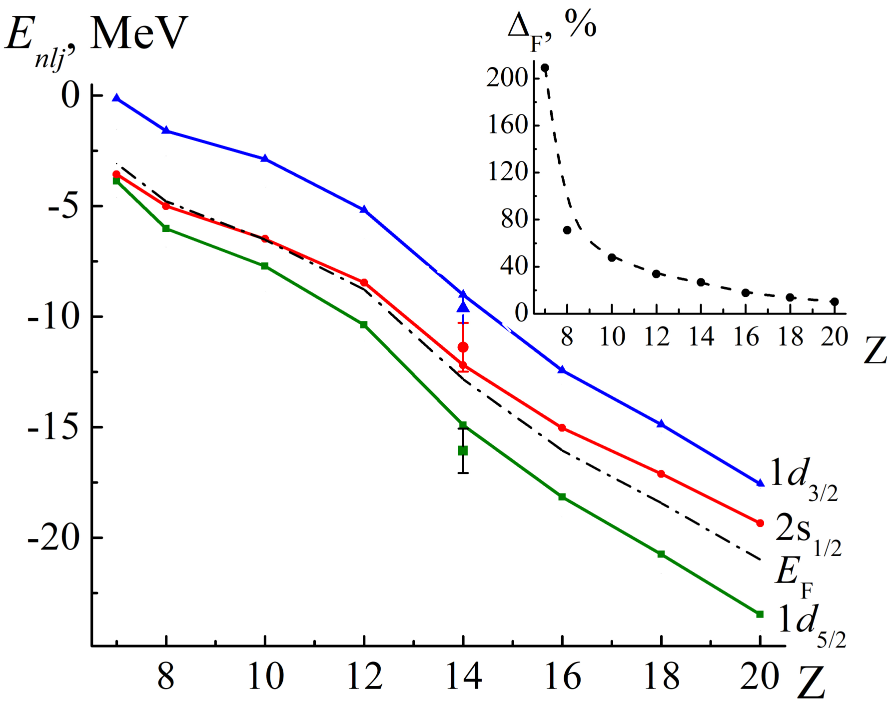
The evolution of neutron single-particle characteristics of isotones with $N = 14, 16$ was studied in the dispersive optical model [1] in Z region from 7 to 20. The calculation was performed with the parameters both extrapolated in accordance with the global parameters KD (KDUQ) [2, 3] and with the diffuseness parameter a_{HF} depending on the neutron excess. With an increase in the neutron excess, the energy gap $N = 14$ and $N = 16$ is reduced and widens respectively. In addition, the deviation $\Delta_F = |{<}E_{1d_{5/2}}, E_{2s_{1/2}}{>} - E_F|$ of the middle between the $1d_{5/2}$ and $2s_{1/2}$ energies from the Fermi energy E_F increases for $N = 14$ isotones. It reflects the disappearance of $N = 14$ magicity when approaching the neutron drip line. While, the deviation $\Delta_F = |{<}E_{2s_{1/2}}, E_{1d_{3/2}}{>} - E_F|$ for isotones with $N = 16$ decreases. An increase in the a_{HF} parameter for unstable isotones enhances this effect. The obtained results are consistent with the double magicity of ^{24}O ($N = 16$) and ^{34}Ca ($N = 14$) nuclei. As an example, Fig. 1 shows the evolution of neutron single-particle energies E_{nlj} near the Fermi energy of isotones with $N = 14$. The deviation Δ_F is represented relative to the value of particle-hole energy gap G.



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EMPIRICAL SYSTEMATICS OF SPONTANEOUS FISSION HALF-LIVES OF HEAVY AND SUPERHEAVY NUCLEI

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The exact calculation of half-lives in spontaneous fission remains an open problem in nuclear physics. In this work, a new systematics of half-lives in spontaneous fission was proposed. For nuclei with the same value of neutron excess (isospin) and charge numbers $90 \leq Z \leq 102$, a linear correlation was found between the decimal logarithm of the half-life of spontaneous fission and the alpha decay energy. An empirical formula has been proposed to determine the half-life of spontaneous fission of even-even nuclei depending on the alpha decay energy and neutron excess. We then extended this formula to calculate the half-lives for odd-A and odd-odd nuclei, as well as for nuclei with $Z \geq 103$. The experimental half-lives were reasonably reproduced using this formula with average deviations of 1.15 for 105 experimentally known nuclei, which means that the formula is reliable for predictions.

NUCLEON PAIRING ENERGY IN EVEN-EVEN NUCLEI

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The pairing energies of nucleons in nuclei largely determine the properties of nuclei and nuclear matter. Despite the generally accepted pairing mechanisms based on the role of superfluid states the description of the nucleon pairing energy is still the topic of modern publications with a different point of view on the pairing mechanisms. At the same time, in all models of nucleon pairing, it is assumed that the nucleon-nucleon interaction is not related to realistic nucleon-nucleon forces but represents some residual interaction from the nuclear forces spent on creating the potential of single-particle motion. How the pair interaction of nucleons in nuclei differs from that of free nucleons, at least for valence nucleons, remains an open question. In this report, we consider the possibility of describing the pairing energy using realistic parameters of nucleon-nucleon scattering without involving ideas about superfluid states of nuclei. The purpose of this consideration is to test the possibility of formulating a description of three- and possibly many-nucleon clusters in nuclear matter using a realistic nucleon-nucleon interaction.

In the framework of the above, the mathematical model represents finding the spectrum of two nucleons placed in an oscillatory potential with a given nuclear quantum energy $\hbar\omega$. The difference between the energy of interacting nucleons and the energy of two non-interacting nucleons in an oscillatory potential gives the desired pairing energy. Yamaguchi's separable potential was chosen as a realistic nucleon-nucleon interaction model.

The results of this consideration are presented in Fig.1. In these figures, the pairing energy is normalized to the energy of the nuclear quantum, and the values are averaged over isotopes (Fig. 1 left) and over isotones (Fig. 1 right).

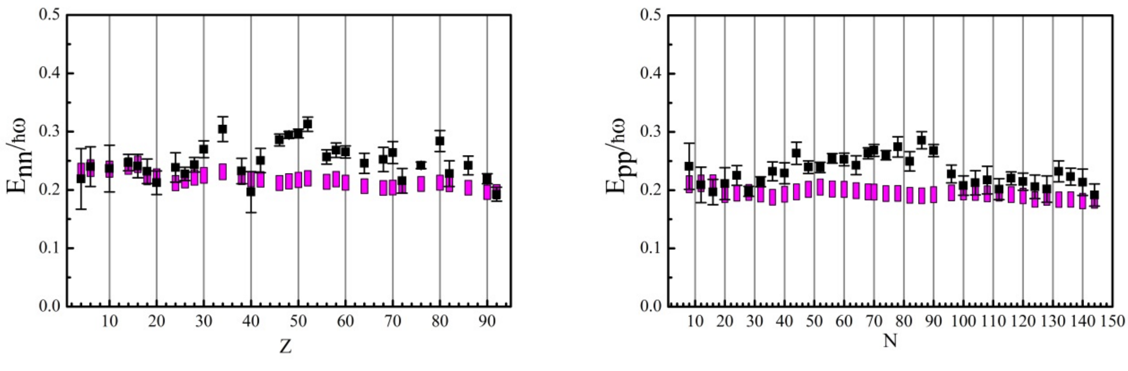

Fig. 1. (left): Experimental and calculated energies of nn-pairing; (right): Experimental and calculated energies of pp-pairing

To construct the drawings, a little more than 600 atomic nuclei were considered. The authors did not find in the literature an equally satisfactory description of the pairing energy on such a large variety without any fitting parameters.

A more detailed description of the approach is given in the authors' publication [1].

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MUON CAPTURE MEASUREMENTS WITH Ba-136 TARGET

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The large energy and momentum transfer of ordinary muon capture makes it an excellent tool to study the nuclear structure at conditions similar to neutrinoless double beta decay and benchmark the corresponding nuclear matrix elements. The MONUMENT collaboration is performing a set of muon capture experiments at the Paul Scherrer Institute in Switzerland. In the report, the measurement principle, the setup and preliminary results performed with Ba-136 target are presented. These measurements will benefit future calculations for leading double beta decay experiments.

SEPARABLE FORCES APPROXIMATION IN THE GENERALIZED THEORY OF FINITE FERMI SYSTEMS

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In a series of papers [1], a generalization of the theory of finite fermi systems (TFFS) was developed within the framework of the Green's function method to consistently account for complex configurations with phonons. However, quantitative estimates of the effects obtained there were not carried out due to the large quantitative difficulties. It seems that these difficulties can be circumvented or greatly reduced if to use the separable forces approximation applied, for example, in the well-known quasiparticle-phonon model (QPM) [2]. In the non-self-consistent QPM, the parameters of separable multipole forces are usually adjusted according to experimental data, in particular, for the lowest-lying 2^+ and 3^--phonons, and a good description of many other excited states of spherical and deformed nuclei is obtained, for more details see [2].

We used "our"separable forces adjusting their two parameters in the corresponding equation for the effective field (vertex) [3, 4] and proceeding from fixed effective quadrupole charges based on the general formula we derived for them. In particular, for $e_{eff}^{n,p}$ =1 and 2 at ω =0 in ^{208}Pb, we obtained that two separable forces parameters are equal.

Within the framework of this approach, a simple and useful relationship between $e_{eff}^{p,n}$ and two parameters of separable forces, that approximate the full amplitude Γ in the standard TFFS, is also obtained.

The results obtained are used to quantify new effects in the generalized TFFS: equations for the regular part Γ^r of the amplitude Γ, the ratios of various phonon-exchange interactions, the equation for the two phonon creation amplitude, which is contained in the concept of tadpole, and other effects.

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SELF-CONSISTENT EVOLUTION: NEW NEURAL NETWORK APPROACH TO BOUND STATE CALCULATIONS

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An application of neural networks for solving quantum mechanical problems has been suggested in [1,2]. Many improvements, including an adaptation of deep neural network techniques [3], have been proposed since. Development of a new computational technology which could lift the curse of dimensionality, however, has not yet been completed, although some steps in this direction have already been made [4,5].

We propose a new approach to training neural networks for approximation of quantum Hamiltonian invariant subspaces corresponding to bound states. The approach is based on training an artificial neural network to solve the Schrödinger equation in imaginary time with initial conditions that put the solution into an invariant subspace.

The advantage of the proposed approach is a simpler objective function which leads to better performance.

Theoretical results are illustrated with numerical examples.

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INVESTIGATION OF LOW-ENERGY SPECTRUM IN $^{250-260}$No CHAIN

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The low-energy multipole spectrum in isotopes $^{250-260}$No is investigated in the framework of fully self-consistent Quasiparticle-Random-Phase-Approximation (QRPA) method with Skyrme forces [1,2]. The representative set of Skyrme parametrizations (SLy5, SLy6, SkM* and SVbas) is applied. The main attention is paid to nuclei ^{252}No and ^{254}No, where we have most of the experimental spectroscopic information [3,4]. In addition to low-energy one-phonon collective states (lm=20,22,30,31,32) and their rotational band, the isomeric states are inspected. In general, a good agreement with the experimental data is obtained. It is shown that, a shell gap in the neutron single-particle spectra of ^{252}No and ^{254}No can lead to specific properties of these two nuclei. In connection with the first experimental evidence of the scissors mode in the ^{254}No [5], the distribution of M1 strength in this nucleus is analyzed.

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SINGLE-PARTICLE STRUCTURE OF MIRROR NUCLEI NEAR ^{48}Ni

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The radial wave functions and the energies of the protons and neutrons in the same states of the corresponding mirror nuclei differ due to the Coulomb interaction. Mirror energy difference (MED) between the energy of protons and neutrons in these states depend on angular momentum (the Thomas-Ehrman effect [1]). The single-particle structure of the mirror nuclei ^{52}Ni-^{52}Cr, ^{50}Ni-^{50}Ti, and ^{48}Ni-^{48}Ca was studied within the dispersive optical model [2]. The parameters of the imaginary part of the potential were determined according to the global parameters [3]. MED of $2p$ valence states with low angular momentum ($l = 1$) was shown to be less than that of $1f$ states ($l = 3$) (Fig [1], a). In Fig. [1],b the calculated difference Δr_{np} between the root mean square radii of protons and neutrons in $1f$, $2p$ states of the investigated mirror nuclei is presented. The difference is greater for $1p$ states compared to $1f$ states. The effect is enhanced approaching the proton drip line. Taking into account such effects is important for more accurate prediction of the features of drip-line nuclei such as double magic ^{48}Ni nucleus.

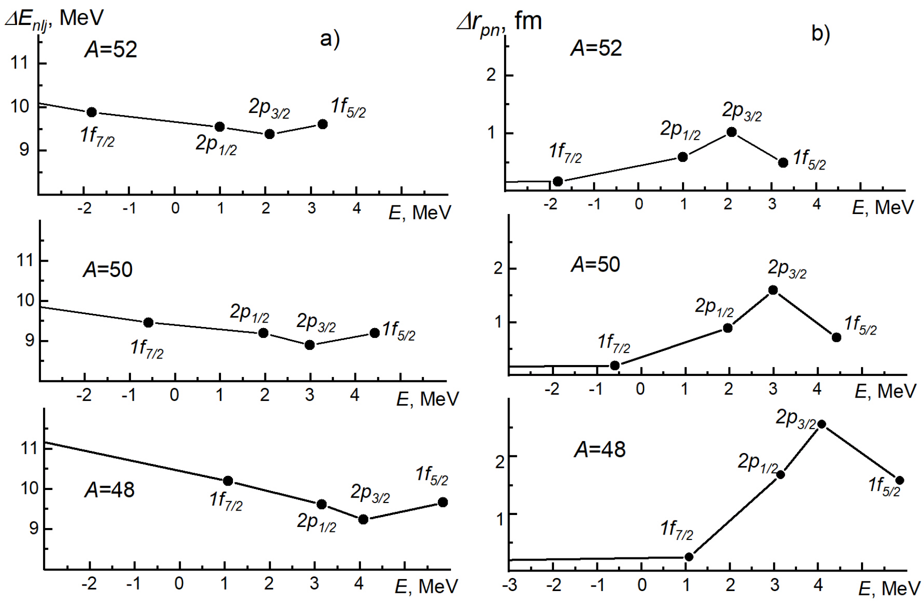

Fig 1. a) MED for the mirror nuclei ^{52}Ni-^{52}Cr, ^{50}Ni-^{50}Ti, ^{48}Ni-^{48}Ca. b)The difference Δr_{np} for the mirror nuclei ^{52}Ni-^{52}Cr, ^{50}Ni-^{50}Ti, ^{48}Ni-^{48}Ca

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COLLECTIVE ALTERNATING-PARITY SPECTRUM OF THE EVEN-EVEN NUCLEI WITH EFFECTIVE TRIAXIALITY

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In present work model of effective triaxiality of even-even nuclei with quadrupole and octupole deformation is developed. To solve for radial part the Schrodinger equation the Davidson potential was used. The alternating parity energy spectrum and wave functions of Schrodinger equation was obtained. The contribution of quantity e_ν – eigenvalues for angular part of polar coordinate taken into account. At the same time, in the expressions for the components of the moments of inertia of the nucleus, the variable of the angular part of the polar coordinates remained as a constant. In presented model energy levels of yrast-band of the alternating parity spectrum determined by six adjusted parameters. And energy levels of the yrast- and first-non-yrast-bands determined by eight adjusted parameters. The application of the model to energy levels of the yrast- and first-non-yrast alternating-parity bands in several rare-earth and actinide nuclei shows a good reproduction of the corresponding experimental energy levels. A description of the alternating parity energy spectrum of even-even nuclei taking into account rotational and vibrational (longitudinal and transverse) degrees of freedom is carried out for the first time. The proposed model is used to describe the excited alternating-parity collective states yrast- and first-non-yrast-bands of even-even nuclei: ^{146,148}Ba, ^{154}Sm, ^{158}Gd, ^{160}Dy, ^{170}Yb, ^{220,224}Ra, and ^{224,226,230,232}Th, was proposed.

INVESTIGATION OF 1^+ EXCITATIONS IN LIGHT AND MEDIUM NUCLEI WITHIN SHELL MODEL

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This work examines the excitation of anomalous parity levels 1^+ in some light and medium nuclei with filled or partially filled shells. Nuclei ^{12}C, ^{16}O, ^{18}O, ^{28}Si, ^{48}Ca are considered. The wave functions of excited states were calculated within the framework of the shell model using the NuShellX program [1]. Within the framework of this program, the calculation of excited states is performed taking into account the connection between the proton and neutron components of the nucleus. In addition, using this program, single-particle transition densities of the considered excitations were also calculated. Wave functions are tested using the values of the reduced probabilities B(M1) of radiation transitions, as well as when describing the differential cross sections of inelastic scattering in the reactions (p,p') and (e,e') with excitation of the levels under consideration. The fragmentation of the strength of the magnetic dipole transition is studied, as well as the contribution of the spin excitation component in the transitions under consideration.

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SHORT-RANGE CORRELATIONS IN THE LIGHTEST NUCLEI WITHIN THE DIBARYON MODEL OF NUCLEAR FORCES

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High momentum components of wave functions and two-nucleon short-range correlations (SRC) for the lightest nuclei with A=2 and 3 are studied within the dibaryon model for 2N and 3N forces [1]. This model accounts for a possibility of an intermediate six-quark (dibaryon) state formation in two-nucleon system at short distances. We evaluate the SRC probability for the deuteron and calculate the universal two-nucleon wave functions for the spin-triplet and spin-singlet channels which define the high-momentum 'asymptotics' in two-nucleon momentum distributions for heavier nuclei. Momentum distributions for A=3 nuclei are found from ab initio variational calculations in the three-body Gaussian basis.

The momentum distributions for ^{3}He and ^{3}H nuclei calculated within the dibaryon model are compared with those found with the conventional meson-exchange nuclear forces. The results obtained are interpreted in view of the recent (e,e') experiments [2] which allowed to extract, in particular, the ratio of pp to np SRC-pairs for the above nuclei.

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ON THE STRENGTH DISTRIBUTION OF ISOSCALAR GIANT MONOPOLE RESONANCE IN MEDIUM-HEAVY SPHERICAL NUCLEI

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Being associated with breathing modes of high-energy nuclear excitations,the Isoscalar Giant Monopole Resonance (ISGMR) is the object of permanent experimental and theoretical studies [1, 2]. In studies of Ref. [2], the detailed theoretical description of ISGMR (together with L=1,2,3) isoscalar GRs) in medium-heavy closed-shell nuclei have been proposed within the semi-microscopic Particle-Hole Dispersive Optical Model (PHDOM). Although this model is not fully self-consistent, it demonstrates unique abilities in describing main characteristics (strength distribution, transition densities, probabilities of direct one-nucleon decay) of various GRs in the above-mentioned nuclei (Refs. [2, 3] and references therein). These abilities appear due to specific features of PHDOM, in which the main relaxation modes of collective (p-h)-type states associated with GRs (Landau damping, coupling these states to single-particle continuum and to many-quasiparticle configurations (the spreading effect)) are together taken into account. In particular, these modes are the main contributors to formation of the GR total width.

In this report, we present a comparison of the strength functions of ISGMR in ^{48}Ca, ^{90}Zr, and ^{208}Pb evaluated within PHDOM [2] and cRPA (continuum-random-phase approximation) with the strength distributions deduced from an analysis of the respective (α,α')-reaction cross sections [4, 5, 6]. In neglecting contribution of pair correlations to formation of the ISGMR strength function (this effect is expected to be weak), a similar comparison is done for open-shell nuclei ^{58}Ni and ^{120}Sn (experimental data are taken from Refs. [5, 6]). As a result, one can conclude that due to the above-mentioned features of PHDOM it is possible within this model to describe reasonably the strength distribution of ISGMR in medium-heavy spherical nuclei. Respective results of other theoretical approaches are also discussed.

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ISOSPIN ANALOGUES OF THE TETRANEUTRON RESONANCE

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Searches for bound or resonant state in the system of 4 neutrons (tetraneutron) have been started more than half a century ago. Theory completely excludes the bound tetraneutron. Numerous theoretical studies allowing for the continuum with modern NN interactions exclude also low-lying tetraneutron resonance narrow enough to be detected experimentally. A notable exception is the predictions of the tetraneutron resonance in Refs. [1-3] using softened realistic NN interactions. The first observation of this resonance was reported in Ref. [4] with marginal statistics of 4 events and later confirmed in Ref. [5] in the ^{1}H(^{8}He,pα) experiment with a reasonable statistical significance. However, some authors are skeptical (see, e. g., Refs. [6-8]) about the interpretation that the tetraneutron resonance per se was observed in Refs. [4,5]. For example, the low-energy peaks were observed in reactions ^{2}H(^{8}He,^{6}Li)4n and ^{2}H(^{8}He,^{3}He)^{7}H$\rightarrow^{3}$H+4n in Ref. [8] at energies consistent with the tetraneutron resonance observed in Ref. [5] which were, however, interpreted as a manifestation of the ^{8}He structure and the reaction mechanism.

If the tetraneutron resonance do really exists, we should expect an existing of its isospin analogues in excited T=2 resonant states in ^{4}H, ^{4}He, ^{4}Li and in the system of 4 protons (tetraproton). Observation of these resonances can serve as a confirmation of the results and their interpretation of Refs. [4,5]. We will also discuss the possibilities of observations of these T=2 resonances in decays of excited states of heavier nuclei.

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NUCLEON-PAIR APPROXIMATION WITH PARTICLE-HOLE EXCITATIONS

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In this talk I shall give a brief introduction to the nucleon-pair approximation of the shell model [1], as well as its extended version with particle-hole excitations included [2]. Some applications of the method will also be presented.

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DELINEATING THE ISLAND OF DEFORMATION IN THE LIGHT GOLD ISOTOPES BY MEANS OF LASER SPECTROSCOPY

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Optical spectroscopy is able to measure subtle shifts in the energy of the atomic electron levels, arising from changes in the charge distribution of the nucleus [1]. For a given isotopic chain, this effect, known as the isotope shift (IS), arises due to changes in the nuclear mass and size. From this, the change in mean-square charge radius ($\delta\langle r^2\rangle$) can be extracted in a nuclear-model independent way. Similarly, spin (I), magnetic dipole (μ) and electric quadrupole (Q) moments can be deduced from the hyperfine splitting of optical lines. The optical spectroscopy is therefore a sensitive and direct method of probing the nuclear ground and metastable states that enable to obtain a wealth of new information about shape evolution across the nuclear landscape.

In this contribution, we present the results of the optical spectroscopy measurements for neutron deficient Au isotopes performed at the ISOLDE facility (CERN). In order to study very neutron deficient isotopes with low yield, it was necessary to use the most sensitive laser spectroscopy method: in-source resonance-ionization laser spectroscopy [2]. The advanced atomic calculations of the factors needed for extraction of the nuclear observables from the measured IS's, enable us to decrease substantially the uncertainties of the $\delta\langle r^2\rangle$ values.

Evolution of deformation in the gold isotopic chain proves to be different from that found earlier in the adjacent chains: shape staggering for Hg and Bi [3] isotopes, gradual increase of deformation in Pt or Po isotopes, retention of the near spherical shape in Pb and Tl nuclei. Thus, the small changes in N and/or Z in this region lead to the dramatic variations in the pattern of the shape evolution which make these data a stringent test of the theory.

The experimental results are compared to mean-field calculations [4], that reproduce the unusual behavior of $\delta\langle r^2\rangle$ fairly well only when the nuclear ground states are chosen in accordance with experimental spin and magnetic moments rather than in accordance with the energy of the corresponding levels. This observation reveals the fundamental deficiency of the current mean-field approaches.

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IN-SOURCE LASER PHOTOIONIZATION SPECTROSCOPY OF HEAVY (N $>$ 126) Bi ISOTOPES

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Nuclei in the "lead region"of the nuclide chart (Z close to 82) are of particular importance for nuclear physics. Nuclides in the vicinity of neutron mid-shell $N = 104$ exhibits striking effects such as shape coexistence, shape staggering *etc*. The heavier isotopes ($N > 126$) are also of great interest. One of the reasons is so-called "shell effect"in charge radii [1]. This effect consists in the presence of the characteristic kink in the charge radii at the $N = 126$ neutron shell closure.

Studies of the heavier isotopes $^{214-218}$Bi (including isomers) were performed at the ISOLDE facility (CERN) using the in-source photoionization laser spectroscopy. The changes of the mean square charge radii and electromagnetic moments were measured.

The observed deviation of the behavior of the magnetic moments from the trend for the lighter isotopes and other isotopic chains may indicate structural changes in the heavy Bi isotopes.

The isomer ^{215}Bi^m ($I = 25/2...29/2$) is of particular interest. Measurement of the isomer shift $\delta\langle r^2\rangle_{215,215m}$ enables checking the hypothesis of the determinative role of the $\nu 1i_{11/2}$ occupancy in the formation of the kink in charge radii when crossing $N = 126$, since the main peculiarity of this isomer is the presence of the unpaired neutron on the $i_{11/2}$ shell.

It's commonly accepted that the kink in charge radii appears only when the neutron $1i_{11/2}$ shell is substantially occupied in nuclei with $N > 126$ [2]. In particular, this kink is quite successfully reproduced in Covariant Density Functional Theories (CDFT) with the variety of covariant energy density functionals [3]. HBF calculations with an additional density-dependent term to the spin-orbit interaction (proposed by Nakada and Inakura [4]) also reproduced more rapid rise of the radii in the heavier isotopes ($N > 126$). Nevertheless, the first rude estimations based on the sign and amplitude of the $\delta\langle r^2\rangle_{215,215m}$ are in favor of the CDFT approach.

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ИССЛЕДОВАНИЕ КОРРЕЛЯЦИЙ СОЛНЕЧНОЙ АКТИВНОСТИ И ПАРАМЕТРОВ РАСПАДОВ ИЗОТОПОВ Co-60 И Fe-55

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Temporal variations of unstable nucleus decay parameters studied extensively in last years, their observation can be signal of unknown physical effects of cosmic origin, in particular, induced by Sun influence. Several experiments reported annual and daily decay rate oscillations in α- and β-decays of some nuclides at the level of .05 % [1-4]. Also, correlations of Mn-54 β-decay rate with solar activity, in particular, with γ-ray solar flares, reported [1]. BSTU - PhIAN – INF- ITEP - JINR collaboration studies decay rate variations for Co-60 β-decay and Fe-55 inverse β-decay. 1.1 and 1.3 Mev gamma-quanta from Co-60 β-decay registrated by Germanium semiconductor detector. X-rays with energy 5,9 and 6,5 KeV from Fe-55 decay registrated by Si-Pin detector.

Possible influence of solar activity on nucleus decay rate was studied during 2015 – 2022 for Fe-55 and Co-60 decay rates. Ten significant decay rate deviations from expected exponential decay rate of the order .5 % with duration from 50 to 188 hours were found [5]. It was shown that such rate dips occur 48 – 80 hours before solar flare events of M and X class with significant reliability [5]. Three analogous Fe-55 and Co-60 decay rate deviations correlated with X class solar flare events were detected synchronously in 2023 – 2024 in PhIAN and ITEP at 3km distance.

γ-radiation produced during solar flares can be direct danger for astronautics, hence early detection of such correlations can improve radiation safety of space flights. SOLARIS project plans to perform simultaneous measurement of Fe-55, Co-60 decay rate parameters at International Space Station and Earth labs. to study their correlations with solar activity .

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APPEARANCE OF SUPERCONDUCTING PAIR CORRELATIONS IN SPHERICAL EVEN-EVEN NUCLEI

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The formation of superconducting pair correlations between like nucleons in the ground state of spherical even-even nuclei is considered within a special Bogoliubov transformation. The influence of the monopole pairing interaction on the energy of single-particle states is taken into account.

It is shown that the emergence of pair correlations depends on the particle number and shell structure.

In open subshell nuclei the correlations exist at any attractive monopole interaction. In this case, nucleon pairs are distributed over all subshells participating in the pairing interaction.

The closed shell nuclei are considered within simplified model with constant pairing interaction. It is confirmed that the superconducting pair correlations appear if the coupling constant G exceeds a certain threshold value. Rough upper and lower estimates are obtained for the threshold value.

sd-SHELL EVOLUTION IN NEUTRON-RICH ^{13}B AND ^{16}C VIA DIRECT REACTIONS

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In unstable nucleus, single particle orbitals undergo rearrangement, leading to various shell evolution phenomena. In order to investigate the *sd*-shell structure in ^{13}B, we need to find all the *s*- and *d*-wave state in ^{13}B. So for searching the missing positive parity state in ^{13}B with a configuration of $^{12}\mathrm{B}_{\,\mathrm{g.s.}} \bigotimes d_{5/2}$, a ^{13}B(*d*, *d*') inelastic scattering experiment was carried out using a 23 MeV/nucleon ^{13}B beam by EN-course (exotic nuclei) beam line at the Research Center for Nuclear Physics (RCNP), Osaka University. Several states at excitation energies of 3.6(1), 4.2(1), 5.4(2), and 6.5(2) MeV in ^{13}B were observed in its excitation energy spectra, which were derived from the energies and angles of the scattered deuterons from ^{13}B using the missing mass method. To determine the parity of each populated state, the inelastic scattering differential cross sections (DCSs) were compared to the distorted wave Born approximation (DWBA) calculations.The 5.4- and 6.5-MeV states were inferred to be positive parity states and considered as potential candidates for the missing *d*-wave neutron excitation state. The gap between *s*- and *d*-shell in ^{13}B and the systematic behaviour of neutron-rich Boron isotopes were also investigated based on the experimental findings.

And in order to investigate whether or not the *sd*-shell inversion in ^{16}C, We conducted a ^{15}C(*d*,*p*) Experiment with a radioactive beam of ^{15}C at 28.5 MeV/nucleon at the RIBLL1 beamline in the Institute of Modern Physics(IMP), Lanzhou at 2022. As of now, I have completed the normalization and calibration of detectors, particle identification, and reconstructed the excitation energy spectrum of ^{16}C using the missing mass method. The ground state and the 3.03 MeV excited state of ^{16}C can be seen in the excitation spectrum, but further analysis is required to determine if this reaction channel generates the 5.45 MeV state or not.

MICROSCOPIC DESCRIPTION OF ISOSCALAR GIANT MONOPOLE RESONANCE IN SPHERICAL NUCLEI

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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].

The random phase approximation (RPA) with the Skyrme-type energy-density functional (EDF) is the most widely used theoretical model for describing the ISGMR [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].

In the present report, we discuss 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 nuclei ^{40,48}Ca and ^{208}Pb. Using the same set of parameters, we describe available experimental data [7,8]. The effects of the phonon-phonon coupling (PPC) [9] lead to a redistribution of the main monopole strength to lower energy states and into higher energy tail [8,10]. In particular, the PPC predictions of the fine structure of the ISGMR in the Ca isotopes are in good agreement with the fine structure which is extracted from experimental data analysis [11].

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DIFFRACTIONLESS SOLUTIONS FOR THE BOUND STATES OF THE MODEL 1D THREE-BODY PROBLEM

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The model of the one-dimensional impenetrable particles with interactions via the boundary conditions is considered. This model, besides its relation to the three-body problem [1-3], describes also the wave diffraction problem for the impedance wedge [4]. Previously, an exact solution was obtained by means of the Maluzhinetz-Sommerfeld transformation [4,2,3]. In the present report it was found that the bound-state solution turns out to be in the diffractionless (Bethe ansatz) form. A simple analytical expression for the eigenvalues is given. The relation to this model problem to the zero-range interaction problem [5] is discussed.

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МОДИФИЦИРОВАННЫЕ МАССОВЫЕ СООТНОШЕНИЯ GKT И GKL

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Локальные массовые соотношения Гарви-Келсона GKT и GKL, предложенные в работе [1], широко использовались для изучения свойств ядерного взаимодействия, нуклонных корреляций, а также для предсказания масс неизвестных ядер. GKT и GKL представляют собой простые арифметические соотношения между массами 6 соседних ядер, выполняющиеся с точностью около 200-300 кэВ на всей совокупности измеренных масс средних и тяжелых ядер. В последние годы интерес к массовым соотношениям этого типа связан с разработкой новых статистических методов анализа данных, позволяющих выявлять закономерности и связи между различными элементами ядерных массовых моделей.

В данной работе рассматриваются модифицированные соотношения VGKL и VGKT с дробными значениями коэффициентов, полученные исходя из условия оптимальности. На основе новых массовых соотношений и экспериментальных данных AME2020 рассчитаны удовлетворяющие им массовые таблицы. В области масс $A \geq 40$ среднеквадратичное отклонение значений новых соотношений VGKT и VGKL примерно на 10% меньше соответствующих значений GKT и GKL, но при этом среднеквадратичное отклонение значений масс в полученных с их помощью массовых таблицах, равняется, соответственно, 204 и 260 кэВ, что в несколько раз меньше значений RMS массовых таблиц GKT и GKL. Новые массовые соотношения в значительно меньшей степени чувствительны к энергии Вигнера при $N = Z$.

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SPECTROSCOPY OF TRANSFERMIUM ELEMENTS @GRAND/SHELS

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At FLNR JINR experiments are carried out to investigate the radioactive decay properties (α, β, γ spectroscopy) and the cross section measurements of transfermium elements synthesised in the fusion-evaporation reaction of an accelerated heavy ion beam with target nuclei using the kinematic separator SHELS [1,2] at the cyclotron U-400 and the gas-filled separator GRAND, located at the Factory of Superheavy Elements. A number of experiments have been devoted to the study of the radioactive decay properties of No and Rf and their daughter nuclei. No and Rf isotopes are produced as a result of the evaporation of one to four neutrons from compound nuclei in the reactions of ^{204}Pb(^{48}Ca,(1–3)n)^{251,250,249}No [3,4], ^{238}U(^{22}Ne,4n)^{256}No [5], ^{204}Pb(^{50}Ti,1n)^{253}Rf [6], ^{207}Pb(^{50}Ti,2n)^{255}Rf [7], ^{208}Pb(^{50}Ti, 1n)^{257}Rf [8], respectively. These transfermium isotopes have sufficiently high production cross sections to allow us to collect good statistics for the study of decay properties by methods of α, β and γ spectroscopy. No and Rf isotopes are interesting because of the possibility to study changes in radioactive decay properties around the neutron subshell $N = 152$, which could provide data necessary to understand how the properties of heavy element isotopes behave in the region of the neutron subshell $N = 162$.

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ИССЛЕДОВАНИЕ СВОЙСТВ УРОВНЕЙ НЕЧЕТНО-НЕЧЕТНОГО ЯДРА ГОЛЬМИЯ С A = 160

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Для установления структуры низколежащих состояний нечетно-нечетного ядра гольмия с $A = 160$ и объяснения т.н. f-запрещенных переходов в этом ядре измерены времена жизни уровней, интенсивно заселяемых электронным захватом и одновременно, используя вариационный принцип Хартри-Фока-Боголюбова, с целью уточнения квантовых характеристик и структуры ядер в этой области, ведутся расчеты свойств среднего поля.

Вместе с тем, в последних экспериментах по исследованию распада облученной протонами ($E_p = 660$ МэВ) на фазотроне мишени гольмия с $= 165$ обнаружен распад гамма перехода с $= 857$ кэВ, принадлежащего распаду ^{160}Ho, (см.рис) с периодом равным 3.5 мин., т.е. в ядре ^{160}Ho найдено новое изомерное состояние. Анализ экспериментальных данных продолжается.

Критерием достоверности полученных результатов служит проведённая таким же образом обработка интенсивных, незадержанных мгновенно совпадающих между собой и с собственными Kx и Lx лучами переходов 86.6, 197.0 кэВ при распаде ^{160}Ho и 98.9, 218.2 кэВ при распаде ^{158}Ho.

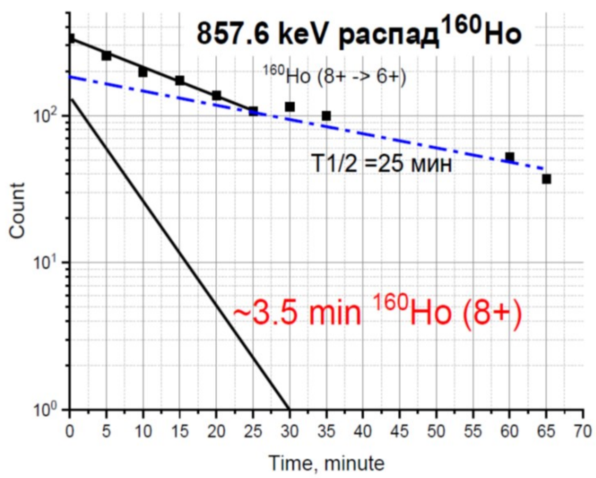

Рис. Распад изомера ($T_{1/2}$=3.5 мин) ядра ^{160}Ho на уровни ядра ^{160}Dy

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ИССЛЕДОВАНИЕ СТРУКТУРЫ НИЖАЙШИХ КВАДРУПОЛЬНЫХ ВОЗБУЖДЕНИЙ В ИЗОТОПАХ Ge

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В настоящее время накоплен большой объем экспериментальной информации по структуре низколежащих возбужденных состояний в изотопах Ge [1-3]. Интерес к этим ядрам связан с тем, что с ростом числа нейтронов происходит переход между сферической и деформированными формами ядра, определяющих их структуру [4,5]. С другой стороны, микроскопические расчеты демонстрируют, что изотопы Ge оказываются мягкими по отношению к триаксиальной деформации. В данном докладе мы анализируем свойства низколежащих 2+ возбуждений в изотопах $^{70-88}$Ge. Вычисления проводились путем построения и диагонализации коллективного квадрупольного гамильтониана [6,7]. Поверхности потенциальной энергии и массовые параметры, рассчитывались в рамках релятивистской модели среднего поля с двумя параметризациями функционала плотности энергии: PC-PK1 и NL3 [8]. Результаты расчетов сравниваются с имеющимися экспериментальными данными и результатами, полученными в рамках других подходов.

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EXCITATION SPECTRA AND ELECTROMAGNETIC TRANSITIONS BETWEEN LOW-LYING NONROTATIONAL STATES

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Calculations of the structure of the low-lying states of nuclei with $Z = 97 - 109$ play an important role in understanding the properties of nuclei belonging to the new region of the nuclide chart, which is available now for experimental study. We calculated quasiparticle-phonon structure and the reduced γ-transition probabilities for the excitedstates with excitation energies below 1 MeV for odd-proton nuclei in this region.

INVESTIGATION OF THE PROPERTIES OF THE FIRST EXCITED 1^- STATES OF EVEN-EVEN NUCLEI

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Various relationships between the characteristics of low-lying states of even-even nuclei, including the first excited 1- state, are derived and discussed. Checking them can become part of the program of experimental research on the created at the National Center for Physics and Mathematics Compton Source of monochromatic photons.

EXPERIMENTAL AND THEORETICAL STUDIES OF NUCLEAR REACTIONS

ASYMPTOTIC NORMALIZATION COEFFICIENTS FOR ^{16}O+N→^{17}O FROM THE ^{16}O(d,p)^{17}O REACTION

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The differential cross sections (DCs) of theneutron transfer ^{16}O(d,p)^{17}O reaction leading to the ground and first excited states of the ^{17}O nucleus were measured at deuteron energies of 36 MeV and they used to extract the spectroscopic factors for the ^{16}O+n→^{17}O vertex[1]. In the present work, the analysis of the experimental DCs of the above mentioned reaction has been performed within the modified distorted wave Born approximation (MDWBA) [2] to obtain the "indirectly determined" values of the asymptotic normalization coefficients for the ^{16}O+n→^{17}O$_{\text{g.s.}}$ and ^{16}O+n→^{17}O (0.87 MeV) vertexes. To determine the absolute values of the ANCs in ^{17}O nucleus, the ANC forthe d→p+n vertex was taken from the value of the nuclear vertex constant, fm, which extracted in Ref. [3]. All calculations were performed using the DWUCK5 code [4].

It was shown that the neutron transfer ^{16}O(d,p) ^{17}O reaction at the projectile energyof 36 MeV was peripheral and the weighted mean value of the extracted ANCs were found to be $C^2_{^{16}\mathrm{O}_n} = 0.855 \pm 0.068$ fm^{-1} for the ^{16}O+n→^{17}O$_{\text{g.s.}}$vertex and $C^2_{^{16}\mathrm{O}_n} = 10.765 \pm 0.345$ fm^{-1} for the ^{16}O+n→^{17}O(0.87 MeV) vertex. The different parameters of the optical potential also were used in the calculation for estimation of the values of ANCs for the ^{16}O+n→^{17}O$_{\text{g.s.}}$ vertex and the ^{16}O+n→^{17}O (0.87 MeV) vertex and their uncertainties.

The weighted mean values of the extracted asymptotic normalization coefficients are used for the calculation of the astrophysical S-factors of the ^{16}O(n,γ)^{17}O reaction at low energies. The work is in progress now.

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PROMPT FISSION NEUTRON SPECTRA IN ^{238}U(p,f) &^{238}U(n,f) AND ^{232}Th(p,f) &^{232}Th(n,f) REACTIONS

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Pre–fission neutron spectra influence the partitioning of fission energy between excitation energy and total kinetic energy of fission fragments. It might be assumed that the (n,xnf) and (p,xnf) neutron contribution, i.e. PFNS shapes might depend on the entrance channel. For incident neutron energies from fission threshold up to $E_n \sim 20$ MeV prompt fission neutron spectra (PFNS) of ^{238}U(n,F) were predicted in [1] and upgraded as described in [2]. Analysis of detailed data for ^{238}U(n,F) PFNS [3] demonstrates sensitivities of PFNS shape near (n,xnf) reaction thresholds to the exclusive pre–fission neutron spectra. The latter are extremely sensitive to the (n,$n\gamma$) and (n,$2n\gamma$) competition. Shapes for ^{238}U(n,F) PFNS [1] at excitations around ^{238}U(n,nf) reaction threshold are strongly supported by the measured data of [3]. The average energies $\langle E \rangle$ [3] of ^{238}U(n,F) PFNS support the approach pursued in [1, 2], lowering of $\langle E \rangle$ is consistent with predicted contributions of ^{238}U(n,nf) and ^{238}U(n,$2nf$) to the observed PFNS and fission cross section. The influence of ^{238}U(n,nf)^1 excusive neutron spectra on ^{238}U(n,F) PFNS at $E_n \sim 6-7$ MeV is sensitive to the energy E_n steps of ~ 0.25 MeV. Integral PFNS is consistent with data [3]. The largest amplitude of excusive neutron spectra at $E_n \sim 6.25$ MeV is envisaged. For the reactions ^{238}U(n,F) and ^{238}U (p,F) shape of PFNS and $\langle E \rangle$ strongly depend on the fissility of composite and residual nuclides, $^{238+1-x}$U and $^{238+1-x}$Np, respectively (Fig. 1). The ^{238}U(p,F) PFNS shape is quite different as compared to that of ^{238}U(n,F), since the contributions of pre-fission neutrons are different both in compound and pre-equilibrium domain. Exclusive neutron spectra (p,xnf)$^{1,..x}$ are consistent with fission cross sections of ^{238}U(p,F) and ^{238}U(p,xn) up to $E_n \sim 30$ MeV. We predict ^{238}U(p,xnf)$^{1,..x}$ exclusive pre-fission neutron spectra, exclusive neutron spectra of ^{238}U(p,xn)$^{1,..x}$ reactions, total kinetic energy TKE of fission fragments and products, partials of average prompt fission neutron number and observed PFNS of ^{238}U(p,F). The dips in PFNS $\langle E \rangle$ of ^{238}U(p,F) are much shallower than in case of ^{238}U(n,F) reaction. Asymmetry of ^{238}U(p,xnf)^1 neutrons with respect to the incident beam momentum is also very small.

Similar analysis/prediction is accomplished for the ^{232}Th(n,F) and ^{232}Th(p,F) PFNS.

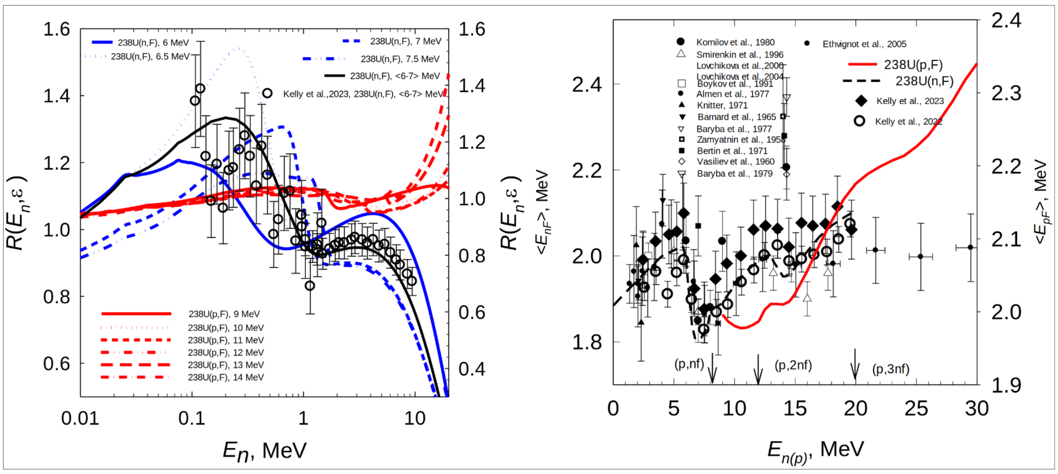

Fig. 1 (left): ^{238}U(n,F) and ^{238}U(p,F) PFNS, En 6–7 MeV; (right): of ^{238}U(n,F) and ^{238}U(p,F) PFNS

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POPULATION OF TETRANEUTRON CONTINUUM IN REACTIONS OF ^{8}He ON DEUTERIUM

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The search for the the multineutron systems is old, but still unsettled problem of the low-energy nuclear physics. Numerous attempts of search for the existence of the tetraneutron as a bound or resonant state have been realized using multiple approaches (e.g. uranium fission reactions, pion-induced double-chargeexchange and transfer reactions). However, no certain evidence of tetraneutron existence have bee obtained.

The situation has changed with the recent studies of 4n population in reactions with ^{8}He, where four neutrons can be found in a spatially-separated neutron-halo configuration. The result of the recent ^{1}H(^{8}He,p α) experiment [1] showed the observation of the "resonance-like structure" at E(4n) = 2.37 MeV with Γ = 1.75 MeV.

The high intensity ^{8}He secondary beam with energy 26 AMeV, produced at the recently commissioned ACCULINNA2 fragment separator [2], was used for the population of the tetraneutron in the ^{8}He+d interaction. The detection the low-energy recoils ^{6}Li and ^{3}He made with high energy and angular resolution allowed us to reconstruct the tetraneutron missing-mass spectra in the two reactions: ^{2}H(^{8}He,^{6}Li)4n and ^{2}H(^{8}He,^{3}He)^{7}H $\rightarrow$ ^{3}H+4n. Both of these approaches showed the evidence for a hump in the 4n continuum at about 3.5 MeV. The applied experimental techniques, the results of the data analysis and simulations are be presented in the report.

In this work we demonstrate that an evidence for the low-energy structures analogous to the observation of [1] can be found in the other reactions with the ^{8}He beam. Such results shed light on the search and spectroscopy of the multineutron system.

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THEORETICAL STUDY OF THE TRANSFER REACTIONS IN THE D + D SYSTEM

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In this work, the D(d, p)T and D(d, n)^{3}He transfer reactions are studied by means of the microscopic multichannel cluster approach in the oscillator representation [1–3]. These reactions are of great interest for pure and applied physics. Their total and partial astrophysical S factors are calculated. The contributions of the different channels are discussed, the most important ones are carefully analysed. Manifestations of the nuclear tensor force in dynamics of the studied transfer processes are considered. A comparison of the obtained results with available experimental data demonstrates a good agreement.

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MEASUREMENT AND ANALYSIS OF THE $^{13}C(\alpha, \alpha 0)^{13}C$ REACTION CROSS-SECTION IN THE ENERGY RANGE OF 2.0 – 7.0 MeV

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The differential cross-sections of the $^{13}C(\alpha, \alpha 0)^{13}C$ reaction were measured at three angles (130°, 150° and 170°) in the energy range of 2.0-7.0 MeV. The thin layer of ^{13}C deposited to the beryllium backing was used as a target. The thickness and enrichment of the target were determined by the ion beam analysis methods. The effect of the carbon build-up was taken into account during the data analysis. The measurement results can be used for re-examination of evaluation of the $^{13}C(\alpha,n)^{16}O$ reaction cross-section using multi-channel R-matrix calculations.

PHOTONEUTRON REACTION CROSS SECTIONS RELIABILITY IN DIFFERENT TYPE EXPERIMENTS

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Absolute majority of data on photonuclear, first of all photoneutron, reaction cross sections was obtained in different type experiments carried out using the beams of quasimonoenergetic annihilation photons and the beams of bremsstrahlung [1]. The methods of receiving the information on reaction cross sections are quite different. On the beams of annihilation photons the cross sections of partial reactions (γ,1n), (γ,2n), (γ,3n),... are directly determined and used for obtaining the total photoneutron reaction cross section $\sigma(\gamma,\mathrm{sn}) = \sigma(\gamma,1\mathrm{n}) + \sigma(\gamma,2\mathrm{n}) + \sigma(\gamma,3\mathrm{n}) + \ldots$ and the neutron yield cross section $\sigma(\gamma,\mathrm{xn}) = \sigma(\gamma,1\mathrm{n}) + 2\sigma(\gamma,2\mathrm{n}) + 3\sigma(\gamma,3\mathrm{n}) + \ldots$. On the beams of bremsstrahlung the neutron yield cross section $\sigma(\gamma,\mathrm{xn})$ is determined at first and used for obtaining partial reaction cross sections with the aid of statistical theory corrections and correspondent difference procedures. The differences of the methods used are the reasons for significant disagreements between resulted reaction cross sections in both shape and absolute value. It was found out using the objective physical criteria of data reliability $\mathrm{F}_i = \sigma(\gamma,\mathrm{in})/\sigma(\gamma,\mathrm{xn})$ for more than 50 nuclei investigated on the beams of annihilation photons and about 10 nuclei investigated on the beams of bremsstrahlung that data obtained using both indirect methods for partial reaction separation contain significant systematic uncertainties which resulted in unreliability of data obtained. Newly evaluated reaction cross sections $\sigma^{\mathrm{eval}}(\gamma,\mathrm{in}) = \mathrm{F}_i^{\mathrm{theor}}\mathrm{x}\sigma^{\mathrm{exp}}(\gamma,\mathrm{xn})$ for large number of nuclei from ^{51}V up to ^{209}Bi obtained by the experimental-theoretical method basing on the joint using of the experimental neutron yield cross sections $\sigma^{\mathrm{exp}}(\gamma,\mathrm{xn})$ and the results of F_i^{theor} calculations in the combined model of photonucleon reactions (CMPNR) [2] are in serious disagreements with the results of both mentioned experimental methods for indirect unreliable separation of partial reactions. At the same time new evaluated data are in agreement with the results of experiments in which the partial reactions (γ,1n), (γ,2n), (γ,3n),$\ldots$ are separated directly and reliably – the activation method on the beam of bremsstrahlung and the method of direct determination on the neutron multiplicity on the beam of photons from laser Compton backscattering of laser radiation on relativistic electrons [3,4].

The research was carried out in the Department of Electromagnetic Processes and Atomic Nuclei Interactions (Centre for Photonuclear Experiments Data) of the MSU SINP.

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POSSIBILITIES OF PHOTONUCLEAR EXPERIMENTS AT $E_\gamma = (1-4)$ MeV ON COLLIMATED γ-SOURCES FROM COMPTON BACKWARD-SCATTERING

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The possibilities of photonuclear experiments at $E_\gamma = (1-4)$ MeV on collimated gamma-sources from Compton backward-scattering of laser radiation on beams of accelerated electrons are considered. The following items are discussed: operation parameters of such gamma-sources; monitoring of their gamma-beams; types of possible photonuclear experiments, including nuclear resonance fluorescence ones (see, e.g., [1]), total absorption ones using transmission method (see, e.g., [2]), and especially experiments on inelastic scattering of gamma-quanta with population of metastable states of nuclei. As an example, for the last case, there are considered cross-sections of the reaction ^{115g}In (γ, γ') ^{115m}In ($E_{exc} = 336$ keV; $T_{1/2} = 4.486$ h) in dependence on E_γ obtained: a – in [3]; b – in [4] (see fig. 1).

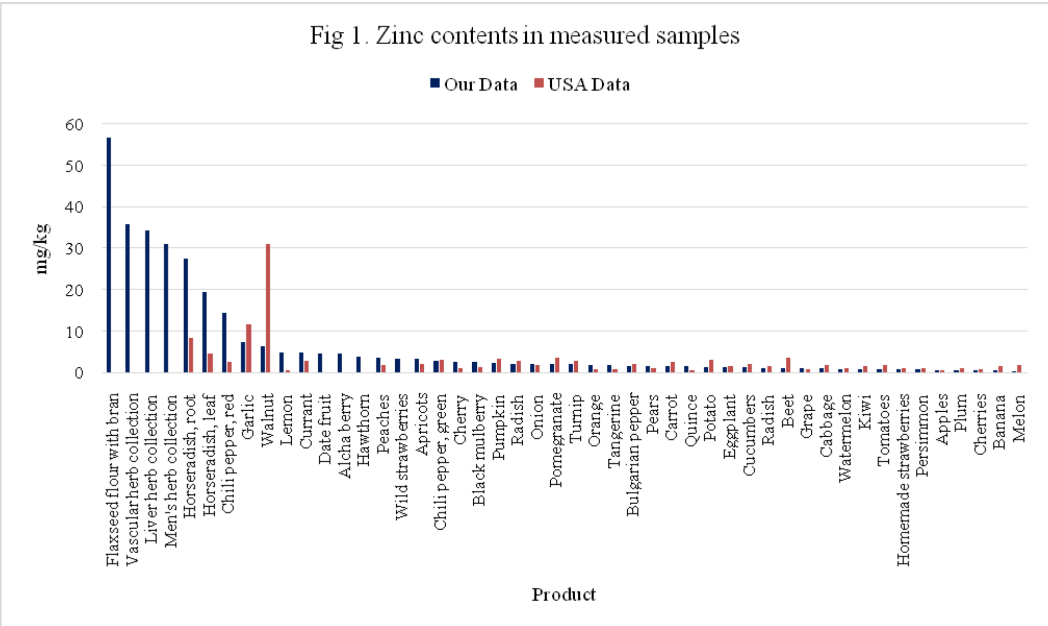

Fig. 1. Cross-sections of the reaction ^{115g}In (γ, γ') ^{115m}In ($E_{exc} = 336$ keV; $T_{1/2} = 4.486$ h) in dependence on E_γ obtained: a – in [3]; b – in [4]

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NEW INDICATIONS AND EVIDENCES OF MULTIBODY PARTITIONS OF ^{252}Cf(SF)

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In our previous publications [1-4] we presented experimental evidences of rare ternary decay mode of low excited heavy nuclei called collinear cluster tri-partition (CCT). Essential feature of this process is that some of the fission fragments (FFs) born during binary fission undergo a break-up, while they pass a solid-state foil. This break-up is delayed and occurs after the binary fission of the mother system. It is reasonable to think of such specific FFs as formed in the shape-isomer states [5]. The break-up is due to the FF inelastic scattering in the foil medium. In the recent series of experiments at the double-armed time-of-flight COMETA spectrometer, we have obtained both indications of the FFs spontaneous fission from the shape-isomer states, and evidences of new modes of the break-up of such fragments in different foils.

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ANALYTIC CONTINUATION OF DIFFERENTIAL CROSS SECTIONS AS A WAY TO DETERMINE ASYMPTOTIC NORMALIZATION COEFFICIENTS. APPLICATION TO THE ^{16}O(d,p)^{17}O REACTION

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Asymptotic normalization coefficients (ANC) are important nuclear characteristics. We discuss a method for determining ANC values from experimental data on differential cross sections of nuclear transfer reactions. The method is based on the use of the analytic continuation of these cross sections to the pole point of the reaction amplitude with respect to the variable $\cos\theta$ where θ is the center-of-mass scattering angle. The method under consideration is used to determine the ANC for the channel ^{17}O($1/2^+$; 0.871 MeV) $\rightarrow$ ^{16}O(0^+; 0 MeV) + n from the data on the ^{16}O(0^+; 0 MeV)(d,p)^{17}O($1/2^+$; 0.871 MeV) reaction. When determining the ANC, the corrections caused by the Coulomb interaction in the initial, final and intermediate states of the reaction were taken into account. It is shown that these corrections have a great impact on the extracted ANC. The found ANC value is compared with the results obtained by other methods.

ДАННЫЕ О НЕЙТРОН-ПРОТОННОЙ ДЛИНЕ РАССЕЯНИЯ, ИЗВЛЕЧЕННЫЕ В РЕАКЦИИ $n +^2 \mathbf{H} \rightarrow n + n + p$ ПРИ ЭНЕРГИИ НЕЙТРОНОВ 5 МэВ

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В работе представлены результаты измерения $^1S_0$ np-длины рассеяния, измеренной в реакции nd-развала при энергии нейтронов 5 МэВ. В кинематически полном эксперименте, проведенном на пучке нейтронов канала РАДЭКС ИЯИ РАН, регистрировались нейтрон отдачи и нейтрон от развала np-системы. Энергия первичного нейтрона и протона от развала np-системы восстанавливалась по известным углам вылета и энергиям двух нейтронов и факту регистрации развального протона в активной дейтерированной мишени. Значение np-длины рассеяния $a_{np} = -30.9 \pm 0.8$ Фм получены из сравнения экспериментальной зависимости выхода реакции nd-развала от относительной энергии np-пары с результатами моделирования. Сделано предположение, что полученное значение длины np-рассеяния в совокупности с данными других экспериментов, в которых np-длина рассеяния извлекалась из реакций nd- и dd-развала при различных энергиях, подвержены влиянию $3N$-сил.

Исследование выполнено в рамках научной программы Национального центра физики и математики, направление №6 «Ядерная и радиационная физика».

ИССЛЕДОВАНИЕ ИСПАРИТЕЛЬНЫХ КАНАЛОВ РЕАКЦИЙ ПОЛНОГО СЛИЯНИЯ С ТЯЖЕЛЫМИ ИОНАМИ, ПРИВОДЯЩИХ К ОБРАЗОВАНИЮ ЯДЕР С $88 \leq Z \leq 102$

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В рамках экспериментов на пучках тяжелых ионов ускорителей ЛЯР, с использованием сепараторов GRAND [1] и SHELS [2-3], в реакциях полного слияния ^{26}Mg+^{204,206,208}Pb, ^{48}Ca+^{204,206,208}Pb и ^{40}Ar+^{209}Bi измерялись сечения образования ядер-испарительных остатков (ER), в каналах xn, αxn и pxn (см Рис 1). Изучались свойства радиоактивного распада нейтронодефицитных изотопов $^{226-230}$Pu, $^{249-254}$No, $^{246-247}$Md и их дочерних продуктов.

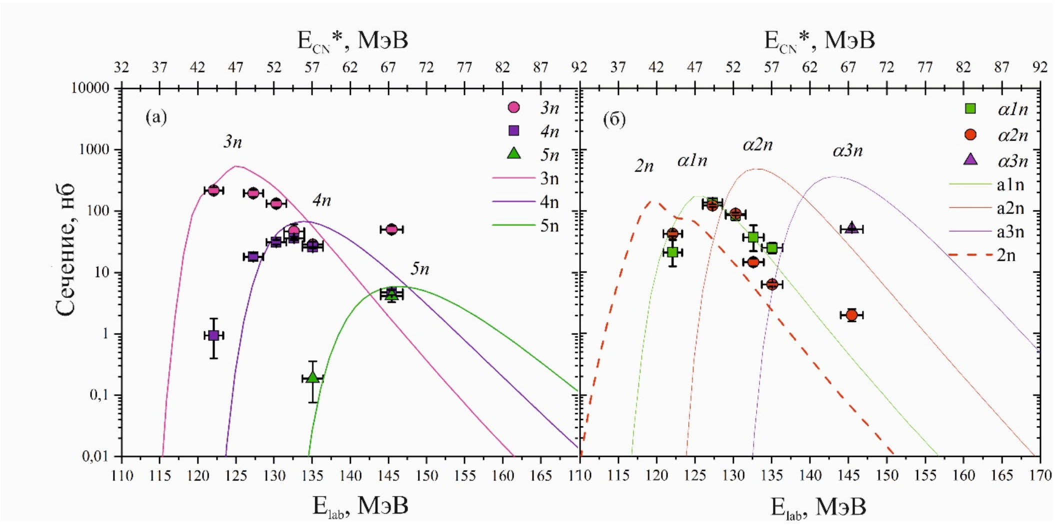

Рис 1. Функции возбуждения образования испарительных каналов xn и αxn для реакции ^{26}Mg+^{208}Pb. Символы – экспериментальные данные, линии – теоретический расчет, выполненный в программе NRV [4].

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STUDY OF THE EXCITATION FUNCTION IN REACTIONS WITH PROTONS FOR INTERMEDIATE AND HEAVY MASS NUCLEI

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Modern nuclear reaction studies show that in next eight years it will be an almost twofold increase in the consumption of radionuclides that are part of radiopharmaceuticals used in both diagnostic and therapeutic methods of nuclear medicine [1]. Today, one of the most promising radionuclide is terbium, whose radioactive isotopes can be used both diagnostic and therapeutic procedures in theranostics methods [2]. Other important radionuclides for theranostics are isotopes of antimony. The ^{117,119}Sb isotopes can be considered for the Auger therapy approach [3]. This leads to study of the basic characteristics of such isotopes and determine the optimal conditions of nuclear reactions for their production.

In this work, the reactions ^{nat}Gd(p,x)^{160,156,155}Tb and ^{117}Sn(p,n)^{117}Sb, ^{119}Sn(p,n)^{119}Sb were studied for proton energies below 14 MeV. This range is could be optimal for producing radionuclides in medical cyclotrons [4]. Therefore, the experimental investigations of the excitation function behavior for regions near its maximum have been carried out. This allows not only to determine the region that is optimal for the production of radionuclides, but also to check a number of modern models described reactions occurring through the compound core, taking into account the contribution from pre-equilibrium processes. For the reaction ^{117}Sn(p,n)^{117}Sb such information was obtained for the first time, which made it possible to clarify the position of the maximum and the behavior of the excitation function for high energies. The obtained data were compared with the prediction models for the ALICE/ASH, PRECO-2006, TALYS codes and with the TENDL-2023 systematics.

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ANALYSIS OF THE PROTON AMPLITUDE OF SCATTERING ON THE BOUNDED NUCLEAR NUCLEONS BASING ON THE PROTON-NUCLEUS SCATTERING DATA

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The experimental data on the proton elastic and inelastic scattering at energies 200-1000 MeV on the nuclei ^{28}Si, ^{40}Ca, ^{58}Ni and ^{208}Pb are investigated using the microscopic optical potential model. Such potential is based on the proton-nucleon amplitude of scattering on the bounded nuclear nucleons. The obtained parameters of the amplitude are compared with those known from analysis of the proton scattering on the free unbounded nucleons.

ВЫЧИСЛЕНИЕ СЕЧЕНИЯ РЕЗОНАНСНОЙ РЕАКЦИИ ^{6}Li(^{2}H, ^{4}He)^{4}He НА ОСНОВЕ РЕЗУЛЬТАТОВ AB INITIO РАСЧЕТОВ СПЕКТРОВ ВЫСОКОВОЗБУЖДЕННЫХ СОСТОЯНИЙ ^{8}Be

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В настоящее время в теоретических исследованиях свойств легких ядер основное место занимают высокоточные микроскопические подходы, в частности ab initio методы описания атомных ядер. Наиболее популярным среди этих методов расчета является оболочечная модель ядра без инертного кора (NCSM). Эта модель дает возможность довольно точно рассчитывать волновые функции основных и резонансных состояний легких ядер. Непосредственно NCSM не может применяться для расчета распадных характеристик ядерных состояний – асимптотических нормировочных коэффициентов закрытых и ширин открытых каналов фрагментации. Для решения данной задачи, авторами был ранее разработан метод ортогонализированных функций кластерных каналов (CCOFM) [1], что существенно расширило поле применимости ab initio подходов в исследованиях спектральных свойств ядерных состояний и открыло перспективы для внедрения высокоточных методов в теоретические исследования резонансных ядерных процессов. В первых исследованиях такого рода были получены сечения реакций p(^{7}Li, ^{4}He)^{4}He и n(7Be, ^{4}He)^{4}He. Проделанные расчеты и их анализ показали как хорошее согласие с экспериментом (дляреакции p(^{7}Li, ^{4}He)^{4}He), так и свои предсказательные возможности для сечения реакции n(^{7}Be,^{4}He)^{4}He [2].

В данной работе мы демонстрируем возможности разработанного подхода на примере расчета сечения более сложной для теоретического анализа реакции ^{6}Li(^{2}H,^{4}He)^{4}He и сравнения их результатов с экспериментальными данными. Сложность задачи заключается в том, что данная реакция идет через состояния 0^+, 2^+ и 4^+ ^{8}Be с чрезвычайно большой энергией возбуждения 22.0 – 25.5 МэВ, плотность которых при данной энергии достаточно велика. Измерения сечения этого процесса демонстрируют два пика — первый их них образуют резонансы 2^+, а второй пик — резонанс 4^+. Абсолютная величина сечения в различных экспериментах отличается практически в два раза. В рамках данной работы удалось идентифицировать резонансы, оказывающие определяющее влияние на сечение данной реакции и впервые в рамках теоретического исследования ядерных реакций сделать заключение о достоверности каждой из версий противоречащих друг другу экспериментальных данных.

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COMPETITION BETWEEN DEEP-INELASTIC TRANSFER AND FRAGMENTATION REACTIONS IN HEAVY-ION COLLISIONS AT FERMI ENERGY REGION

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Experimental data in the reaction $^{40}Ar+^{9}Be$ at projectile energy 36 MeV per nucleon obtained at the wide-aperture magnetic mass separator COMBAS were analyzed to investigate the competition between different collision reaction mechanisms in the Fermi energy region. As was shown in our previous papers velocity distributions of the forward-emitted fragments in the reactions at this energy range exhibit a very asymmetric shape, revealing the presence of at least two main components in the reaction mechanism. The right one with the peak at projectile energy is assumed to rise from direct (fragmentation) processes and is described by the Goldhaber distribution, the contribution of the left-hand side of the velocity distribution is connected with dissipative processes, it is naturally to assume that the main contribution to the dissipative processes responsible for the decrease in the velocity is made by deep-inelastic transfer reactions. Taking the ratio of these two contributions, we conclude that both mechanisms play approximately equal role in the reaction mechanism at projectile energies at the Fermi energy region. The results of modeling isotope distributions in different transport approaches and EPAX, AA and HIPSE models are presented and discussed.

NEUTRON-INDUCED FISSION CROSS SECTION OF ^{237}Np UP TO 500 MeV

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The ^{237}Np neutron-induced fission cross section was measured relative to the ^{235}U(n, f) cross section in the energy range from 0.2 MeV to 500 MeV using the GNEIS neutron time-of-flight spectrometer and the pulsed neutron source based on the 1 GeV proton synchrocyclotron of the NRC KI - PNPI (Gatchina). The experimental setup consisted of two position-sensitive MWPC counters, which also allowed simultaneous measurement of the angular distributions of the fission fragments [1]. A brief description of the experimental set-up, data processing and the preliminary results obtained are presented.

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ОПРЕДЕЛЕНИЕ НИЗКОЭНЕРГЕТИЧЕСКИХ ПАРАМЕТРОВ pp-СОСТОЯНИЯ В РЕАКЦИИ $d+{}^1\mathrm{H}\rightarrow p+p+n$

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В работе представлены результаты исследования реакции $d+{}^1\mathrm{H}\rightarrow p+p+n$ на ускорителе У-120 НИИЯФ МГУ. В кинематически полном эксперименте, проведенном при энергии дейтронов 15.3 МэВ, регистрировались в совпадении протон от развала синглетного pp ${}^1S_0$ состояния и вторичный нейтрон. В результате анализа формы энергетического спектра "развальных"протонов определены низкоэнергетические параметры pp-состояния: величина энергии виртуального синглетного pp-состояния и соответствующее ей значение pp-длины рассеяния.

Исследование выполнено в рамках научной программы Национального центра физики и математики, направление № 6 «Ядерная и радиационная физика».

ON SOLVING THE PROBLEM OF HEAVY ION COLLISIONS IN AN OPTICAL MODEL

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We present algorithm implements the solution of the inverse problem, i.e., calculates the unknown coupling constant $g(E)$ and scattering matrix $S(g(E),E)$ from condition $|S(g(E),E)|^2 = 1 - |T(E)|^2$ by means of the secant method. The required amplitudes of transmission $T(E)$ and reflection $R(E)$ subject also to the condition $|R(E)|^2 = 1 - |T(E)|^2$ of the model with incoming wave boundary conditions (IWBCs) are previously calculated by the standard MAPLE implemented KANTBP 4M program.The algorithm provides a one-to-one correspondence between the OM with a complex-valued potential and the model of IWBCs with a real-valued potential.

The efficiency of the proposed approach is shown by solving numerically the scattering problem and calculating the reference fusion cross section for a pair of heavy ions ^{16}O+^{144}Sm in the single-channel approximation of the close-coupling method.

A.A. Gusev, O. Chuluunbaatar, V.L. Derbov, R.G. Nazmitdinov, S.I. Vinitsky, P.W. Wen, C.J. Lin, H. M. Jia, L. L. Hai, Symbolic-numerical algorithm for solving the problem of heavy ion collisions in an optical model with a complex potential, Lecture Notes in Computer Science 14139, pp. 128–140 (2023).

ИССЛЕДОВАНИЕ РЕАКЦИЙ ПОД ДЕЙСТВИЕМ БЫСТРЫХ НЕЙТРОНОВ НА ЯДРЕ ^{10}B С ИСПУСКАНИЕМ ТРИТИЯ С ПОМОЩЬЮ КООРДИНАТНОГО ДЕТЕКТОРА

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Взаимодействие быстрых нейтронов с ядром ^{10}B при энергиях от 3 до 7 МэВ, сопровождающегося вылетом ядра ^{3}H, исследуется с целью выделения реакции с рождением ядра ^{8}Be* в возбужденном состоянии. Эта реакция выделяется на фоне трехчастичной реакции с вылетом тритона и двух альфа-частиц. Моделирование ионизационных потерь вторичных ядер ^{3}H и ^{4}He в твердых и газовых слоях двух позиционно-чувствительных многопроволочных детекторов с чувствительными размерами 100×100 и 50×50 мм^2 показало, что на диаграммах, построенных из потерь в двух газовых слоях, события локализуются в различных областях. Результат эксперимента с детектором 100×100 мм^2 показал возможность выделения реакции с вылетом ядер ^{3}H и ^{8}Be*. Новый детектор 50×50 мм^2 содержит два слоя бора-10 и проволочную систему из двух катодов и двух сеток и поэтому обладает увеличенной эффективностью и селективностью к исследуемой реакции.

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

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Activation techniques for studying nuclear reactions producing high-spin isomeric states are discussed. It is demonstrated that some specific properties of a beam of low-energy alpha particles that make this beam especially interesting for obtaining and studying these states.

Results of the investigations of the yield of high-spin and low-spin isomers in reactions ^{41}K(α,n)^{44}Sc, ^{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 as examples of such unique features. The anomalous behavior of the isomeric cross-section ratio (the presence of a pronounced maximum) for the first of these reactions is confirmed. Uniquely large isomeric cross-section ratios for the second and third ones are obtained. The features of the fourth reaction turned out to be promising for its application in fundamental research. Indeed, this reaction at an energy of 23 – 25 MeV provides the possibility of obtaining, using the secondary acceleration in the frame of the SPIRAL ISOLDE scheme of its products, the purest beams of high-spin isomeric nuclei.

SYSTEMATIC STUDY OF FUSION AND FISSION PROCESS IN HEAVY AND SUPERHEAVY MASS REGIONS

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Analyzing the current cosmic elemental composition opens the door to the origin of the cosmic elements. This requires a detailed analysis of the r-processes nucleosynthesis. Among them, our research is aimed at obtaining information on the fission of neutron-rich nuclei in the heavy and superheavy mass regions [1]. Fission fragments of neutron-rich nuclei in the superheavy elemental regions are thought to contribute to the r-process nucleosynthesis, and thus have a significant effect on the elemental composition of the universe. However, the fission of these neutron-rich regions is not accessible experimentally, so theoretical evaluation is important.

We have systematically calculated the mass distribution of fission fragments in the heavy and superheavy mass regions using the dynamical model with the same conditions, and analyzed the characteristics of fission fragments.

From these extensive systematic calculations, we found that the mass distribution of fission fragments in the neutron-rich region shows certain characteristic tendencies within the dynamical model, but the systematics of the fission properties change around the "Island of Stability", where nuclei have a strong nuclear structure. We would like to discuss, for example, how the specificity of the fission mode of Island of Stability the r-process network calculations.

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STIMULATION OF Re-186m ISOMERIC NUCLEI DE-EXCITATION IN HIGH-CURRENT Z-PINCH PLASMA AT THE "ANGARA-5-1" FACILITY

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Recently, in a laser plasma with an average electron temperature $\Theta \sim 1$ keV and a lifetime $\tau \approx 0.3$ ns, it was found out the stimulation of de-excitation of nuclear isomers (SDENI) Re-186m (half-life $T = 2 \times 10^5$ years) to the ground state of the Re-186 nuclei (T = 90 hours) with a probability $P \approx 1 \cdot 10^{-7}$, which apparently occurred through an intermediate trigger level with a half-life of $\tilde{1}0$ days. To increase the SDENI probability, it was proposed to use longer-lived electric discharge plasma instead of laser plasma (see Ref. [1] and references in there).

In Ref. [2], a methodology for SDENI experiments was developed for Re-186m isomers in the Z-pinch plasma of the "Angara-5-1" facility at Troitsk Institute for Innovation and Fusion Research. Plasma was obtained by implosion of a two-cascade cylindrical multiwire assembly (liner) with a current pulse of 4 MA and 1 MV voltage passing through it. The outer cascade of the liner with a diameter of 12 mm and a linear mass of 300 μg/cm was composed of Al-wires with a diameter of 8 μm, and the internal cascade with a diameter of 6 mm and a linear mass of 20 μg/cm was made of W-wires of 6 μm diameter. A Re-layer of 0.5 μm thick with the Re-186m isomer was deposited on W wires by electrolysis. The first experiments showed a SDENI-induced disturbance of the radioactive equilibrium between the isomer and the ground state of the Re-186 nucleus in Z-pinch plasma at $\Theta = 400$ eV and $\tau = 10$ ns. The intensity I of 137 keV γ-quanta of Re-186 decay from a sample of plasma matter after three plasma shots, decreased with time t and reached its stationary value after $t \approx 40$ days. Based on the parameters of the I(t) time dependence, we estimated the SDENI probability of $P \approx 2 \cdot 10^{-7}$ in the plasma.

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INVESTIGATION OF SPECTRAL STRUCTURE OF ^{11}Be IN BREAKUP REACTIONS WITHIN QUANTUM-QUASICLASSICAL APPROACH

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We investigate the breakup of the ^{11}Be halo nuclei on a light (^{12}C) target within quantum-quasiclassical approach in a wide range of beam energy (5–67 MeV/nucleon) including the low-lying resonances of ^{11}Be. The obtained results are in good agreement with existing experimental data at 67 MeV/nucleon. The developed computational scheme can potentially be used for interpretation of low-energy breakup experiments on different targets in studying spectral properties of nuclei. In particular, the region around 20-10 MeV/nucleon is of great interest, since this is the energy range of HIE-ISOLD at CERN and the future ReA12 at MSU, it has hardly been investigated theoretically so far.

LIGHT AND MEDIUM–HEAVY NUCLEI PHOTONEUTRON REACTION CROSS-SECTIONS IN BREMSSTRAHLUNG BEAM EXPERIMENTS

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In cases for many (∼50) nuclei from ^{51}V to ^{209}Bi the experimental data on photoneutron partial reactions (γ,1n), (γ,2n), (γ,3n) cross sections directly obtained using beams of quasimonoenergetic annihilation photons [1] do not satisfy objective physical criteria of data reliability [2–5]. The reasons are systematic uncertainties of experimental photoneutron multiplicity sorting method basing on partial reactions separation via measurement of neutron energies. Therefore, the experimental-theoretical method for partial reaction cross-section evaluation basing on physical criteria was used for analysis of reliability of data obtained using quite different method on the beams of bremsstrahlung [6]. Partial reaction cross sections are separated and determined in such kind experiment using statistical theory corrections to the neutron yield cross section $\sigma(\gamma,\mathrm{xn}) = \sigma(\gamma,1\mathrm{n})+2\sigma(\gamma,2\mathrm{n})+3\sigma(\gamma,3\mathrm{n})+...$ measured at first. Experimental cross sections of the reactions (γ,1n) and (γ,2n) are definitely unreliable in the cases of ^{51}V, ^{52}Cr, ^{59}Co, but enough reliable in the case of ^{90}Zr. The reason is that the role of two-nucleon reaction (γ,1n1p) was not taken into account, though this reaction competes with also two-nucleon reaction (γ,2n). It was shown via the results of calculation in the frame of the Combined photonuclear reaction model [5] that energy positions and amplitudes of cross sections of (γ,1n1p) and (γ,2n) reactions are very close to each other in the cases of ^{51}V, ^{52}Cr, ^{59}Co, but in the case of ^{90}Zr the value of (γ,1n1p) reaction cross section is very small and could be negligible. This conclusion is analogous to that of the preliminary investigation of the cases of ^{127}I, ^{165}Ho, ^{181}Ta [7]. It means that in the cases of relatively light nuclei ^{51}V, ^{52}Cr, ^{59}Co, as well as ^{58,60}Ni [8] the reaction (γ,1n1p) plays important role in nucleus photodisintegration but its contribution is not correctly described by statistical theory corrections.

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ИССЛЕДОВАНИЕ УГЛОВЫХ РАСПРЕДЕЛЕНИЙ И СЕЧЕНИЙ ИЗЛУЧЕНИЯ ГАММА-КВАНТОВ НА ЯДРАХ Si, O И C В РЕАКЦИЯХ С БЫСТРЫМИ НЕЙТРОНАМИ

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Ядерные реакции, происходящие под действием быстрых нейтронов с различными веществами, важны как для практического применения, так и с точки зрения фундаментальных исследований. На базе Лаборатории Нейтронной Физики им. И.М.Франка (ОИЯИ) реализуется международный проект «TANGRA» (TAgged Neutrons and Gamma RAys) по изучению рассеяния меченых нейтронов на атомных ядрах. В рамках проекта создано несколько многофункциональных конфигураций экспериментальных установок, в основе которых лежит использование метода меченых нейтронов (ММН). [1,2,3]

Одна из целей проекта «TANGRA» – создание и развитие базы данных по сечениям реакций взаимодействия нейтронов с энергией 14.1 МэВ с ядрами различных элементов и характеристическим γ-линиям для расширения применимости метода меченых нейтронов для элементного анализа различных материалов и веществ. На его базе ведётся поиск и систематизация экспериментальных результатов по угловым распределениям и сечениям излучения γ-квантов.

Данная работа посвящена измерению этих характеристик для ядер Si [1], O [2], C [3], испускаемых в ходе девозбуждения ядер-продуктов реакций с быстрыми нейтронами. Измерения этих характеристик производились на новой конфигурации установки «TANGRA», состоящей из двух полупроводниковых HPGe детекторов, которые имеют высокое энергетическое разрешение и четырёх сцинтилляционных детекторов LaBr. Такая комбинация детекторов позволяет измерять малоинтенсивные γ -линии с помощью детекторов высокого разрешения и угловые распределения для наиболее выраженных γ-переходов.

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ROLE OF ENTRANCE CHANNEL ANGULAR MOMENTUM ON THE MASS-ENERGY DISTRIBUTIONS OF ^{224}Th

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In heavy-ion induced reactions, the interaction mechanism is primarily governed by the projectile beam energy and angular momentum (L) of the composite system. The angular momentum brought in by the projectile have significant influence on the fission barriers [1-3]. The effects of L on fission have been less investigated due to the difficulty of producing the same compound nucleus (CN) via different projectile-target combinations [4]. Therefore, an attempt has been made to produce a fissioning nucleus through different entrance channels at similar excitation energies in order to investigate the role of entrance channel angular momentum.

The experiments were performed at the Flerov Laboratory of Nuclear Reactions (FLNR), JINR, Russia, using energetic beams of ^{16}O and ^{48}Ca delivered from the U400 cyclotron. The thin targets of ^{208}Pb and ^{176}Yb were bombarded with the ^{16}O and ^{48}Ca beams, respectively at different energies above the Coulomb barrier to produce the fissioning nucleus, ^{224}Th. The measurements of the reaction binary products were carried out by utilizing the double-arm time-of-flight (TOF) spectrometer CORSET [5]. Assuming the conservation of mass of the composite system of projectile and target, the double-velocity method was employed to determine the mass and energy of the reaction products.

The reactions, ^{16}O + ^{208}Pb and ^{48}Ca + ^{176}Yb, lead to the formation of the same composite system, ^{224}Th above the Coulomb barrier. The Mass-Total Kinetic Energy (M-TKE) distributions of the primary binary fragments from ^{224}Th has been obtained from the present measurement. The latter reaction is subject to significant influence of quasifission reaction mechanism in addition to fusion-fission process. Subsequently, the events corresponding to fusion-fission process only were selected on the measured M-TKE distribution profiles to investigate the role of angular momentum on the fission reaction mechanism. Detailed multimodal analysis has been carried out on the experimental mass and energy distributions of the fission fragments.

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TOTAL REACTIONS CROSS SECTIONS MEASURING METHODS

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Properties of nuclear sizes, such as material and charge root-mean-square radii and density distributions of nuclear matter, provide us with basic information for understanding the structure of the nucleus [1, 2]. One of the experimental approaches to extracting these parameters, particularly for radioactive nuclei, is based on measuring the total reaction cross sections σR and their energy dependencies $\sigma R(E)$ [3-5]. The σR measurement provides us with an objective and model-independent test for various theoretical models.

Currently, the development of methods for measuring σR is especially important due to the low intensities of beams of exotic nuclei located at the boundary of nucleon stability [5].

The paper provides an overview of methods for measuring total reaction cross sections, provides a systematic description of the methods, and outlines the main directions of their development. Particular attention is paid to the analysis of 4π methods for measuring the total cross sections of reactions with radioactive nuclei in the energy range 5 – 50 MeV/nucleon [6,7].

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MEASUREMENT OF ANGULAR DISTRIBUTIONS OF DIFFERENTIAL CROSS SECTIONS OF PRODUCTS OF THE ^{7}Li+^{10}B REACTION

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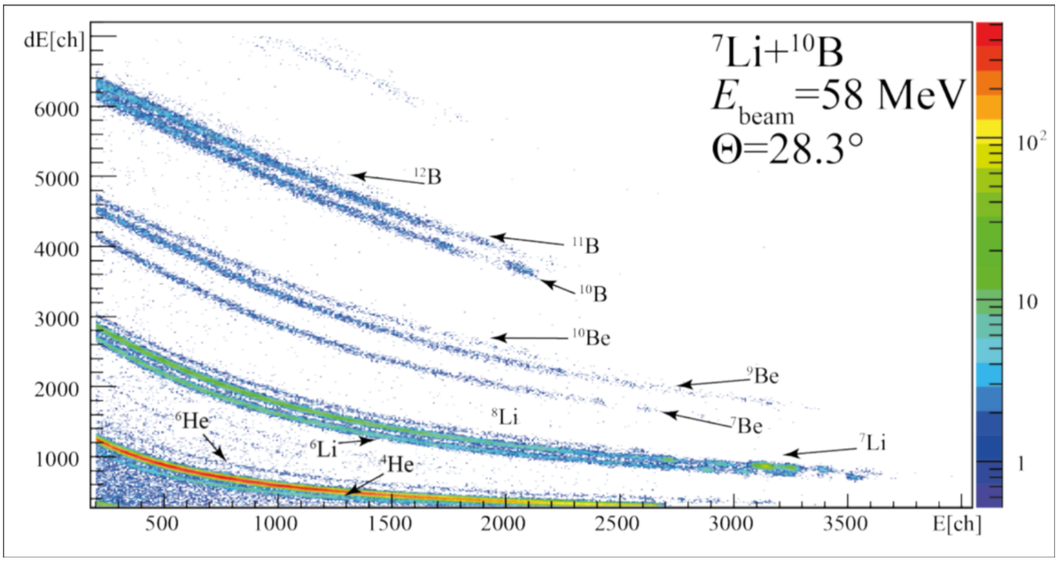
Measurements were carried out of the angular distributions of the differential cross sections of the reaction products ^{7}Li+^{10}B $E_{\mathrm{LAB}} = 58$ MeV. One of the objectives of the measurements was to compare the root-mean-square radii of the ground and excited states of nuclei obtained in the reaction. In the experiment, the angular distributions of $^7\mathrm{Li}_{\mathrm{g.s.}}$, $^6\mathrm{Li}_{\mathrm{g.s.}}$, $^6\mathrm{Li}^*$(3.56 MeV), as well as $^{11}\mathrm{B}^*$(8.56 MeV) were of interest. The $^6\mathrm{Li}^*$ nucleus is in the $J^\pi = 0^+$; $T = 1$; $E = 3.56$ MeV is the isobaric analogue state of $^6\mathrm{He}_{\mathrm{g.s.}}$. The $^{11}\mathrm{B}^*$ nucleus is in the $J^\pi = 3/2^-$ state; $E = 8.56$ MeV, according to [1], is a cluster state, similar to the previously discovered Hoyle state $^{12}\mathrm{C}^*$, $J^\pi = 0^+$; $T = 0$; $E = 7.65$ MeV, predicted in [2] and first discovered in [3] by measuring the angular distributions of differential cross sections. The measurements were carried out on the ^{7}Li beam ($E_{\mathrm{LAB}} = 58$ MeV) of the U-400 accelerator of the FLNR JINR using 8 $dE - E$ semiconductor telescopes. A typical two-dimensional $dE - E$ spectrum is shown in Fig. 1.



Experimental matrix $dE \times E$ of reaction products ^{7}Li + ^{10}B, at an angle $\Theta_{\mathrm{LAB}} = 28°$ at energy $E_{\mathrm{LAB}} = 58$ MeV.

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INFLUENCES OF THE ISOSPIN-ASYMMETRY AND NUCLEAR SKIN THICKNESS ON THE STRUCTURE AND REACTIONS OF HEAVY NUCLEI

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The isospin-asymmetry and its related nuclear matter properties influence most of the nuclear structure, reactions and decays. For instance, the values of the density diffuseness in finite nuclei and its anisotropy and polarization, rely on the asymmetry characteristics of the nucleon-nucleon interaction and nuclear matter at sub-saturation densities. This is related to the allowed maximum isospin asymmetry value for bound asymmetric nuclear matter. Increasing the isospin-asymmetry within the surface and tail regions of the nucleus makes these regions more soft relative to the internal region, and this consequently increases its single-particle and collective dynamicity. This in turn affects its structure and its reactions with other nuclei. Detailed influences of the isospin asymmetry and its related neutron/proton skin thickness, and the symmetry energy coefficients of nuclear matter on the fusion reaction of nuclei and its α and cluster decays will be discussed.

FISSION OF ^{243}Am BY NEUTRONS OF INTERMEDIATE ENERGY: ANALYSIS OF CROSS SECTION AND ANGULAR ANISOTROPY OF FISSION FRAGMENTS

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The results of measurements of fission cross sections and angular distributions of fission fragments from neutron-induced fission of ^{243}Am in the energy range 1-500 MeV are presented in [1]. The measurements were performed on the neutron time-of-flight spectrometer based on the GNEIS neutron complex at the 1GeV proton synchrocyclotron of the NRC "Kurchatov Institute-PNPI (Gatchina). The data obtained can be used to gain insight into the barriers of Am isotope fission, the transition states at these barriers, the magnitude of the collective enhancement in the level density of deformed nuclei, and the role of direct and pre-equilibrium processes in the interaction of intermediate-energy neutrons with nuclei.

In this work, the cross section for the fission of ^{243}Am nuclei by neutrons with energies from 0.1 to 300 MeV was calculated using the Talys-1.9 program [2]. Our modification of this program [3,4] made it possible to obtain not only the total fission cross section, but also the differential fission cross section. It has been shown that the fission barrier parameters from the RIPL-3 library [5], used as default parameters in Talys-1.9, do not reproduce the energy dependence of the total fission cross section in the entire energy range considered. The parameters of the barriers and the coefficients of the additional collective enhancement of the level density at the barriers have been determined, which make it possible to satisfactorily reproduce the energy behavior of the fission cross section up to an energy of 120 MeV. It is also shown that in the range from 3 to 120 MeV, the angular anisotropy of fission fragments is satisfactorily described within the framework of a statistical approach to the formation of the fission probability distribution over the projection K of the nuclear spin onto the deformation axis.

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INVESTIGATION OF (γ,xn)-REACTIONS ON NATURAL IRIDIUM AT 55 MeV BREMSSTRAHLUNG ENERGY

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The study of photonuclear reactions is an important fundamental task for obtaining information about the structure of the nucleus and the nature of the nuclear forces. At present, only reactions involving the escape of one or two neutrons in the giant dipole resonance region are well studied. We have studied the flux-weighted average cross sections of (γ,xn) reactions on natural iridium at bremsstrahlung with an end-point energy of 55 MeV.

The determination of the flux-weighted average cross sections of the studied photonuclear reactions was carried out by activation analysis methods. The source of the 55 MeV bremsstrahlung was a racetrack microtron of the Lomonosov Moscow State University Skobeltsyn Institute of Nuclear Physics. In the experiment, an assembly of an iridium target and a tantalum monitor target was irradiated for one hour. The irradiated targets were then measured using Ortec and Canberra semiconductor spectrometers with ultrapure germanium detectors having an energy resolution of 1.8-2.0 keV for 1333 keV ^{60}Co gamma radiation. The detection efficiency of the spectrometers was determined using standard calibration sources ^{152}Eu, ^{226}Ra, ^{137}Cs.

The table summarises the experimental values of the flux-weighted average cross sections of the photonuclear reactions studied on natural iridium. The experimental values obtained were compared with theoretical values calculated in the framework of the constant temperature Fermi gas model and the Gogny-Hartree-Fock-Bogoluybov temperature-dependent density model using the Talys 1.96 program code.

Flux-weighted average cross sections of the studied (γ,xn) reactions on natural iridium

Reactions	exp
^{193}Ir(γ,n)^{192}Ir	99(6)
^{193}Ir(γ,3n)^{190}Ir+^{191}Ir(γ,n)^{190}Ir	48(4)
^{193}Ir(γ,4n)^{189}Ir+^{191}Ir(γ,2n)^{189}Ir	23(2)
^{193}Ir(γ,5n)^{188}Ir+^{191}Ir(γ,3n)^{188}Ir	6,0(5)
^{191}Ir(γ,4n)^{187}Ir	3.1(2)
^{191}Ir(γ,5n)^{186}Ir	1.1(1)
^{191}Ir(γ,6n)^{185}Ir	0.20(4)

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TARGET DEPENDENCE OF THE ISOTOPE DISTRIBUTIONS IN HEAVY-ION REACTIONS AT FERMI ENERGIES

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Heavy-ion reactions at Fermi energies are a tool to produce new isotopes far from stability line. Previous experiments show that the production of neutron-reach isotopes is enhanced when the heavy target is used instead of the light one. In this report we compare isotope distributions calculated in transport-statistical approach BNV-SMM with the three frequently used models: empirical EPAX , geometrical-macroscopic Abrasion-Ablation and phenomenological HIPSE, and experimental data obtained in collisions of ^{18}O projectile on ^{181}Ta and ^{9}Be targets at 35 MeV per nucleon obtained at COMBAS set-up in FLNR, JINR. The experimental ratio of cross-sections obtained in the reactions on heavy ^{181}Ta and light ^{9}Be target in the collision with the same projectile and the same ratio obtained as model predictions is discussed. Some explanations of the observed features are presented.

ОЦЕНКА КОЭФФИЦИЕНТОВ КОРРЕЛЯЦИИ СПИНОВ ФРАГМЕНТОВ ДВОЙНОГО ДЕЛЕНИЯ ЯДЕР

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Представленная работа посвящена развитию квантово-механического описания различных характеристик атомных ядер, возникающих в процессе двойного деления. Основной акцент в рамках данного исследования делается на оценку коэффициентов корреляции спинов фрагментов деления (ФД).

Методика построения коэффициентов корреляции спинов строится на основе концепции «холодного» делящегося ядра [1], т. е. когда предфрагменты деления не претерпевают нагрева на всем пути их спуска с внешнего барьера деления и вплоть до точки разрыва. В рамках этой концепции энергия возбуждения ФД уходит на их неравновесную деформацию, поэтому за формирование спинов ФД отвечают делительные моды нулевых колебаний, а именно продольных wriggling- и bending-колебаний [2], учет которых позволяет непротиворечиво описать исследуемое явление и связанные с ним величины, в том числе коэффициенты корреляции спинов ФД спонтанного и низкоэнергетического вынужденного двойного деления ядер-актинидов.

Предложенная методика расчета коэффициентов корреляции интересна тем, что позволяет избежать температурного подхода, поскольку в рамках развиваемой методики ФД находятся в «холодных», но неравновесных по своей деформации состояниях. Полученные оценки не согласуются с результатами, представленными в экспериментальной [3] и теоретической [4] работах, которые предполагают отсутствие корреляции между спинами ФД, хотя в рамках рассмотренной концепции впервые получены результаты разумно согласующиеся с законом сохранения полного спина.

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^{6}Li+d REACTION TOTAL CROSS SECTIONS

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^{6}Li+d reaction total cross sections were obtained within the deuteron energy interval from 50 keV to 180 MeV with the use of resonant optical-model code OptModel [1,2]. Deuteron exchange process experimentally not separated from the elastic scattering was taken into account in the code. All available experimental data on differential cross sections of deuteron elastic scattering on ^{6}Li nucleus as well as total ^{6}Li+d reaction cross sections in range E_d=0.05-10 MeV obtained in our SABA library [3] from evaluated cross sections of inclusive ^{6}Li(d,xn), ^{6}Li(d,xp), ^{6}Li(d,d1), ^{6}Li(d,xt), ^{6}Li(d,xhe), ^{6}Li(d,xα) reactions were analyzed. Cross sections evaluation is described carefully in this paper. New optical potentials for ^{6}Li+d were obtained.

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DETECTION SYSTEM OF THE DGFRS-2 SETUP: FIRST APPLICATIONS IN LONG TERM IRRADIATIONS WITH INTENSE HEAVY ION BEAMS AT DC-280 CYCLOTRON

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Double Side Silicon Detector (DSSD) based spectrometer of the DGFRS-2 setup has been applied in a different heavy ion induced complete fusion nuclear reactions leading to formation of superheavy nuclei. Nuclear reactions with ^{48}Ca, ^{40}Ar, ^{54}Cr projectiles were used [1,2]. Materials of ^{206}Pb, ^{nat}Yb, ^{232}Th, ^{238}U, ^{242}Pu, ^{243}Am were used as targets. We report about different stability tests during these long term experiment. Radiation damage induced of achange in leakage current values of DSSD detectors are under consideration.Formation of the evaporation residue (ER) registered energy spectrum measured with DSSD focal plane detector is presented. Comparison with the PC-based simulation code for these spectra generation is made for different cases. A specific of application of "active correlation" real-time method is reported in brief too [3]. Review of the design of the DGFRS-2 spectrometer is preceding the main results [4-6].

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EXAMINATION OF COLLECTIVE AND SINGLE-PARTICLE MODELS FOR EXCITED STATES OF ^{13}C BELOW 10 MeV IN NUCLEAR REACTIONS INDUCED BY 18 MeV DEUTERON BEAM

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The first 10 excited states of the carbon isotope were studied in terms of single-particle and collective models of excitation. Experimental cross sections were obtained by the well-known $\triangle$E–E method. Elastic scattering data were analyzed using an optical model including a nucleus–nucleus interaction potential, while inelastic scattering data were processed using the coupled-channels approach. For the single-particle model, the spectroscopic amplitudes were obtained through calculations of the large-scale shell model with the YSOXT effective NN-potential. A double folding potential was obtained for the d + ^{13}C system. A comparison of model calculations with the experimental cross sections was demonstrated.

RESONANCE AMPLIFICATION OF NUCLEAR REACTION X(a,b)Y NEAR THE a+X CHANNEL THRESHOLD

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Deviation of the cross section for the nuclear reaction X(a, b)Y from the Gamow formula due to an interaction additional to the Coulomb one in the entrance channel has been analyzed. It is shown that the reaction cross section has an oscillating structure at low energies. If the maximum of the first oscillation is close to the threshold of the channel a+X, it has a resonance behavior. To analyze the effect, simple relations between the period and the amplitude of the oscillations with parameters of the interaction have been derived. Specifically, they predict the cross-section oscillations of fusion reactions of the type X(a,b)Y for slow collisions between nuclei (a) and atomic target (X), as, for example, the reaction D(d,p)T between deuterons (d) and deuterium atoms (D) [1].

This simple formalism is used for analysing the resent data on process $e^+ + e^- \to \Lambda_c^+ + \bar{\Lambda}_c^-$ obtained recently by the BESIII Collaboration [2].

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STUDY OF THE ACTIVITY YIELDS OF ^{186,188}Re IN (γ, pxn) REACTIONS

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^{186}Re and ^{188}Re are promising radionuclides for use in theranostic nuclear medicine. For the successful implementation of these medical radionuclides, it is very important to find methods to produce them cheaply and rapidly. ^{186}Re is being produced in the ^{185}Re(n, γ)^{186}Re reaction from targets enriched in ^{185}Re. However, high radionuclide purity of this isotope is difficult to achieve. This is due to the complexity of separating the target radionuclide from the matrix. The main way to produce ^{188}Re is the ^{188}W→^{188}Re generator system. Since ^{nat}W consists of 4 isotopes ^{182}W(26.5%), ^{183}W(14.3%), ^{184}W(20.64%) and ^{186}W(28.43%), metallic tungsten targets enriched in ^{186}W are used to produce the parent radioisotope ^{188}W in double neutron capture reactions [^{186}W(n, γ), ^{187}W(n, γ)^{188}W] followed by thermochromatographic separation of ^{188}Re. Due to the complexity and cost of producing ^{186}Re and ^{188}Re by the reactor method, there is an important need to find alternative ways to produce these promising medical radioisotopes.

To solve this problem, we have carried out studies to obtain the activities of ^{186,188}Re under irradiation of natural osmium by bremsstrahlung with an end-point energy of 55 MeV. An osmium target and tantalum monitor target assembly was irradiated for one hour at the Lomonosov Moscow State University Skobeltsyn Institute of Nuclear Physics racetrack microtron. The irradiated targets were then measured using Ortec and Canberra semiconductor spectrometers with ultrapure germanium detectors with an energy resolution of 1.8-2.0 keV for 1333 keV ^{60}Co gamma rays. The detection efficiency of the spectrometers was determined using standard calibration sources ^{152}Eu, ^{226}Ra, ^{137}Cs.

Gamma transitions accompanying ^{186}Re and ^{188}Re decays were reliably identified in the gamma spectra and activity yields were obtained: Y_A(^{186}Re)=(3.2±0.3)×10^5 Bq/g×μA×h, $_A$(^{188}Re)=(9.6±0.3)×10^5 Bq/g×μA×h. The results obtained are discussed.

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EMISSION OF HIGH-ENERGY ^{4}He AND ^{6,7}Li NUCLEI IN NUCLEAR REACTION OF ^{56}Fe IONS ON ^{238}U TARGET

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The energy spectra of alpha particles and ^{6,7}Li nuclei emitted at an angle of 0° in the reaction induced by a ^{56}Fe beam (400 MeV) incident on a ^{238}U target were measured by means of the high-resolution magnetic analyzer (MAVR setup) [1]. The resulting spectra (Fig. 1) were found to contain fast alpha particles and ^{6,7}Li nuclei with the energy corresponding to the two-body and three-body exit channels [2]; the energy of alpha particles was close to the two-body kinematical limit. In the region of lower and higher energies, the ratios of the cross sections for the emission of alpha particles to the cross sections for the emission of lithium nuclei are very different, which indicates different mechanisms for the formation of these nuclei. The obtained data were analyzed based on the model of moving sources. The emission of nonequilibrium alpha particles and ^{6,7}Li nuclei in the forward direction is also considered within the quantum time-dependent approach [2, 3].

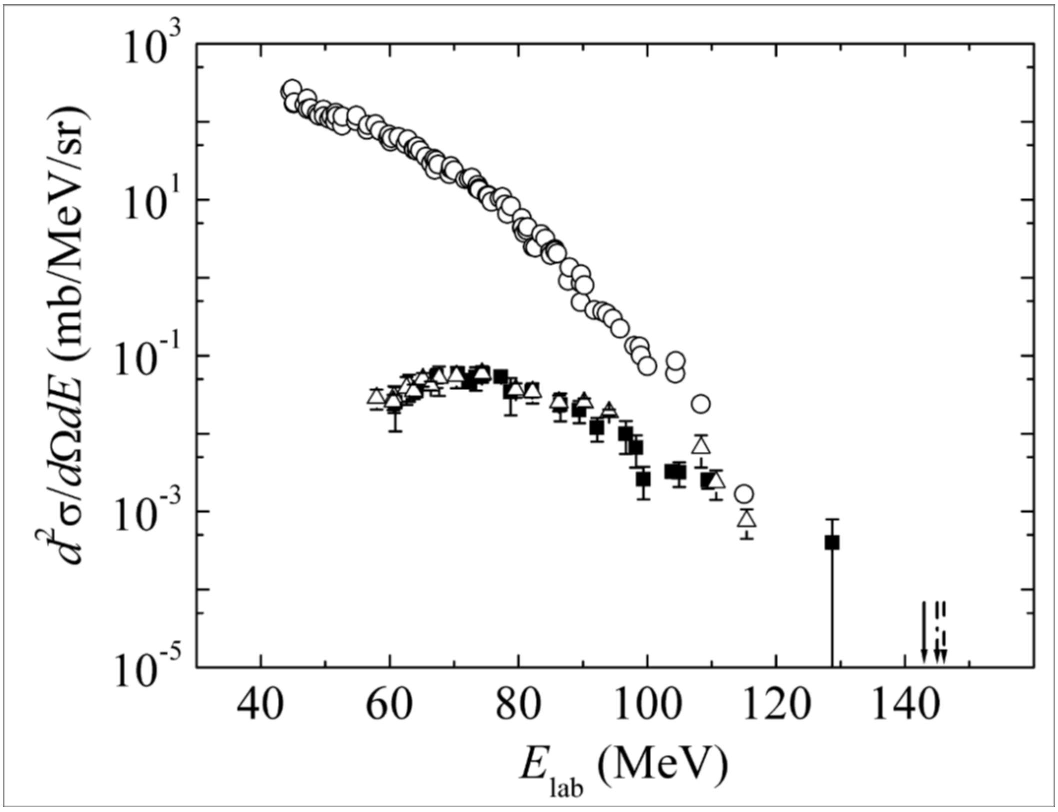

Fig. 1. Energy spectra of alpha particles (circles), ^{6}Li (squares), and ^{7}Li (triangles) measured at an angle of 0° in the reaction ^{56}Fe (400 MeV) + ^{238}U.

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DETERMINATION OF NUCLEAR MATTER RADII USING S-MATRIX FOR ELASTIC SCATTERING OF IDENTICAL NUCLEI

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New approach based on combination of the optical model with the modified optical potential and the classical trajectories is proposed for calculations of the effective matter radii of the identical colliding nuclei. The example of the angular distribution for ^{6}Li + ^{6}Li elastic scattering is shown in Fig. 1a. The plot of the value $1-|S_l|^2$, where S_l is the diagonal element of the S-matrix, is shown in Fig. 1b. The quantum partial reaction probability $1-|S_l|^2$ can be transformed into the semiclassical partial reaction probability

$$P_R(R_{\min}) = \left\{1 + \exp\left[\frac{R_{\min} - R_{\mathrm{R}}}{a_{\mathrm{R}}}\right]\right\}^{-1}$$

as a function of the minimum distance between the centers of the colliding nuclei $R_{\min}$ depended on energy E and impact parameter b taking into account the relation: $l \sim kb$. For ^{6}Li + ^{6}Li elastic scattering at $E_{\mathrm{lab}} = 40$ MeV the results of calculations are $R_{\mathrm{R}} = 5.76$ fm and $a_mathrmR =$ 0.47 fm. The quantity R_{R} may be interpreted as the sum of the effective matter radii R_{m} of the identical nuclei $R_{\mathrm{R}} = 2R_{\mathrm{m}}$. So the determined effective matter radius of the ^{6}Li nucleus is $R_{\mathrm{m}} = 2.88$ fm, the experimental rms charge radii is 2.589 fm [2]. Similarly, the effective matter radii of the ^{9}Be, ^{11}B, ^{12}C and ^{16}O nuclei were calculated using data from [2], they are 4.0 ± 0.05, 3.3 ± 0.05, 4.0 ± 0.05 and 3.3 ± 0.05 fm, accordingly.

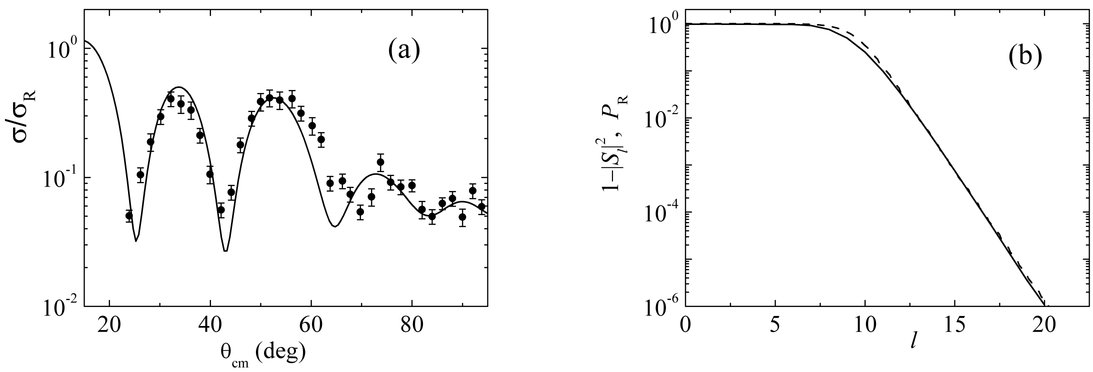

Fig.1. (a) The experimental angular distributions (points) for elastic scattering of ^{6}Li + ^{6}Li at Elab = 40 MeV [1] and the results of calculations in the optical model with modified real part of the optical potential (curve). (b) Comparison of the dependences of the quantum partial reaction probability $1-|S_l|^2$ (solid curve) on the orbital angular momentum l for elastic scattering ^{6}Li + ^{6}Li at $E_{\mathrm{lab}} = 40$ MeV with the semiclassical partial reaction probability $P_{\mathrm{R}}\left[R_{\min}(1/k, E)\right]$ (dashed curve).

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FISSION MODES AND DEFORMED NUCLEAR SHELLS IN MASS AND ENERGY DISTRIBUTIONS OF FISSION FRAGMENTS OF ^{237}Pu COMPOUND NUCLEI FORMED IN ^{233}U(α,f) REACTION AT 24 AND 29 MeV INCIDENT ALPHA PARTICLE ENERGY

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Mass and energy distributions of fission fragments of ^{237}Pu compound nuclei formed in ^{233}U(α,f) reaction at 24 and 29 MeV incident alpha particle energy were measured at U-150M cyclotron at Institute of Nuclear Physics, Almaty, Kazakhstan using 2E method. Measured distributions at two different compound nuclei excitation energies were each decomposed into separate yields from fission modes and deformed nuclear shells using a method that takes into account mass yield, average total kinetic energy and variance of average total kinetic energy. This method also assumes that mass yield of each mode and each deformed shell has a shape of gauss distribution. Such assumption reduces the number of parameters required to fit experimental data and as such increases the sensitivity of the method to yields of weaker deformed shells. This allowed to separate yield of $Z = 50$ spherical shell from yield of $Z = 52$ deformed shell, yield of $N = 88$ deformed shell from yield of $N = 84$ deformed shell and yield of $N = 50$ spherical shell from yield of $N = 46$ deformed shell.

ИССЛЕДОВАНИЕ ВАРИАЦИИ МНД

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Исследование процесса эмиссии мгновенных нейтронов деления в реакциях деления, индуцированного нейтронами необходимо для понимания общих закономерностей деления ядер и процессов распределения энергии между фрагментами. Процесс деления ядра рассматривается как эволюция заряженной жидкой капли в процессе конкуренции между кулоновскими силами отталкивания и ядерными силами притяжения, приводящей в результате к разрыву ядра на пару осколков деления (ОД). Большая часть энергии возбуждения делящегося ядра передается мгновенным нейтронам деления (МНД), испущенными ОД после полного ускорения кулоновскими силами. Экспериментальные исследования различных характеристик эмиссии МНД необходимы для понимания динамики деления ядра плоть от седловой точки до разрыва. Одним из интересных наблюдений явилось увеличение из тяжелого ОД при увеличении энергии возбуждения делящейся системы [1], которое до сих пор не нашло ясного объяснения. Поэтому необходимы дальнейшие систематические исследования корреляций между характеристиками фрагментов деления и эмиссией МНД. Исследования процесса эмиссии МНД в делении, индуцированном нейтронами

EXPERIMENTAL STUDIES OF CLOSED SHELLS INFLUENCE ON FUSION-FISSION AND QUASIFISSION COMPETITION IN REACTIONS WITH ^{40,48}Ca

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Fission of atomic nuclei studies is one of the main problems of the modern nuclear physics. Quasifission is considered to be one of the competing processes for fusion-fission of heavy and superheavy nuclei, preventing the formation of the complex compound nuclei. These two mechanisms are being governed by the shell effects [1-4].

The following work is dedicated to experimental studies of fusion-fission and quasifission mechanisms in ^{40,48}Ca+^{208}Pb at energies around the Coulomb barrier. Such choice of reactions is determined by the existence of $Z = 20$, $N = 20$, $N = 28$ closed shells in calcium isotopes. The experiment was carried out at the U-400 accelerator in FLNR JINR. Mass and total kinetic energy (MTKE) distributions were measured with the use of double-arm time-of-flight spectrometer CORSET.

In this work we presented MTKE distributions for fusion-fission and quasifission processes in reactions ^{40,48}Ca+^{208}Pb at incident energies 197.5-222 MeV for ^{40}Ca and 208-281 MeV for ^{48}Ca. It was also shown how the contribution of fusion-fission and quasifission processes change with the excitation energy.

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DIMENSIONS OF ^{6}Li IN LOW-LYING STATES

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^{6}He is one of the simplest nuclei with a halo in the ground state 0^{+}; its study has received considerable theoretical attention [1]. In [2], an assumption was made about a halo-like structure in the isobar-analogue state of the 3.56 MeV state, 0^{+} ^{6}Li. This structure is a spatially extended halo-like structure with an alpha particle core and a proton and neutron surrounding it. In [3], it was shown that the radius of the 3.56 MeV, 0+ state is 2.5 ± 0.2 fm and, within errors, coincides with the radius of ^{6}He, which allows for the possibility of the presence of a halo (proton-neutron, and in some works called tango-halo) [4]. Let us recall that the spatial structure of the ^{6}He nucleus was predicted to be quite complex, in which correlations of two types appeared: “cigar” and “dineutron”.

The question arises: does the structure of the state change so much when going from ^{6}He to the isobar analogue in ^{6}Li that it requires the introduction of a special type of “tango-halo” [4]. To answer this question, new experimental data were required. Not long ago, the ^{7}Li(d,t)^{6}Li experiment was performed on the deuteron beam of the U-150M cyclotron at the Institute of Nuclear Physics (Almaty, Republic of Kazakhstan) at an energy of 14.5 MeV. The angular distributions of the studied nuclear reactions cover the angle range from 18° to 128° (lab.). The angular distributions for the ground and first four states were obtained: 2.19, 3.56, 4.31 and 5.36 MeV. The experimental data were analysed within the framework of the DWBA method and the coupled channel method. The analysis is currently ongoing to estimate the radii of low-lying excited states. There is some indication of an increased radius of the 3.56 MeV state, confirming its halo nature.

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SEARCH FOR HALO STRUCTURES IN ^{8}Li

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One of the main directions of modern nuclear physics is the study of exotic nuclei far from the stability line, i.e. nuclei with an excess of neutrons or protons. One of the most famous representatives of exotic nuclei is halo.

In the A=8 multiplet, a halo was firstly discovered in ^{8}B in [1] based on increased quadrupole moment. It was shown that the halo structure is ^{7}Be core and a valence proton. It should be noted that the halo is detected despite the presence of both the Coulomb and centrifugal barriers. In [2], the presence of a proton halo in ^{8}B was confirmed using the total cross section, as well as the root-mean-square radius R_{rms} = 2.58 fm and the halo radius R_h = 4.24 fm. The question arises about the possibility of the halo in ^{8}Li. In [1], using the value of quadrupole moment for ^{8}Li, it is said that there is a thin neutron skin around the ^{7}Li core. In [2], using total cross section, it is stated that there is no halo in ^{8}Li. To analyze the possibility of the halo in ^{8}Li, we propose to use (d,p) reaction. Deuteron stripping is usually used as a sample of the single-neutron structure of nuclear states for last decades. The ^{7}Li(d,p)^{8}Li experiment was performed using the deuteron beam of the U-150M cyclotron at the Institute of Nuclear Physics (Almaty, Republic of Kazakhstan) at an energy of 14.5 MeV. The ^{7}Li isotope (enrichment $\approx$ 90 %) was used as a target. The angular distributions were measured in the angle range from 18° to 80° (lab). Angular distributions were obtained for the ground and first two excited states 0.98 and 2.26 MeV.

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DEVIATIONS FROM A.BOHR'S FORMULA FOR FISSION FRAGMENTS ANGULAR DISTRIBUTIONS WITH TAKING INTO ACCOUNT ZERO WRIGGLING-VIBRATIONS OF THE FISSILE NUCLEUS

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The description of the fission fragments (FFs) angular distributions requires the use of quantum concepts about the dynamics of the fission process. It was demonstrated [1] that during spontaneous and low-energy induced binary fission FFs near the scission point should be in cold nonequilibrium states. For the construction of FFs angular distributions, it is necessary to take into account only zero transverse wriggling-vibrations of the fissile nucleus [2] near its scission point. The directions of FFs emission from the fissile nucleus, according to A. Bohr's hypothesis [1], are close to the symmetry axis of the fissile nucleus, which makes it possible to represent the amplitude of the FFs an-gular distribution in the form of a smeared delta function determined by the coherent superposition of large relative orbital momenta L of these fragments. The appearance of this superposition can be associated with the occurrence of zero collective transverse vibrations of pre-fragments in the vicinity of the scission point of the fissile nucleus, which leads to large values of the relative orbital momenta L of the FFs. Using the distribution of orbital momentum [3] $P(L) = 1/(\pi C_w) \exp(L^2/C_w)$, where C_w is the coefficients of wriggling -vibrations [2], the possibilities of detecting deviations of the FFs angular distributions in low-energy binary fission of aligned acti-nide nuclei by resonant neutrons and for the sub-barrier photofission of even-even actinides from the angular distributions described by the A. Bohr's formula are investigated. From the comparison of the relative measurement errors of the anisotropy coefficients in the FFs angular distributions with deviations of the theoretical values of the anisotropy coefficients calculated by taking into account the wriggling-vibrations of the fissile nucleus from their values calculated using the A.Bohr for-mula, an estimate of the wriggling vibration parameter , were carried out.

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THE EFFECT OF THE NON-AXIAL SHAPE OF NUCLEI ON THE FISSION CHARACTERISTICS IN THE LANGEVIN APPROACH

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Description of nuclear fission is still an important problem. This is proved by the existence of various models attempting to describe maximally possible characteristics of the investigated process.

Similar goal is also faced by the model developed [1, 2] in the present study, which describes the dynamics of fission of heavy nuclei in the low- and medium-energy range. It is based on the use of a multidimensional system of Langevin equations responsible for changing the deformation configuration of the fissile system, whose surface is given [3] by Fourier parametrization. The potential of the deformed compound nucleus is described within the macroscopic-mircroscopic approach [4].

In earlier works [1, 2], the model considered the dynamical change of only three parameters corresponding to the nucleus deformation. Their physical meaning corresponds to the elongation of the system, the asymmetry of the pre-fragments, and the thickness of the neck connecting them. This was sufficient to consider the fission process at the final stage - the descent from the last barrier, i.e., we used the pre-deterministic hypothesis of the unavoidable breakup of the system by splitting the nucleus into fragments. This assumption, together with certain initial conditions [2], made it possible to simplify the calculations of such fission characteristics as the mass and charge distributions of the fragments and the total kinetic energies, which were in good agreement with experiment.

In several papers [5 − 8], where similar Langevin models are also used, the fission process was considered starting from the ground state of the system and, obviously, providing the system with sufficient excitation energy to overcome the fission barriers. Nevertheless, only few (e.g. [6, 8]) take into account the non-axiality of the nucleus shape, which has direct influence on fission barrier heights, which is crucial in low-energy fission. However, it is also important for understanding the influence of this parameter on the departure of pre-fission particles, e.g. neutrons.

Therefore, the aim of this work is to generalise the existing model to the four-dimensional case, introducing the nuclear surface non-axiality parameter. Together with taking into account temperature effects acting on the diffusion tensor and shells, the above-mentioned distributions of primary fragments of low-energy fission of actinide nuclei are obtained. The main focus of the work is the comparative analysis of the obtained results with previous ones, due to which the previously used hypotheses are evaluated. In addition new boundary conditions, artefacts and other difficulties encountered in the numerical solution of the four-dimensional system of stochastic Langevin equations are identified. The obtained conclusions allow us to improve the model and prepare it for new modifications.

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FORMATION MECHANISM OF DECAY FRAGMENTS IN SPONTANEOUS TERNARY FISSION OF HEAVY NUCLEI

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A model for describing spontaneous ternary fission of heavy nuclei is presented. It follows from the suggested model that heavy nuclei have the same half-lives in spontaneous ternary and binary fission processes. The collinear cluster tripartition process observed in experiments is found to be the dominant reaction channel in spontaneous true ternary fission of heavy nuclei within our model. Competition between binary fission and the formation of a trinuclear system, which is responsible for the ratio of spontaneous ternary and binary fission yields, is introduced.

РАЗВИТИЕ КВАНТОВОЙ ТЕОРИИ СПОНТАННОГО ДВОЙНОГО ДЕЛЕНИЯ

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Проблема описания спинов фрагментов деления (ФД), а также их относительного орбитального момента обсуждаются более шести десятилетий, причем она является частью фундаментальной задачи по развитию квантовой теории деления. В настоящей работе показано, что для случая спонтанного деления появление коллективного деформационного движения делящегося ядра определяется структурой наборов переходных делительных состояний введенных О. Бором [1], отвечающих выходам различных пар фрагментов деления. Причем указанные ФД вплоть до точки разрыва должны находиться только в холодных и сильно неравновесных по своим деформациям состояниях. В рамках подхода [2] были получены энергии возбуждения для ядра ^{252}Cf, которые в случае легкого и тяжелого ФД лежат в диапазонах от 7.5 МэВ до 32.5 МэВ и от 5 МэВ до 20 МэВ соответственно. Используя оболочечные поправки к жидкокапельной модели ядра, полученные [3], были восстановлены неравновесные деформации ФД, которые не удается наблюдать экспериментально, но возможно оценить теоретически. Далее в рамках сверхтекучей модели атомного ядра, развиваемой в работе [4] были получены моменты инерции ФД в подходах с использованием осцилляторного и прямоугольного потенциала, а также гидродинамической модели. Используя нулевые поперечные bending- и wriggling-колебания делящегося ядра [5], были построены спиновые распределения, причем наилучшего согласия удалось достичь с экспериментальными данными [6] и лучшего по сравнению с другими теоретическими группами [7, 8] в рамках сверхтекучей модели атомного ядра с прямоугольным потенциалом. Далее используя неравновесные деформации ФД, предлагается провести расчет потенциалов деформации для каждой пары ФД и оценить относительные выходы ФД, поскольку этот механизм позволит качественно восстановить кривую массового выхода ФД. Указанный подход кардинальным образом отличается от широко развиваемого подхода западных научных групп, в основе которого лежит нагрев ядра до температур порядка 1 МэВ.

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РАЗВИТИЕ КВАНТОВОЙ ТЕОРИИ ДВОЙНОГО ДЕЛЕНИЯ АТОМНЫХ ЯДЕР

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Описание полного набора наблюдаемых характеристик спонтанного и вынужденного двойного деления родительского ядра (A, Z) основано на введении в развитую раннее квантовую теорию деления ядер [1-7] представления, в котором двойное деление ядра (A, Z) рассматривается по аналогии с ядерным альфа-распадом ядер как распад указанного ядра (A, Z) на легкий (A_L, Z_L) и тяжелый (A_H, Z_H) фрагменты распада, связанные соотношениями $A = A_L + A_H$, $Z = Z_L + Z_H$. При этом относительный выход фиксированной пары фрагментов распада (A_L, Z_L), (A_H, Z_H) определяется переходным делительным состоянием родительского ядра [1], связанным с его коллективным деформационным движением для случая вылета рассматриваемой пары. Отметим, что экспериментальное зарядово-массовое распределение пар фрагментов имеет экстремальный характер с максимумом при определенных значениях $(A_{L_{(0)}}, Z_{L_{(0)}})$. Появление этого максимума естественно связать с энергиями переходных делительных состояний $E(A_L, Z_L; A_H, Z_H)$, которые для $A_L = A_{L_{(0)}}$, $Z_L = Z_{L_{(0)}}$; $A_H = A_{H_{(0)}}$, $Z_H = Z_{H_{(0)}}$ должны быть наиболее близкими к значениям энергий $E(\beta)$, отвечающим максимумам деформационных барьеров деления.

К числу важных экспериментальных характеристик двойного деления ядер можно также отнести кинетические энергии фрагментов деления, энергии возбуждения этих фрагментов, множественности и энергии мгновенных нейтронов и γ-квантов и спиновые распределения фрагментов деления. Все эти характеристики, в отличие от относительных выходов фрагментов деления, в зависимости от (A_L, Z_L) имеют приближенно линейный характер в окрестности $(A_{L_{(0)}}, Z_{L_{(0)}})$.

В отличие от подходов, в которых спиновые распределения фрагментов деления определяются температурами этих фрагментов (T_L, T_H) [8], в квантовом подходе указанные спиновые распределения описываются при учете коллективных bending- и wriggling-колебаний фрагментов деления в предразрывной конфигурации делящегося ядра [2, 5, 9].

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АНАЛИЗ КВАНТОВЫХ ХАРАКТЕРИСТИК СПОНТАННОГО И ВЫНУЖДЕННОГО ДВОЙНОГО ДЕЛЕНИЯ ЯДЕР

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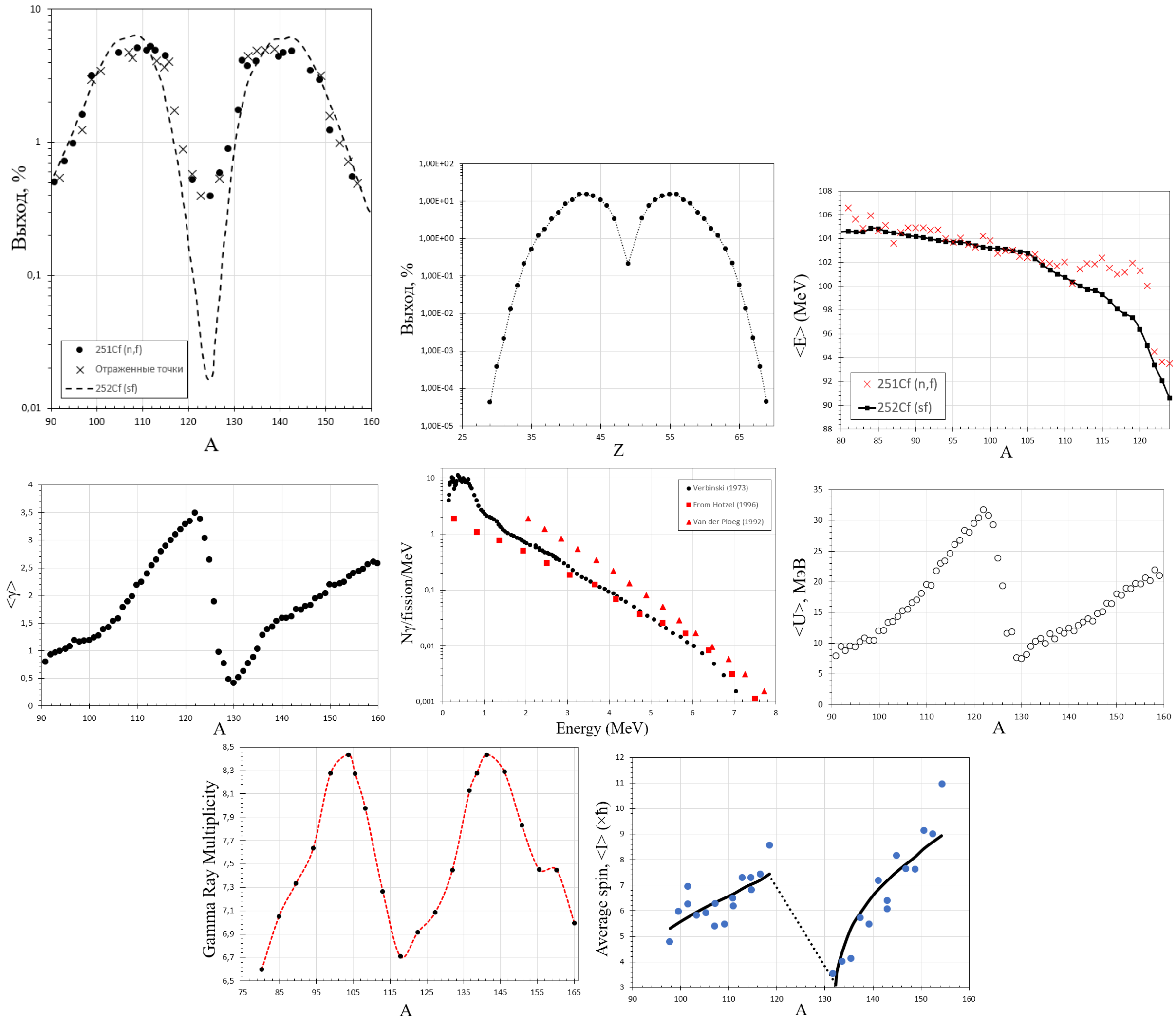
В работе проведен анализ экспериментальных выходов фрагментов для большой группы ядер (A, Z), испытывающих двойное спонтанное (^{240}Pu, ^{244}Cm, ^{246}Cm, ^{248}Cm, ^{250}Cf, ^{252}Cf) и вынужденное (с участием тепловых нейтронов) деление (^{234}U, ^{236}U, ^{240}Pu, ^{244}Cm, ^{246}Cm, ^{250}Cf, ^{252}Cf). Эти распределения имеют экстремальный характер с максимумом при определенных значениях $(A_{L_{(0)}}, Z_{L_{(0)}})$. К числу важных характеристик также можно отнести кинетические энергии фрагментов деления, энергии возбуждения этих фрагментов, множественности мгновенных нейтронов, энергетические выходы γ−квантов и спиновые распределения фрагментов деления.

Рассмотрим поведение указанных выше характеристик на примере [1-7] спонтанного и вынужденного деления ядра ^{252}Cf.



Заметно, что вероятность симметричного деления для спонтанного и вынужденного деления различны, и значительно увеличивается в случае индуцированного деления, хотя во всей остальной области выходы близки друг к другу. В области наиболее вероятных выходов пар фрагментов деления распределения кинетических энергий для спонтанного и вынужденного делений совпадают.

Из проведенного анализа характеристик представленных на графиках можно заметить, что все указанные характеристики имеют приближенно линейную зависимость от массового числа A в окрестности $(A_{L_{(0)}}, Z_{L_{(0)}})$ и $(A_{H_{(0)}}, Z_{H_{(0)}})$, поэтому с их помощью нельзя объяснить выраженный максимум в выходах фрагментов деления. Поэтому представляется естественным связать появление указанных максимумов с энергиями переходных делительных состояний $E(A_L, Z_L; A_H, Z_H)$, которые для $A_L = A_{L_{(0)}}$, $Z_L = Z_{L_{(0)}}$; $A_H = A_{H_{(0)}}$, $Z_H = Z_{H_{(0)}}$ должны быть наиболее близкими к значениям энергий $E(\beta)$, отвечающим максимумам деформационных барьеров деления.

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EXOTIC STRUCTURE STUDIES OF LIGHT NEUTRON-RICH NUCLEI VIA TRANSFER REACTIONS

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In order to study the exotic structures in unstable nuclei at around N = 8, we develop a silicon + CsI(Tl) detection array with large acceptance[1,2], which is suitable for the transfer reactions induced by radioactive beams on the proton and deuteron targets in inverse kinematics. First of all, 57(7)% d-wave and 19(7)% s-wave intruder components in the g.s. of ^{12}Be are deduced from a new ^{2}H(^{11}Be, p) ^{12}Be reaction, which is dramatically different from the g.s. of the one-neutron halo nucleus ^{11}Be with a dominant s-wave intrusion[3,4]. Lately, 12(2)% d- and 5(2)% s-wave intruder strengths in the g.s. of ^{13}B are determined from a new ^{1}H(^{13}B, d)^{12}B reaction. The sudden change of the intruder sd-wave intensity between ^{13}B and ^{12}Be needs further theoretical interpretation[5]. Moreover, a new resonant state at 3.21+ 0.12- 0.04 MeV, located just 40 keV above the one-neutron separation threshold, was observed for the first time in ^{12}Be from the ^{2}H(^{11}Be, p) reaction. This state is assigned a spin-parity of 0- according to the systematics of the level scheme of the N = 8 isotones and decay width analysis[6]. Recently, another new resonant state at Ex = 4.8 ± 0.1 MeV with an intrinsic width of 0.42 ± 0.28 MeV is populated by the ^{2}H(^{13}B, ^{3}He) reaction via a l = 1 proton transfer for the first time.The spin-parity of 2+ is tentatively assigned to this resonance according to the analysis of its angular distributions as well as the theoretical calculations[7].

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STUDY OF THE EXCITATION OF ISOMERIC STATES IN THE REACTIONS (γ, n), $(n,2n)$ AND (n, γ) ON BARIUM ISOTOPES

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In this work, we studied the excitation cross sections of isomeric states in nuclear reactions of the (γ, n), $(n,2n)$ and (n, γ) type on barium isotopes. The isomeric yield ratios were measured by the induced radioactivity method. Samples of natural Ba (the barium peroxide samples) have been irradiated in the bremsstrahlung beam in the energy range of $10 \div 35$ MeV with energy step of 1 MeV. For 14.1 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[1].

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. Using the isomer yield ratio and the total cross section of the (γ, n) reaction [2] 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 was 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 $^{27}Al(n, \alpha)^{24}Na$ ($T_{1/2} = 15$ h, $E_\gamma = 1368$ keV). For reaction (n, γ), $^{197}Au(n, \gamma)$ 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. The dependence of isomeric ratios on the mass number of the isotope was obtained. Theoretical values of the isomeric ratios have been calculated by using code TALYS-1.6.

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APPEARANCE OF THE HINDRANCE TO COMPLETE FUSION IN HEAVY-ION COLLISIONS

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The hindrance to complete fusion is studied as a function of the charge asymmetry of colliding nuclei and orbital angular momentum of the collision. The formation of a dinuclear system (DNS) in the heavy ion collisions is calculated dynamically and its evolution is considered as multinucleon transfer between its fragments. The results prove that a hindrance at formation of a compound nucleus (CN) is related with the quasifission process which is breakup of the DNS into products instead to reach the equilibrated state of the CN. The role of the angular momentum in the charge (mass) distribution evolution for the given mass asymmetry of the colliding nuclei has been demonstrated. The results of this work have been compared with the measured data for the quasifission yields in the ^{12}C+^{204}Pb and ^{48}Ca+^{168}Er reactions to show the dependence of the hindrance on the mass asymmetry of the entrance channel [1]. The new mechanism of the incomplete fusion [2] and the analysis of the mixing of the quasifission yields with the ones of the very asymmetric fusion-fission processes [3] allow us to conclude that complete fusion occurs due to multinucleon transfer through the window (neck) between interacting DNS nuclei. The isotopes ^{272}Ds and ^{280}Ds are formed in the cold ^{64}Ni+^{208}Pb and hot ^{48}Ca+^{232}Th fusion reactions, respectively. In spite of the small fusion probability 10^{-5} in the former reaction, the ER cross section is large $\sigma_{\mathrm{ER}} = 15$ pb due to small excitation energy E^*_{CN}=12.7 MeV [4] and large fission barrier of ^{272}Ds. Though the hindrance to complete fusion small for the hot ^{48}Ca+^{232}Th fusion reaction, the maximal value 0.7 pb of the ER cross section was observed for the 4n channel [5] since fission barrier is 3.29 MeV for the CN ^{280}Ds.

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STUDY OF NUCLEON TRANSFER PROCESSES IN THE REACTIONS ^{48}Ca + ^{197}Au, ^{48}Ca + ^{9}Be

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In this work, we present the results of studying nucleon transfer processes in the reactions ^{48}Ca + ^{197}Au, ^{48}Ca + ^{9}Be at energies above the Coulomb barrier. The experiments were performed at the Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research, Dubna. A ^{48}Ca beam with an energy of 400 MeV was accelerated by the U-400 cyclotron and transported to the reaction chamber of the high-resolution magnetic analyzer MAVR [1]. The measured angular distributions of the products of the reaction ^{48}Ca + ^{197}Au are presented in Fig. 1. For isotopes of K, Ar (Fig. 1(a)) and Sc, Ti (Fig. 1(b)) corresponding to few-nucleon transfer, maxima are seen in the vicinity of the grazing angle; for isotopes of S, P (Fig. 1(a)) and V, Cr (Fig. 1(b)) corresponding to multinucleon transfer, the angular distributions are practically isotropic. This behavior is consistent with the observations described in detail in review [2]. The obtained experimental data will be analyzed based on numerical solution of the time- dependent Schrödinger equation for nucleons [3].

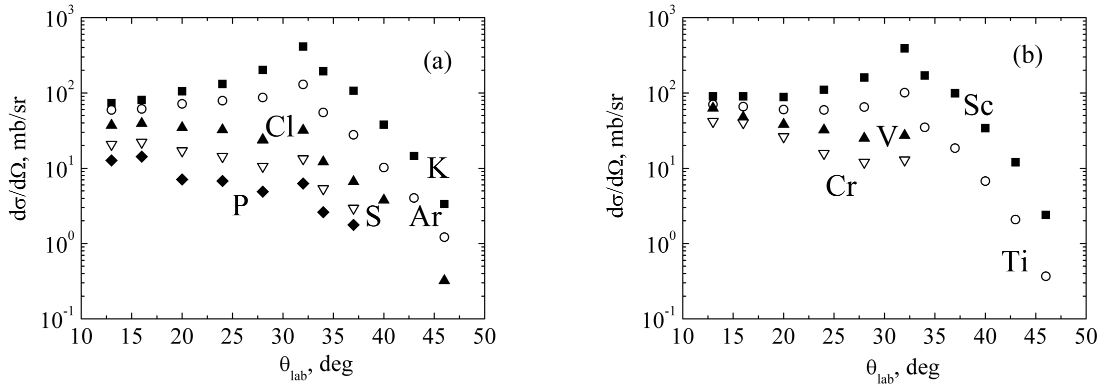

Fig. 1. Differential cross sections of the channels of stripping (a) and pick-up (b) of protons in the ^{48}Ca + ^{197}Au reaction at a beam energy of 400 MeV.

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SIGNIFICANCE OF THE PROJECTILE ATOMIC MASS IN THE BREAKUP PROCESS

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In probing the internal structures of halo systems through breakup reactions, the attention is largely reserved to the ground and continuum structures of the weakly bound projectile. It is shown that some breakup features can be revealed by focusing on the projectile atomic mass, which is found to be a significant quantitative parameter in the breakup process.

EXPERIMENTAL STUDY OF MODAL FISSION OF EXITED HEAVY NUCLEI

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Recent observation of mass-asymmetric fission in neutron-deficient Hg and Pt nuclei has reignite interest in studying the fission properties of heavy nuclei both theoretically and experimentally.

To study the multimodal fission of excited preactinide (Pt, Hg, Pb) and heavy actinide (Fm, Cf, No) nuclei formed in reactions with O, Ar and Ca ions at various excitation energies a series of experiments was conducted.

The measurements were carried out at the U400 cyclotron of the Flerov Laboratory of Nuclear Reactions (JINR, Dubna, Russia) using the double-arm time-of-flight spectrometer CORSET [1].

The observed peculiarities in the fission fragment mass-energy distributions for all studied nuclei may be explained by the presence of a symmetric fission mode and asymmetric fission modes, manifested by the different total kinetic energies and fragment mass splits. The yield of symmetric mode grows with increasing excitation energy of compound nucleus. The stabilization role of proton numbers at $Z \approx 36, 38$, $Z \approx 45, 46$, and $Z = 28/50$ in asymmetric fission of excited preactinide nuclei was observed [2, 3]. It was also shown that in the fission of heavy actinides, the increased yield of fragments in the mass region $\tilde{1}00$ u is associated with the influence of the deformed proton shell $Z \approx 38$.

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NEUTRON TRANSFER IN REACTIONS ^{7}Li,^{48}Ca + ^{197}Au AT ABOVE-BARRIER ENERGIES

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Studies of neutron transfers with the formation of neutron-excess Au isotopes in the reaction are presented for reactions ^{7}Li ,^{48}Ca + ^{197}Au. Using the activation method, the formation cross sections for target-like products were measured. An assembly of several gold targets was irradiated with an ion beam 48Ca at energies 228, 257, 286 MeV. Total flux of particles passing through the collector was measured by elastic scattering on the target Au (2 µm) located after the activation stack [1].

Experimental cross sections for isotopes $^{191-203}$Au (in reaction ^{48}Ca+^{197}Au) were obtained, which were produced in the stripping and pick-up neutrons, up-to ±6 neutrons respectively. The time-dependent Schrödinger equation for the outer neutrons was used to calculate the probability of neutron transfer. The isotopic distributions obtained from measurements were compared with calculations from the TDSE approach and the Grazing code. [3][4].

These results offer valuable insights into the feasibility of generating neutron-rich nuclei through neutron transfer reactions and extend the prospects for producing exotic neutron-rich nuclei by selecting appropriate combinations of projectiles and targets.

Similar study was carried out for the ^{7}Li (70 MeV)+Au reaction. Neutron transfer reaction for 1n and 2n channels were observed as well as neutron evaporation channels for fusion reaction, leading to the formation of compound nucleus. Data analyze for this reaction is still in progress now.

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REGISTRATION OF FISSION PRODUCTS IN $^{48}Ca+^{238}U$ REACTION BY TIME OF FLIGHT SPECTROMETER

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This paper presents the results of measuring fission fragments in $^{48}Ca+^{238}U$ reactions using a time-of-flight system developed at the MAVR facility (the experimental setup is shown in Fig. 1a). A microchannel plate (MCP) detector was used to determine the mass of the resulting fission fragments, which offers high temporal resolution and high efficiency in registering heavy charged particles. A distinctive feature of this methodology is the ability to directly measure the masses of the nuclear reaction products based on flight time and energy values. The paper includes a technical description of the system and an experimental block diagram, which allow for evaluating the system's effectiveness under actual experimental conditions, as well as data on the characteristics of fission fragments, including mass, temporal, and energy distributions (see Fig. 1b) in heavy ion fission reactions. The obtained results can be utilized in studying the mechanisms of heavy nucleus fission and provide important data within theoretical research in nuclear physics. In the future, it is planned to study of other reactions, such as $^{40}Ar+^{197}Au,^{238}U$, $^{136}Xe+^{197}Au$, ^{238}U.

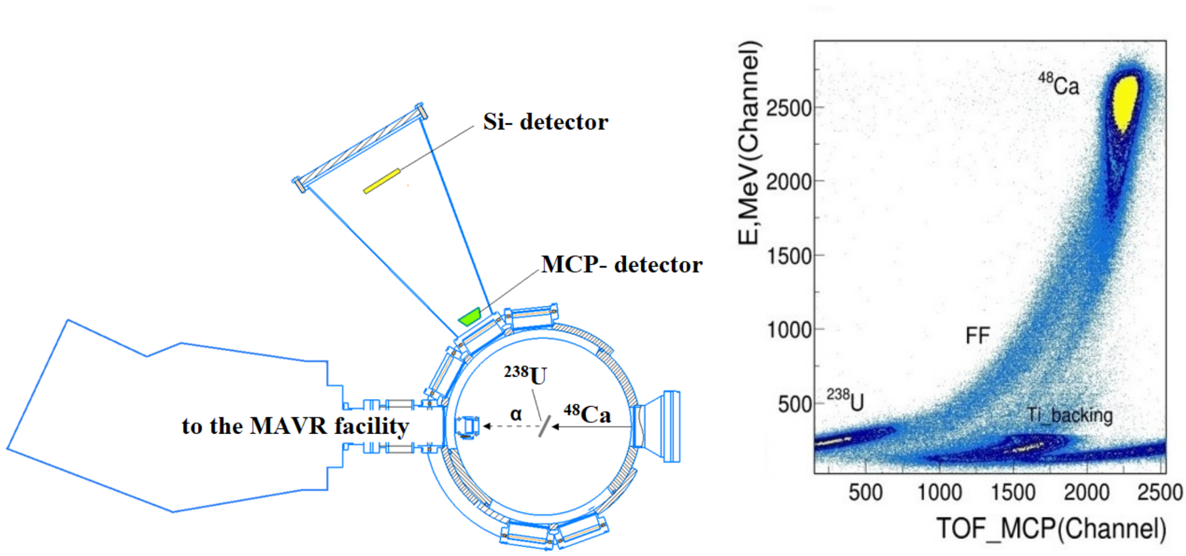

Fig. 1: a) Diagram of the time-of-flight spectrometer connected to the reaction chamber at MAVR; b) Two-dimensional matrix showing the output of reaction products of $^{48}Ca+^{238}U$ by time of flight and their energies

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OBSERVATION OF POSITIVE PARITY WAVE IN LOW ENERGY SPECTRUM OF ^{7}He

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The ^{7}He nucleus was studied using the ^{6}He(d, p)^{7}He reaction in inverse kinematics at 29A·MeV ^{6}He beam delivered by the ACCULINNA-2 fragment separator (FLNR, JINR). The registration of neutrons from $^{7}\mathrm{He} \rightarrow \mathrm{n} + 6$ He decay made it possible to derive the ^{7}He ground state parameters, the decay energy of 0.38(2) MeV and width of 0.11(3) MeV. The forward-backward asymmetry in the neutron emission from unbound states of ^{7}He has been found. That implies the presence of a positive parity wave in the ^{7}He spectrum.

ELASTIC SCATTERING AND NEUTRON TRANSFER IN THE COLLISION ^{7}Li (58 MeV) + ^{10}B

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The study of nucleon and cluster transfer reactions makes it possible to obtain information on the structure of the investigated nuclei (clusters, neutron halo, etc.) and its manifestation in nuclear reactions [1]. This work continues our systematic studies of nucleon and cluster transfer mechanisms in reactions with various projectiles and targets (for example, d + ^{9}Be [2], ^{3}He + ^{9}Be [3]). Here, we will analyze the results of the experiment on measuring angular distributions for elastic scattering and neutron transfer channels in the collision ^{7}Li (58 MeV) + ^{10}B. The experiment was carried out at the U-400 cyclotron of the Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research, Dubna, Russia. The obtained experimental angular distributions for the elastic scattering channel and neutron transfer channel ^{10}B(^{7}Li,^{6}Li$_{g.s.}$)^{11}B$_{g.s.}$ are shown in Fig. 1(a) and (b), respectively. A theoretical analysis of the experimental data will be done within the optical model and the DWBA approach. From the analysis of the experimental data on elastic scattering of ^{7}Li + ^{10}B, the parameters of the optical potential will be determined, which will be used in the description of neutron transfer channels, including ^{10}B(^{7}Li,^{6}Li$_{g.s.}$)^{11}B$_{g.s.}$.

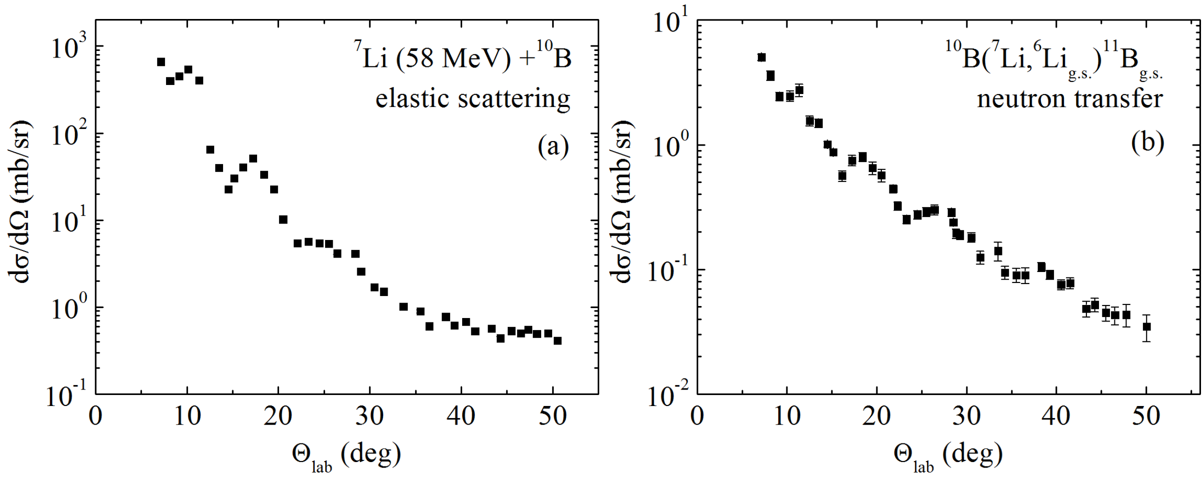

Fig. 1. Experimental angular distributions for the elastic scattering channel (a) and neutron transfer channel ^{10}B(^{7}Li,^{6}Li$_{g.s.}$)^{11}B$_{g.s.}$ (b) in the collision ^{7}Li (58 MeV) + ^{10}B.

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EXPERIMENTAL STUDY OF MNT PROCESS IN THE REACTION ^{209}Bi + ^{238}U AT ENERGY 1.85 GeV

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Nowadays multinucleon transfer reactions (MNT) are considered as a perspective way to synthesize and investigate heavy and superheavy nuclei. Synthesis of superheavy elements in the MNT reactions in collisions of uranium ions with actinide nuclei is of particular interest. However, it is also important to obtain the experimental data in the reactions like ^{209}Bi + ^{238}U for deeper understanding of the MNT mechanisms and planning the future experiments.

The ^{209}Bi + ^{238}U reaction at ^{209}Bi beam energy of 1.85 GeV was measured at the Flerov Laboratory of Nuclear Reactions with CORSET setup [1] to investigate mass and energy distributions of fragments formed in the MNT reactions. Primary and secondary mass and energy distributions of survived binary products (projectilelike and targetlike MNT fragments) have been obtained as a result of the measurements. Simultaneous using of three time-of-flight arms with energy measurements (ToF-E arms) allowed us also to register three body events: light MNT fragment and both products of sequential fission of excited heavy MNT fragment. As a result, primary mass distributions of fissioned targetlike MNT fragments have been recovered using ToF-E method. The obtained experimental results will be presented.

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ABOUT THE EFFICIENCY OF THE ELECTRON BEAM ION SOURCES AND TRAPS (EBIS/T)

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The ion source of the electron beam type (ESIS, which is the EBIS in certain condition of the reflex mode of operation) will be used at NICA acceleration complex. Thus the research of the EBIS theoretycal efficiency is important and relevant. The talk presents the results of analysis and numerical computer simulation of the efficiency of an ion trap for the production of highly charged ions formed by the space charge of an electron beam, depending on its parameters and ionization conditions. The efficiency is defined as the product of the degree of compensation of the ion trap by ions and the relative number of ions with the required charge in the full charge spectrum. According to the numerical simulation the maximum number of ions with the required charge is possible only at a strictly specified pressure of the cooling substance, which is called optimal and depends on the electron current density and the composition of the cooling substance. At optimal coolant pressure, the efficiency is almost independent of the current density in the ion trap, but strongly depends on the charge state of the ions. A significant drop in the efficiency of the ion trap is shown with an increase in the ion charge.

MICROSCOPIC ANALYSIS OF ELASTIC SCATTERING AND TRANSFER REACTION IN THE ^{7}Li+^{10}B COLLISION AT ENERGY 58 MeV

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Analysis of cross sections of the ^{7}Li+^{10}B elastic scattering and the transfer reaction ^{7}Li+^{10}B→^{6}Li+^{11}B at the beam energy E_{LAB} = 58 MeV is carried out by using the microscopic optical potential (OP) [1]. Such OP is calculated by a corresponding double folding procedure taking into account antisymmetrization effects and depends on the nucleon density distribution of interacting nuclei. The only free parameters are the depths of the real and imaginary parts of the OPs determined by fitting the experimental angular distributions for the elastic scattering channel and the transfer channel obtained in 2023 at the U-400 cyclotron of the Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research, Dubna, Russia [2]. A reasonable agreement of the theoretical results with the experimental data is achieved which confirms a peripheral character of the scattering.

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INFLUENCE OF ANGULAR MOMENTUM ON MASS-TOTAL KINETIC ENERGY DISTRIBUTION OF FRAGMENTS FORMED IN THE ^{24}Mg + ^{232}Th AND ^{48}Ca + ^{208}Pb REACTIONS

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Investigation of the influence of angular momentum and the excitation energy of the compound nucleus on the Mass-Total Kinetic Energy (M-TKE) distribution of fission fragments give important insight into the fission process. The aim of the present work is to study the influence of compound nucleus angular momentum on the M-TKE distributions of fission fragments formed in the ^{24}Mg + ^{232}Th and ^{48}Ca + ^{208}Pb reactions, both the reactions leading to the formation of ^{256}No* compound nuclei.

The experiments were carried out using the U400 cyclotron at the Flerov Laboratory of Nuclear Reactions, Dubna, Russia. Thin targets of ^{232}Th and ^{208}Pb bombarded with 125 - 181 MeV ^{24}Mg and 208 - 281 MeV ^{48}Ca beams, respectively, to populate the ^{256}No* compound nuclei at different excitation energies. The mass-energy distributions of binary reaction products were measured by the double-arm time-of-flight (ToF-ToF) spectrometer CORSET [1]. In order to understand the influence of angular momentum of the compound nucleus on the M-TKE distribution, a detailed analysis has been carried out for the obtained M-TKE distributions.

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STUDY OF THE BREAK-UP OF FISSION FRAGMENTS IN SOLID-STATE FOILS USING DOUBLE-HIT EXPERIMENTAL APPROACH

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In our previous publications [1-4], we discussed various manifestations of the decay channel of low excited heavy nuclei, called collinear cluster tri-partition (CCT). The break-up of the fission fragment was observed while the fragment passes a solid-state foil. The bulk of the results were obtained in the framework of the so-called missing mass method when only two fragments are directly detected, and a deficit between their total mass and the mass of the mother system serves as a sign of a multibody decay. In order to increase reliability of identification of such events so called "double-hit" experimental approach was applied in our recent experiments at the COMETA setup in FLNR (JINR). COMETA is a double-armed mosaic time-of-flight spectrometer of fission fragments [2]. Digital images of all the signals from PIN diodes and micro-channel plates based "start" detector were obtained using multichannel fast flash-digitizer. Off-line processing of the recorded data allowed us to select the decay events where two fragments were detected in the same PIN diode ("double-hit" event) during the time-selection gate of 200 ns. For the selected events, the prescission configuration of the mother nucleus seems to be a chain which includes different magic nuclei.

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QUENCHING FACTOR OF SPECTROSCOPIC FACTORS EXTRACTED FROM SINGLE-NUCLEON TRANSFER REACTIONS

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The spectroscopic factors are generally quenched relative to the occupancy numbers predicted by the independent particle model(IPM), which is quantified by the reduction/quenching factor Rs[1,2] and is associated with nucleon-nucleon correlations [3,4]. Rs extracted from knock-out reactions were found to be strongly dependent on the isospin asymmetry ($\Delta S = Sn - Sp/Sp - Sn$ for neutron/proton removing reaction) [5,6]. Rs deduced from the transfer reactions induced by stable nuclei were found to be independent on ΔS[7], while it's controversial from the unstable nuclei with large ΔS. For example, Rs from (d,^{3}He) of neutron-rich Li isotopes decreases significantly as the number of neutrons increases [8], while that from Ar and O isotopes was found weak dependencies[9,10].

In order to more clearly study the dependence between Rs and ΔS of unstable nuclei, a combined experiment with radioactive beams of ^{15}C and ^{16}N was performed at Radioactive Beam Line in Lanzhou (RIBLL) in 2022[12,13]. The differential cross sections in the mass center system for the single-nucleon transfer reactions of ^{15}C(p, d)^{14}C, ^{15}C(d, ^{3}He)^{14}B and ^{16}N(p, d) ^{15}N were obtained . By comparing the experimental angular distributions to the DWBA theoretical calculations, the spectroscopic factors and the corresponding Rs with $\Delta S = -19.12, 8.99$ and 19.86 MeV were extracted. Weak dependencies were found from these single-nucleon transfer reactions induced by weakly bound nuclei, which were performed in one experiment using the same target in order to reduce the systematic errors as much as possible.

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ROLE OF MOMENTUM TRANSFER IN HEAVY ION INDUCED PRE-COMPOUND EMISSION REACTIONS AT ENERGIES BELOW 7 MeV/NUCLEONS

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The understanding of the pre-compound emission process in light ion induced reactions has been well established during last few decades [1-3] but in heavy ion reactions it needs to be further explored. Recent investigations on reactions induced by heavy ion beams ^{12}C, ^{14}N, ^{16}O and ^{19}F with target nuclei ^{159}Tb, ^{169}Tm, ^{175}Lu and ^{185}Ta (A=159-185) indicate presence of pre-compound emission contribution at low energies below 4-7 MeV/nucleon, where only compound nucleus process is likely to be dominant. Aiming to develop a mass number dependence systematics in pre-compound emission process, a precise analysis of measured excitation functions for several reactions induced by ^{12}C, ^{14}N, ^{16}O and ^{19}F beams on various target nuclei of (A=159-185) has been performed with statistical model code PACE4[4,5]. An independent contribution of pre-compound emission has been obtained for each target nuclei by comparing measured values of cross section with their theoretical counterparts. The analysis of present experimental data on pre-compound emission gives an interesting empirical exponential relation between excitation energy and atomic mass number (A) of target nuclei.

Further, in order to determine the role of momentum transfer in heavy ion reactions, the experiments have been carried out at the Inter University Accelerator Centre (IUAC), New Delhi, India, to measure the recoil range distributions (RRDs) and spin distributions (SDs) of several residues in ^{12}C+^{169}Tm and ^{16}O+^{159}Tb, ^{169}Tm systems at energies above the Coulomb barriers. The analysis of recoil range distribution measurements shows two distinct linear momentum components corresponding to pre-compound and compound nucleus processes. The analysis of SDs indicates that a relatively lower value of input angular momentum is associated with pre-compound as compared to the compound nucleus process in a same reaction. The experimental results on the analysis of RRDs and SDs are quite interesting and are throwing a new insight in to the reaction dynamics of low energy heavy ion pre-compound emission process. Further details will be presented.

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STUDY OF THE COULOMB DECAY OF LIGHT FRAGMENT PROCUCED IN THE TERNARY FISSION OF ^{252}Cf

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Theoretical analysis of experimental data on the ternary fission of ^{252}Cf is performed in the semi-classical trajectory approach. The energy and angular distributions, total kinetic energies of the fragments in the ternary fission of ^{252}Cf are obtained in this model using the Monte-Carlo simulations. The calculations well reproduce these experimental data with the same set of the model parameters for different types of the lightest fragments, i.e. hydrogen, helium, lithium, beryllium isotopes. As earlier suggested in [1], there is a contribution of short-living isotopes to the energy spectra of ^{4,6}He, such as ^{5}He and ^{7}He. Using the estimated [2] decay width of ^{7}He we have calculated the energy and angular distribution of the ^{4}He fragment obtained in the $4n$ decay of ^{8}He emitted in the ternary fission. The energy and angular distributions of the neutrons om this decay are also estimated. We can conclude, that study of neutron and fragment energy and angular distributions in ternary fission may provide the information on decay of neutron-rich short living isotopes as ^{8}He.

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STUDY OF ALPHA CLUSTER STRUCTURES IN THE ^{46}Ti NUCLEUS

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We present the results of experimental and theoretical studies on the role of clustering on the structure of excited states of ^{46}Ti. The ^{46}Ti nuclei were produced in a ^{45}Sc(^{3}He, d)^{46}Ti proton pickup reaction at a bombarding energy of 30 MeV [1]. Excited levels of ^{46}Ti were observed in a wide energy range from 2 to 16.5 MeV. Levels from 10.4 to 16.5 MeV were observed for the first time and populated with a high probability. Calculations within the framework of the dinuclear system model [2] showed that the population of states with energies $Ex \geq 10$ MeV in ^{46}Ti as well as their structure can be explained by the formation of the ^{42}Ca+^{4}He alpha cluster system, corresponding to the superdeformed state of ^{46}Ti. The structure of alpha-cluster states in the $^{44-52}$Ti isotopic chain has been analyzed. The results are compared with experimental data on the formation of alpha-cluster binary systems in ^{44,46,52}Ti, obtained previously in the reactions ^{40,42,48}Ca(^{7}Li,tα)^{40,42,48}Ca [3].

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EXPERIMENTAL AND THEORETICAL STUDIES OF NUCLEAR REACTIONS

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A study of the total fusion and breakup cross-sections in the breakup of ^{11}Be projectile on the lead target shows that, even for the neutron- halo projectile, the breakup channel remains the most dominant reaction channel at sub-barrier energies, as in the case of the proton-halo projectile ^{8}B reported in other studies. It is found that this feature emanates from the enhancement of the breakup cross-section, due to the continuum- continuum couplings coming exclusively from its Coulomb component. We further argue that the enhancement of the Coulomb breakup cross-section at sub-barrier incident energies could be associated with the projectile breaking up on the outgoing trajectory.

STUDY OF ^{209}Bi(γ, xn) RELATIVE REACTION YIELDS IN ENERGY RANGE 35-60 MeV

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In order to study relative yields of ^{209}Bi(γ, xn) reactions, samples of 99.99% pure bismuth-209 were exposed at LINAC-200 electron beam with tungsten convertor at energies 35, 40, 45, 50, 55, 60 MeV. Activities of obtained products of photonuclear reactions with different neutron multiplicity, from (γ, 2n) to (γ, 7n) were measured. Relative yields normalized to ^{206}Bi yield were calculated. Obtained yields were compared with the experimental results already available in EXFOR database.

Yields obtained by measurements were compared with the results of theoretical calculations and data from public nuclear databases such as IAEA-2019, LEND-99 and TENDL-2021. Bremsstralung spectra and various systematic effects were simulated by GEANT4.

SYMMETRY BREAKING EFFECTS IN THE INTERACTION OF SLOW NEUTRONS WITH LEAD NUCLEUS

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Spatial parity breaking effects in the interaction of slow and resonant neutrons with Lead nucleus will be investigated. For scattering and capture processes, spin rotation, asymmetry of emitted neutrons and asymmetry of emitted gamma quanta were evaluated and compared with existing experimental data. Parity breaking effects were evaluated in the frame of the formalism of the mixing states of compound nucleus with the same spin and opposite parities [1]. Applying the approach described in [2], from theoretical evaluations and related scattering and capture experimental data, weak matrix element was extracted. Matrix element of weak non leptonic interaction is usually of order of meV and for slow neutrons, parity violation effects are of order of $10^6 - 10^4$ and lower. Similar values were obtained in the analysis of parity violation effects on other processes and nuclei [2]. From obtained results, the existence of a new negative resonance of compound nucleus near the neutron threshold it is confirmed [3].

Symmetry breaking effects in the scattering and capture process on Lead nucleus are planned to be measured at basic facilities from FLNP JINR Dubna and from other neutrons research centers from Russia.

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THE ISOSPIN SPLITTING OF GDR AND PHOTOPROTON REACTIONS ON MERCURY ISOTOPES

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There is very little experimental data on cross sections of photonuclear reactions on mercury in the literature, and for energies of the order of 50-60 MeV there is no data at all. To obtain cross sections for an equivalent quantum during the reactions of $^{nat}Hg(\gamma,inkp)$, a sample of natural mercury was irradiated with a beam of bremsstrahlung from the RTM-55 linear electron accelerator of SINP MSU with an upper limit of 55 MeV.

As a result of the experiment, cross sections for an equivalent quantum on a natural mixture of mercury isotopes were calculated using the formula:

$$\sigma_q^{prod} = \frac{\sum_i \eta_i \int_{E_{thresh}}^{E^m} \sigma(E) \cdot W(E,E^m)dE}{\frac{1}{E^m}\int_0^{E^m} E \cdot W(E,E^m)dE},$$

in this formula, $W(E,E^m)dE$ is the number of γ-quanta in the energy range dE per electron of the accelerator hitting the braking target, $\sigma(E)$ is the cross section of the studied photonuclear reaction, E is the energy of γ-quanta of bremsstrahlung, $E^m = 55$ MeV is the kinetic energy of electrons incident on the inhibitory target, E_{thresh} is the threshold energy of the reaction under study, η_i is the percentage of the initial nuclei in the natural mixture.

The obtained cross sections were compared with the results of theoretical calculations performed using the combined model of photonucleon reactions developed at SINP MSU [1-2] and according to the TALYS program [3]. As can be seen from comparative table 1, the experimental data are in good agreement with calculations within the framework of the CMFR, which takes into account not only the isospin splitting of the giant dipole resonance (GDR) and the quasi-neutron photoabsorption mechanism, but also the contribution to the cross section of the isovector quadrupole resonance and the overtone of the GDR (GDR2). For photoproton reactions, the results obtained under the TALYS program were underestimated.

Also, experimentally and using CMFR [1-2], cross sections for an equivalent quantum for $T_{>}-$ and $T_{<}-$components were obtained, which allow us to observe the isospin splitting of the GDR.

Table 1. Experimental values of cross sections per equivalent quantum, as well as cross sections per equivalent quantum, calculated using the combined model of photonucleon reactions [1-2] and the TALYS program [3]

Isotope	Reaction of Formation	σ_q^{prod}(55 MeV), mb	$\sigma_{q\,CMPR}^{prod}$ (55 MeV), mb	$\sigma_{q\,TALYS}^{prod}$ (55 MeV), mb
^{196}Au	$^{nat}Hg(\gamma, in1p)$	0.084 ± 0.004	0.071	0.056
$^{198g+m}$Au	$^{nat}Hg(\gamma, in1p)$	0.400 ± 0.020	0.473	0.124
^{199}Au	$^{nat}Hg(\gamma, in1p)$	0.481 ± 0.024	0.495	0.122
$^{200g+m}$Au	$^{nat}Hg(\gamma, in1p)$	0.33 ± 0.03	0.319	0.099

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PHOTOPROTON REACTIONS ON ERBIUM ISOTOPES

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This work presents an experimental and theoretical study of photoproton reactions on erbium isotopes. Currently, the nuclear databases (EXFOR) only contain data on photoneutron reactions on a natural mixture of erbium isotopes [1] and on the isotope ^{166}Er [2]. No data on photoproton reactions is available.

The experiment was performed by irradiating a target made of a natural mixture of erbium isotopes with the bremsstrahlung of the racetrack pulsed microtron RTM-55 of the Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, with a beam energy of 55 MeV. The residual activity spectra were analyzed to identify isotopes formed from photonuclear reactions based on their gamma ray energy and half-life. The cross sections per equivalent photon for a natural mixture of erbium isotopes were calculated based on the induced activity in the target by formula:

$$\sigma_q^{prod} = \frac{\sum_i \eta_i \int_{E_{\text{thresh}}}^{E^m} \sigma(E) \cdot W(E,E^m) dE}{\frac{1}{E^m} \int_0^{E^m} E \cdot W(E,E^m) dE},$$

where $W(E,E^m)$ is the bremsstrahlung spectrum of γ produced at the incidence of the beam of accelerated electrons with the energy E^m=55 MeV on the bremsstrahlung target, $\sigma(E)$ is the cross section of the studied photonuclear reaction, E is the energy of bremsstrahlung photons, E_{thresh} is the threshold energy of the reaction under study, η_i is the percentage of the initial nuclei in the natural mixture of Er isotopes and the index i corresponds to the number of the reaction contributing to the production of the studied isotope.

The experimental cross sections per equivalent photon were compared with calculations using the TALYS program [3] and the combined model of photonucleon reactions (CMPR) [4,5]. In contrast to the TALYS program, the CMPR accounts for the isospin splitting of the giant dipole resonance (GDR), which leads to increased cross sections of photoproton reactions. The comparison of experimental and theoretical data reveals that TALYS significantly underestimates the cross sections of photoproton reactions. The isospin splitting of the GDR should be considered for an accurate description of photonuclear reactions.

Table. Comparison of experimental and theoretical cross sections per equivalent photon, calculated using the combined model of photonucleon reactions and the TALYS program for photonuclear reactions on a natural mixture of erbium isotopes.

Isotope	$T_{1/2}$	Isotope production reaction	$\sigma^{\rm prod}_{\rm q\ exp}$, mb	$\sigma^{\rm prod}_{\rm q\ CMPR}$, mb	$\sigma^{\rm prod}_{\rm q\ TALYS}$, mb
^{161}Er	3.21 h	$^{\rm nat}$Er(γ, in)	0.292 ± 0.026	0.459	0.539
^{163}Er	75 min	$^{\rm nat}$Er(γ, in)	4.928 ± 0.96	5.765	6.913
^{169}Er	9.392 d	^{170}Er(γ,1n)	18.801 ± 4.355	26.982	23.036
^{161}Ho	2.48 h	$^{\rm nat}$Er(γ, in1p)	$(7.36 \pm 13.48) \cdot 10^{-3}$	$10.27 \cdot 10^{-3}$	$5.877 \cdot 10^{-3}$
^{162m}Ho	67 min	$^{\rm nat}$Er(γ, in1p)	$(5.543 \pm 0.628) \cdot 10^{-3}$	*	$7.920 \cdot 10^{-3}$
^{166}Ho	26.824 h	$^{\rm nat}$Er(γ, in1p)	0.262 ± 0.011	0.594*	0.101
^{167}Ho	3.1 h	$^{\rm nat}$Er(γ, in1p)	0.257 ± 0.029	0.617	0.078
^{168}Ho	2.99 min	^{170}Er(γ,1n1p)	0.040 ± 0.007	0.064	0.043
^{169}Ho	4.72 min	^{170}Er(γ,1p)	0.100 ± 0.017	0.255	0.024

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QUANTUM MECHANICAL ANALYSIS OF ANGULAR OSCILLATIONS AT SCISSION POINT: IMPLICATIONS FOR FISSION FRAGMENT ANGULAR MOMENTUM GENERATION

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Nuclear fission presents a striking phenomenon where the initial spin-zero spontaneously fissioning nucleus results in primary fission fragments with significant angular momenta (2-8 $\hbar$) [1]. Various theories have been proposed to explain the mechanism behind this phenomenon, differing in whether they attribute the generation of angular momentum to happen at scission point or at post-scission stages of fission process. In the previous studies, using the dinuclear system concept [2], we explored the role of angular oscillations at scission point in generating the angular momentum of primary fission fragments. The angular momenta of the fragments calculated as a function of the number of evaporated neutrons was found to be in a good agreement with available experimental data for ^{252}Cf spontaneous fission. However, recent experiments [3] have shown no significant correlation between the spins of fragment partners, seemingly contradicting the idea that angular momentum is generated at the scission point. Here, we present a fully quantum-mechanical treatment of angular vibrations at the scission point, explaining the absence of correlation in fission fragments angular momenta and supporting the view that angular momentum is indeed generated at the scission point. We apply this model to recent experimental data for ^{252}Cf spontaneous fission.

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РОЛЬ ДИНАМИКИ ПРИ ОПИСАНИИ НЕЙТРОННЫХ МНОЖЕСТВЕННОСТЕЙ В СПОНТАННОМ ДЕЛЕНИИ ТРАНСФЕРМИЕВЫХ ЯДЕР

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Теоретические расчёты нейтронных множественностей в спонтанном делении трансфермиевых ядер проведены в рамках усовершенствованной модели точки разрыва [1]. В модели предполагается, что после прохождения барьера деления ядро может быть описано как суперпозиция двойных систем, характеризующихся массами, зарядами и деформациями фрагментов. Эволюция начального распределения двойных систем анализируется при помощи мастер-уравнения, учитывающего вероятности изменения деформаций фрагментов, передачи нуклонов между фрагментами и развала по координате относительного расстояния. Последний процесс приводит к формированию первичного распределения осколков деления. Получено хорошее согласие с недавними экспериментальными данными по нейтронным множественностям в спонтанном делении ^{246}Fm [2] и ^{256}Rf [3].

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VALIDITY ANALYSIS OF GAMMA-RAY STRENGTH FUNCTION MODELS FOR RADIATIVE CAPTURE REACTIONS OF HEAVY NUCLEI

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Accurate simulation of radiative capture reactions (RCRs), which hold significant importance in various areas of nuclear physics and technology, relies on precise evaluation and modeling of gamma-ray strength functions (GSF). Therefore, several phenomenological and microscopic GSF models have been developed in nuclear reaction codes for practical applications. Since theoretical GSF models behave differently mainly at low energies, GSF models require normalization, typically performed based on experimental data of total radiative width (TRW). In this investigation, it is observed that such normalization fails to adequately reproduce the experimental data of neutron-induced RCRs for ^{238}U and ^{233}Th heavy nuclei. Therefore, re-normalization values are presented for each model and it is demonstrated that such re-normalization brings various GSF models closer together in behavior at low energy regions and a range is obtained for GSF at low energies, where its actual value lies in this range. It is also shown that the widely used standard Lorentzian (SLO) model shows the most reliable fit to the experimental data with the least amount of required normalization.

NEUTRINO PHYSICS AND NUCLEAR ASTROPHYSICS

ON THE POSSIBILITY OF THE MAJORANA NATURE OF NEUTRINOS

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One of the most popular explanations for the smallness of the neutrino mass is the seesaw mechanism [1], in which the neutrino should be a Majorana fermion. The concepts of C and CPT conjugations play an important role in the theory of Majorana fermions. We have shown that in the literature there are five nonequivalent concepts of charge conjugation (*C1* – *C5*) and, accordingly, five possible types of Majorana fermions:

1. A fermion coinciding with its conjugate according to Pauli [2].
2. A fermion coinciding with its charge conjugate according to Majorana [3] and Kramers.
3. A truly neutral fermion coinciding with its antiparticle [3].
4. A fermion coinciding with its conjugate according to Schwinger [4].
5. A fermion coinciding with its charge conjugate with charge conjugation by means of creation and annihilation operators.

Previously, we have proven that Majorana fermions of the second type cannot be physical particles [5]. In this work, we analyze the possibility of a neutrino being a Majorana fermion of the other types.

We have proven that the non-QFT Pauli conjugation operator *C1*, defined in the framework of the theory of "holes" in the Dirac Sea, is equivalent to the QFT conjugation operator *C4*. Charge conjugation *C3* is equivalent to the CPT inversion with reversal of the sign of the spin projection and chirality. The most commonly used in QFT conjugation *C4* is antiunitary, reverses the particle chirality, and is not a charge conjugation. Its result coincides with the *C5* charge conjugation only for chiral symmetric fermions.

We have proven that a comparison of operators in the coordinate representation and the representation of occupation numbers allows us to uniquely determine the phases of the operators P and C, up to sign, and limit the number of variants of charge conjugation and Majorana spinors.

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SEARCH FOR SINGLE AND TRI-NUCLEON DECAYS OF ^{76}Ge IN GERDA

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Single- and multi-nucleon decays, violating baryon number conservation, are predicted in several extensions of the Standard Model. The main goal of the GERDA (GERmanium Detector Array) experiment was to search for the neutrinoless double-beta decay of ^{76}Ge. Beside this, many other GERDA results of searching for various processes beyond the Standard Model were obtained. Among them, a possible manifestation of the inclusive, i.e. mode independent, decay of a single neutron and proton as well as specific modes of tri-nucleon decays in ^{76}Ge is investigated.

GERDA explores the possible disappearance of a single nucleon in ^{76}Ge by looking for the β-decay of the ^{75}Ge ground state to an excited state of ^{75}As in coincidence with the γ-ray emitted in the subsequent ^{75}As de-excitation. Proton decay could populate first the unstable ^{75}Ga nucleus that later decays by β-emission to ^{75}Ge. The tri-nucleon ppp-, ppn-, and pnn-decays of ^{76}Ge lead to ^{73}Cu, ^{73}Zn, and ^{73}Ga nuclei, respectively. These nuclei are unstable and eventually proceed by the β-decay of ^{73}Ga to ^{73}Ge (stable). Searching for the ^{73}Ga decay, which dominantly populates the 66.7 keV ^{73m}Ga state, is considered. Our analysis also includes nnn-decay occurring through ^{73m}Ge.

No signal candidates were found for either single or tri-nucleon decays of ^{76}Ge. This leads to lifetime limits for the inclusive decay of a single nucleon in ^{76}Ge: for neutrons $\tau_n > 1.5 \times 10^{24}$ yr and for protons $\tau_p > 1.3 \times 10^{24}$ yr at 90% CI. This is the first limit obtained for ^{76}Ge. The limit on the sum of the decay widths of the four inclusive tri-nucleon decays was obtained that corresponds to a lower lifetime limit of 1.2×10^{26} yr (90% CI). This result improves previous limits for tri-nucleon decays by one to three orders of magnitude.

CAPTURE OF NEUTRINOS FROM THE ACCELERATOR BY IODINE-127 NUCLEI

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Current studies of neutrino-nucleus interactions have come to a situation where it has become both possible and necessary to study in detail the capture of neutrinos by nuclei. In this paper we study the interaction of high-energy neutrinos from the SNS accelerator with the detector based on the Iodine-127 [1]. We calculate the resonance structure of the charge-exchange strength function $S(E)$ and its influence on the neutrino capture cross sections of the ^{127}I nucleus. Three types of isobaric resonances: the giant Gamow-Teller resonance (GTR) [2], the analog resonance and the low lying pygmy resonances [3] are investigated in the framework of the self-consistent theory of finite Fermi systems [4]. The calculations of neutrino capture cross sections $\sigma(E)$ for the ^{127}I nucleus have been carried out taking into account the resonance structure of the strength function $S(E)$ and the influence of GTR on the energy dependence of $\sigma(E)$ has been analyzed and it has been obtained that the contribution of GTR exceeds 80% in the calculations of the cross-section $\sigma(E)$. The contribution of high energy neutrinos to the neutron emission process with the formation of ^{126}I and ^{125}I isotopes has been analyzed.

These results can be used to interpret experimental data and modeling results for planning new-generation experiments on the detection of rare events, such as SNO+ [5], LEGEND [6], CUPID [7], and others.

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THE SIGNATURE OF NEUTRON FLUENCES OF THE ARTIFICIAL PULSE NUCLEOSYNTHESIS

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An extreme high intensive neutron pulses ensure the conditions for pulse nucleosynthesis realized in nature (at neutron concentration $> 10 \times 10^{19}$ cm^{-3}): at different mechanism of supernova explosions, in very massive stars, at merging and destroying of neutron stars). In the artificial condition the nucleosynthesis can occur in the close zone of nuclear/thermonuclear explosions where the neutron fluxes reach the units of 10×10^{24} cm^{-2} during the short pulse $\sim 10^{-6}$ s (*pr*- promt rapid process). The purpose of executed experiments on nucleosynthesis were production of transuranic elements by multiple (n,γ)-captures in the irradiated target (manufactured from the ^{238}U or more heavy/mixture isotopes as ^{232}Th, ^{237}Np, ^{238}U, ^{242}Pu and ^{243}Am). The first time the creation of isotopes with neutron excess up to mass $A = 255$ was obtained and discovered in the Mike experiment [1]. During the Plowshare scientific program and some next USA nuclear tests (as Anacostia, Kennebec, Par, Barbel, Tweed, Cyclamen, Kankakee, Vulcan and Hutch) the transuranium isotopes up to $A = 257$ was registered [2-4].

Basing on the proposed ABM-model it was simulated the transuranium isotope yields for five large scale pulse experiments (Mike, Anacostia, Barbel, Par and Vulcan) for creation of uranium isotopes up to $A = 257$. The model target irradiated by sequential (n,γ)-neutron captures is the mixture of ^{238}U (main isotope) with admixture of the ^{239}Pu injected into the plasma ball [5,6]. The model includes the elements of the dynamics with temperature decrease down to ~ 2 keV and expansion of the matter with linear velocity ~ 190 km/s. The obtained results indicated on the roughly linear dependence of the isotope Y-yield relations from the neutron fluence [7]. It were considered the next pairs of neighboring isotopes with atomic masses $A = 245$ and 244, $A = 246$ and 245, $A = 247$ and 246.The relation 246/245 (i.e., yields with masses $A = 246$ and 245) depending on the fluences is the most strong demonstrator of the linear dependence. The analysis of transuranic isotope yields and them relation can be sensitive signature of the fluences realized in artificial nucleosynthesis.

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TUNED ELECTRON-NUCLEUS RESONANCE AS A TOOL OF PRODUCING THE ^{229}Th ISOMER

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Much attention is paid to the problem of creating nuclear optical clocks and, accordingly, the next generation frequency standard. Record samples of atomic clocks demonstrate an error within several units of 10^{-18}, while in order to solve challenging fundamental and applied problems it is necessary to further reduce the errors by another order of magnitude. The development of heavy-ion clocks has good prospects. A further reduction in the error would allow to resolve the long-standing question about the possible drift of the fundamental constants. The most pressing task of modern physics is the search for dark matter and energy. Here the fundamental idea is to detect wave oscillations of particles of ultralight matter in its interaction with ordinary matter. And their use to search for the drift of fundamental constants has irreplaceable features, since the contribution from the nuclear component, compared to the Coulomb component, to the transition frequency is much stronger than in optical ones. Some projects are based on the joint use of atomic and nuclear clocks, using the specified features of the latters.

The number one candidate for the creation of nuclear clocks is the unique nuclide of ^{229}Th, whose excited state $3/2^+[631]$ lies at a height of only 8.355740(3) eV above the ground state $5/2^+[633]$. The possibility of further refining its energy by means of resonance optical pumping is discussed. Attention is focused on considering the broadening of the resonance in order to reduce scanning time. The two-photon method proposed exploits the radical broadening of the isomer line due to mixing with the electron transition. This is not burdened with the cross-section reduction, in contrast with internal-conversion-based resonance broadening or intended extra-broadening of the spectral line of a pumping laser. In the case under consideration, according to the calculations, it turns out to be two orders of magnitude more efficient. It is applicable to both ionized and neutral thorium atoms. Realization of the method supposes excitation of the both nucleus and electron shell in the final state.

ACTIVE AND STERILE NEUTRINO OSCILLATIONS INSIDE THE SUN IN A PHENOMENOLOGICAL (3+1+2)-MODEL

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The phenomenological model with three active and three light sterile neutrinos is considered taking into account terrestrial experimental data, which indicate anomalies at short distances beyond the minimally modified Standard Model with three massive active neutrinos [1, 2, 3, 4]. One of the sterile neutrinos is assumed in this work to have comparatively different mass versus masses of two others, that is corresponding to a (3+1+2)-model of neutrinos. Model parameters values used for the description of oscillations of both active and sterile massive neutrinos into the Sun are chosen. Oscillation characteristics of solar neutrino together with sterile neutrino contributions have been evaluated taking into account the neutrino interaction with the matter inside the Sun. We use the standard solar model (SSM) [5, 6, 7]. Results obtained are in harmony with observational data and can be used for development of sterile neutrinos models.

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CRUST OF ACCRETING NEUTRON STARS

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The report presents the results of a series of papers on modelling the nuclear physical processes in the outer layers (crust) of neutron stars in low mass X-ray binaries. In these systems, material is transferred from the companion star to the neutron star, a process known as 'accretion' in astrophysical literature. As a result, the original crust is replaced by accreted material.

We demonstrate that the presence of free neutrons (unbound in atomic nuclei) in the inner crust plays a crucial role in the nuclear physical process of forming the accreted crust. Neutrons redistribute rapidly between the layers of the inner crust due to superfluidity and diffusion (with diffusion being important near the boundary between the outer and inner crust, where neutrons are not superfluid). This effect was not considered in previous models developed over approximately 40 years. It leads to a radical change in the nuclear reactions chains and the composition of the crust.

Consequently, several previously accepted statements are shown to be incorrect. For instance, it was previously believed that the main reactions in the inner crust were electron capture and neutron emission, and the transition to the inner crust was associated with reaching the neutron drip line. In our work, we demonstrate that reverse reactions occur in the inner crust (neutron capture and electron emission), and the boundary between the inner and outer crusts is determined by the redistribution of free neutrons in the crust and the star's core, maintaining diffusion-hydrostatic equilibrium.

The heating efficiency of the crust has been shown to be significantly lower than previously estimated. We confront these results with observations of accreting neutron stars.

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MEASUREMENT α-PARTICLE QUENCHING IN TELLURIUM-LOADED LIQUID SCINTILLATORS

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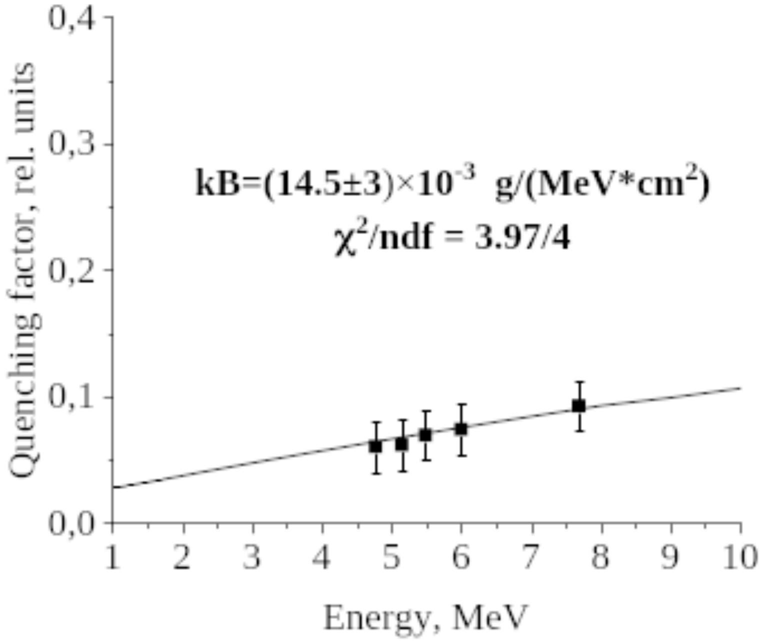
Amplitude spectra of α-particle with different energies ^{239}Pu (5.15 MeV) and ^{226}Ra (4.77, 5.49, 6.00, 7.69 MeV) were measured for samples of liquid scintillators (LS) based on linear alkybenzene and containing various tellurium-containing additives (diphenyltellurium di-2-ethylhexanoate, complex compound of diphenyltellurium oxide and di-(2-ethylhexyl)phosphoric acid and tellurium dibutanediol-1,2-ate). The data obtained are presented in comparison with unloaded LS. Based on the semi-empirical method proposed in [1], which built on the classical Birks formula with total stopping power for electrons and ions (calculated using ESTAR and SRIM), estimates of the Birks constants for LS were obtained.



Quenching factor as a function of α-particle energy for unloaded liquid scintillator based on linear alkylbenzene

The results obtained make it possible to predict the behavior of alpha particles with energies from 1 to 10 MeV when they are detected by liquid scintillators.

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APPLICATION OF ZnSe CRYSTALS IN CALIBRATION EXPERIMENTS

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Characteristics of neutrino absorption reaction by ^{82}Se nucleus – low threshold value, production of 75 keV gamma-quanta together with electron generation [1], high value of absorption cross section of neutrinos, irradiated by ^{51}Cr source [2], make Zn^{82}Se crystals to be perspective material for search of new types of neutrino in calibration experiments. In (3+1) model an expression for neutrino path length in setup in presence of oscillations is obtained for spherical geometry. The scheme of experiment, which gives the possibility to investigate $\Delta m^2 > 1$ eV^2 domain is proposed.

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NEUTRINOS FROM DYNAMO-DRIVEN SUPERNOVAE

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The dynamics of neutrinos in hot and dense magnetized matter, corresponding to dynamo-driven supernova explosion, is considered. It is shown that taking into account fluctuations in the interaction of neutrinos with matter leads to the Fokker-Planck equation for the dynamics of the distribution function in the phase space. The component of the kinetic equation additional to the transfer effect [1] is determined by straggling in neutrino collisions in a magnetized nucleon gas due to the Gamow-Teller neutral current interaction. The effect of fluctuations leads to an additional increase in the hardness of the neutrino spectra. The effects of neutrino oscillations in magnetic field and dense matter on detection by the KM3NeT and Baikal-GVD observatories are discussed. It is shown that the applications of the k-fold coincidence technique in data processing makes it possible to increase the upper limits of the distance for the observation threshold by a factor of $1.5\sqrt{k}$.

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SrI_2(Eu) SCINTILLATION NEUTRINO DETECTOR WITH ULTRA-LOW ENERGY THRESHOLD

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A concept of SrI_2(Eu) scintillation neutrino detector with ultra-low energy threshold is being developed in INR RAS to detect recoil electrons with energy lower than 1 keV. The detector will have a simple scalable structure and consist of 64-channel layers of scintillation detector modules. The modules consist of four small SrI_2(Eu) crystals with SiPM readout. The detector can be used to study neutrino spectrum at low-energy range for isotope decay and reactor neutrinos. The SrI_2(Eu) scintillator has light yield of up to 120 p.e./keV that provides the ability to detect extremely low energy deposition. Setting detection threshold of 6 photoelectrons allows to detect energy deposition greater than 100 eV, if SiPMs photon detection efficiency (PDE) is 50%. SrI_2(Eu) emission spectrum aligns well with SiPM maximum PDE. SiPMs operation temperature below -60° ensures the suppression of dark current rate (DCR) of used SiPM-matrixes and satisfies the low threshold measurement requirement. SiPMs DCR waste studied for different temperatures and operating voltages. The parameters of detector modules were studied for few samples of scintillators produced by different companies. The measurements show satisfactory light yield of tested samples.

THE FAYANS ENERGY-DENSITY FUNCTIONAL IN APPLICATIONS TO NEUTRONS STARS

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The energy-density functional in the form proposed by Fayans has proved to be convenient and efficient for describing a large class of nuclear phenomena from nuclear masses and radii to proton and neutron density distributions and decay probabilities. Originally the parameters of the potential functional (FaNDF0) were tuned to reproduce the variational calculations of the nuclear equation of state with the ν_{14} potential and Urbana three-nucleon forces. Nowadays the parameter set DF3 has become very popular. We study the compositions and mass-radius relations of neutron stars using these two parameterizations. We find general relations between parameters of the functions and the expansion parameters of the nuclear equation of state at the saturation density. We set bounds on the Fayans functional parameters so that the corresponding maximum masses and radii of neutron stars satisfy new empirical constraints.

NUCLEOSYNTHESIS IN A LOW-MASS NEUTRON STAR CRUST. STRIPPING MODEL

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The lanthanides traces discovery in the kilonova spectra after recording a gamma-ray burst and gravitational waves [1] confirmed theoretical scenarios for the development of the r-process [2], associated with the neutron stars merger at the end of a close binary system evolution. After successful r-process simulation that occurs as a result of the neutron stars merger and observing these events, it became clear that this scenario is crucial for the heaviest nuclei formation. However, the neutron stars evolution in close binary systems strongly depends on their masses. With a large neutron stars masses difference, a stripping scenario is implemented instead of merging [3], which, in particular, has different heavy elements nucleosynthesis path [4,5].

In this work the nucleosynthesis in the low-mass neutron star crust, which loses mass due to accretion onto a larger companion and explodes upon reaching a hydrodynamically unstable configuration [3] is discussed.

It is shown that in the stripping scenario the exploded residue substance expands and, while its density is high, new elements nucleosynthesis occurs. In the inner crust it originates mainly due to the r-process with characteristic values of electrons to baryons initial ratio Ye<0.3. Nucleosynthesis in the outer crust in the scenario under consideration occurs mainly due to explosive nucleosynthesis with a sharp increase in temperature caused by a shock wave. Various decompression options for subnuclear density matter in the inner crust, preceding nucleosynthesis and forming the initial seed nuclei, are considered. The amount of heavy elements formed in a neutron star crust is $M \sim 0.041 M_{\odot}$, which is at least an order of magnitude greater than the yield of heavy elements in the close masses neutron stars mergering scenario [6].

The work was carried out within the state assignment framework of the National Research Center «Kurchatov Institute».

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HIGH-ENERGY NEUTRINO GENERATION AT JETS FROM SUPERMASSIVE BLACK HOLES

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The famous Blandford-Znajek mechanism or process (Blandford R.D., Znajek R.L. Mon. Not. R. Astr. Soc. 179 433 (1977)) explains the formation of relativistic jets from the fast-rotating accreting black hole due to the electric current trough black hole event horizon. The working efficiency of the Blandford-Znajek mechanism is justified recently by numerous numerical simulations of the General Relativistic Magnetohydrodynamics (GRMHD) accretion onto rotating Kerr black hole at the most powerful supercomputers in the world. In this process the acceleration of protons and other nuclei is impossible due the energetic losses in the powerful radiation field from the accretion disk.

From physical point of view the favorable place for acceleration of protons and other nuclei are the outflowing jets from accreting supermassive black holes, hitting the dense plasma clouds along the jets. It must be happened far enough from the black hole e vent horizon, radiation field from the accretion disk becomes a rather weak (at the distance 1 pc or more). Therein is the generation of high-energy neutrino as secondary particles.

The maximum energy of these neutrinos estimated by the method (or criterium) by Hillas (Hillas A.M. Annu. Rev. Astron. Astrophys. 22 425 (1984)), may reach 1015 eV. These high-energy neutrinos are accessible for observations by the largest neutrino telescopes, such as IceCube at the South Pole and Baikal Neutrino Telescope (Baikal Gigaton Volume Detector, Baikal-GVD).

INVESTIGATION OF REACTOR ANTINEUTRINO IN THE DANSS EXPERIMENT

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Detector DANSS detects antineutrino flux from the 3.1 GW industrial nuclear reactor VVER-1000 of the Kalinin Nuclear Power Plant at distances 10.9, 11.9, 12.9 meters over 8 years. By 2024 statistics of more than 8 million inverted beta decay events have been collected. New analyses of the data exclude a large area of parameters for hypothetical short base reactor neutrino oscillations to sterile state. Additionally, a new study of high energy part (8-12 MeV) of reactor antineutrino spectrum was carried out. The neutrino spectrum dependence on the ^{239}Pu fission fraction and the ratio of cross sections for ^{235}U and ^{239}Pu will be shown. A status of the DANSS upgrade will be reviewed. Twice better energy resolution of 12% at 1 MeV and increased by 70% sensitive volume will provide more sensitive and precise studies of reactor antineutrino in the DANSS experiment over next years.

ОБ ОСОБЕННОСТЯХ ГИПЕРОННЫХ ВЗАИМОДЕЙСТВИЙ В НЕЙТРОННЫХ ЗВЁЗДАХ

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Изучение свойств барион-барионных взаимодействий является на сегодняшний день актуальной темой исследований в области ядерной физики. При этом гиперон-нуклонные и, тем более, гиперон-гиперонные взаимодействия изучены гораздо хуже, нежели нуклон-нуклонные. Подходящей средой для изучения свойств барионных взаимодействий являются нейтронные звёзды, поскольку их материя состоит из барионов и лептонов и может быть описана с помощью методов ядерной физики. Более того, экстремальные условия, реализующиеся внутри нейтронных звёзд, такие как сверхвысокие давление и плотность, позволяют исследовать различные особенности барионных взаимодействий, которые не проявляются в нормальных условиях.

В данной работе мы концентрируемся на изучении свойств гиперонных взаимодействий в нейтронных звёздах. Предполагается, что материя нейтронных звёзд состоит из нуклонов, лептонов и гиперонов. Для описания взаимодействия используются силы Скирма, а для расчёта масс и радиусов нейтронных звёзд – уравнение Толмана-Оппенгеймера-Волкова.

Мы исследуем влияние зависимости от плотности гиперон-нуклонного взаимодействия на характеристики нейтронных звёзд. Также рассматривается вопрос о плотности, при которой появляются гипероны в нейтронных звёздах. Эта характеристика, по нашему мнению, имеет важное значение для описания нейтронных звёзд, в материи которых присутствуют гипероны [1, 2]. В связи с этим изучается зависимость плотности в точке появления гиперонов от свойств гиперон-нуклонного взаимодействия. Наконец, мы исследуем вопрос о зависимости от плотности гиперон-гиперонного взаимодействия и предлагаем новый способ описания этого взаимодействия в нейтронных звёздах.

Исследование выполнено за счет гранта Российского научного фонда № 24-22-00077.

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STATUS AND RESULTS FROM nuGeN EXPERIMENT AT KALININ NUCLEAR POWER PLANT

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The experiment nuGeN investigates neutrino properties at Kalinin nuclear power plant (KNPP, Udomlya, Russia). The experimental setup was installed under the third unit of the KNPP at a distance of 11.1-12.2 m from the reactor core. The enormous antineutrino flux at this place of $(3.6-4.4)\times10^{13}$ $\nu/(\mathrm{cm}^2$ sec), good overburden of 50 m w.e. and suitable background conditions provide the one of the best places for search of coherent elastic neutrino scattering, magnetic moment of neutrino and other rare processes. The signals are recorded by a specially designed low-background, low-threshold, 1.4 kg germanium detector. The surrounding of the detector by active and passive shielding allows to mitigate background from external radiation. Special techniques were developed to detect nuclear recoils with energy depositions below 300 eV. The detection efficiency for signals from events with energy higher than 250 eV is more than 80 %. The spectrometer demonstrates good and stable performance. More than 1600 kg·days of data has been accumulated so far. A detailed overview of the experimental setup, the current status of measurements, and the new results will be presented at the conference.

A SEARCH FOR CORELLATION OF NEUTRINO EVENTS IN THE BOREXINO DETECTOR WITH TRANSIENT ASTROPHYSICAL PHENOMENA

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The Borexino detector was a low-background real-time liquid scintillator setup with primary focus on solar neutrino spectroscopy. The detector has been in operation since May of 2007 up until October of 2021 at the underground facilities of Gran-Sasso National Laboratory.

Here, we present the results of our search for correlations between Borexino signals and known astrophysical transients (such as fast radio bursts, gamma-ray bursts and gravitational waves) that has been registered within the same time period.

EXPLORING OF ONE POTENTIAL SOURCE OF ULTRA-HIGH-ENERGY COSMIC PARTICLES

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Recently, it was announced that a team of scientists from the Telescope Array project recorded the second most powerful cosmic ray in the history of observations. This was reported at the University of Utah (USA). The energy of the beam, recorded by the Telescope Array, is approximately 2.4×10^{20} eV. Astrophysicists explain that nothing in our galaxy could produce such a stream of particles. This paper explores one potential source of ultra-high-energy cosmic rays (UHECRs), focusing on the idea that dense strongly interacting matter formed in quark stars (QS) could generate UHECRs.

Only 2-3 experimental observations have been mentioned, none of which have been confirmed. However, a recent study by I. Bombaci et al. [Phys. Rev. Lett. 126, 162702 (2021)] proposed that the low-mass companion of the black hole in GW190814 might be a strange quark star.

Experimental results from the RHIC and LHC ultrarelativistic heavy ion experiments show that strongly interacting matter produced in such collisions displays collective behavior. We propose that parton collective behavior could lead to the formation of a coherent group of partons.

An interaction of a parton with this group, similar to a photon's interaction with a high-energy electron, could result in the parton gaining energy through the inverse Compton effect. Consequently, the parton could be accelerated similar to a photon in the inverse Compton effect. The dense strongly interacting matter potentially existing in QS suggests that these stars might be a novel source of UHECRs.

SEARCH FOR STERILE NEUTRINO WITH THE DAYA BAY FULL DATASET

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Modern neutrino physics contains a few anomalies that can not be described by the three-neutrino mixing and oscillation framework. Reactor neutrino experiments observed a deficit of the anti-neutrino flux at 2.5σ level with respect to the prediction (Huber-Mueller model). Gallium detectors for solar neutrinos observed a deficit of events from radioactive calibration sources of neutrino (^{37}Ar and ^{51}Cr) at 2.3σ level.

These anomalies could be explained with one or more sterile neutrinos, which interact only gravitationally.

The reactor experiment Daya Bay has stored $5.55 \cdot 10^6$ IBD candidates from the interaction of electron antineutrinos. The statistics have been accumulated on a distance from 400 m to 2 km between reactor and detectors. It makes the experiment sensitive to sterile neutrino in a wide range of sterile mass splittings Δm^2_{41}.

Since no significant signal of sterile neutrino was observed, it enables us to exclude a large region of sterile neutrino parameter space. The sensitivity to sterile amplitude $\sin^2 2\theta_{14}$ achieves $5 \cdot 10^{-3}$ with 95% confidence level in a region of $2 \cdot 10^{-4}$ eV$^2 < \Delta m^2_{41} < 2 \cdot 10^{-1}$ eV^2.

The overview of the experiment and results of the analysis of the full dataset of Daya Bay will be presented.

ASTROPHYSICAL S-FACTOR AND REACTION RATE OF THE DIRECT ^{16}O(p, γ)^{17}F CAPTURE PROCESS

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The direct ^{16}O(p, γ)^{17}F radiative capture reaction is a key sequence in the proton-proton and carbon-nitrogen-oxygen (CNO) cycles in the massive asymptotic giant branch(AGB) stars[1]. The astrophysical S-factor and reaction rate are studied in the framework of the two-body potential cluster model [2, 3]. Comparative analysis of the S factor was performed for various empirical values of the asymptotic normalization coefficients (ANC) for the ^{17}F($5/2^+$) ground and ^{17}F($1/2^+$) excited bound states, respectively. The contributions of dipole and quarupole electromagnetic transitions are described at the long-wavelength approximation. The form of the Woods-Saxon type two-body p^{16}O-potential is taken from Ref.[4], with the central, spin-orbital and corresponding Coulomb parts. The four sets of potentials describe correctly the experimental phase shifts, the empirical ANCs and the binding energies of the ground $d_{5/2}$ and the first excited $s_{1/2}$ bound states. As it can be seen in Fig.1, the proposed VM2 potential very well describes the experimental astrophysical S factors for the direct ^{16}O(p,γ)^{17}F radiative capture reaction at whole energy region. Moreover, on the basis of the chosen model the reaction rate is estimated for this process in the stellar temperature interval. The theoretical results are well consistent with the results of the NACRE collaboration and other theoretical works [1].

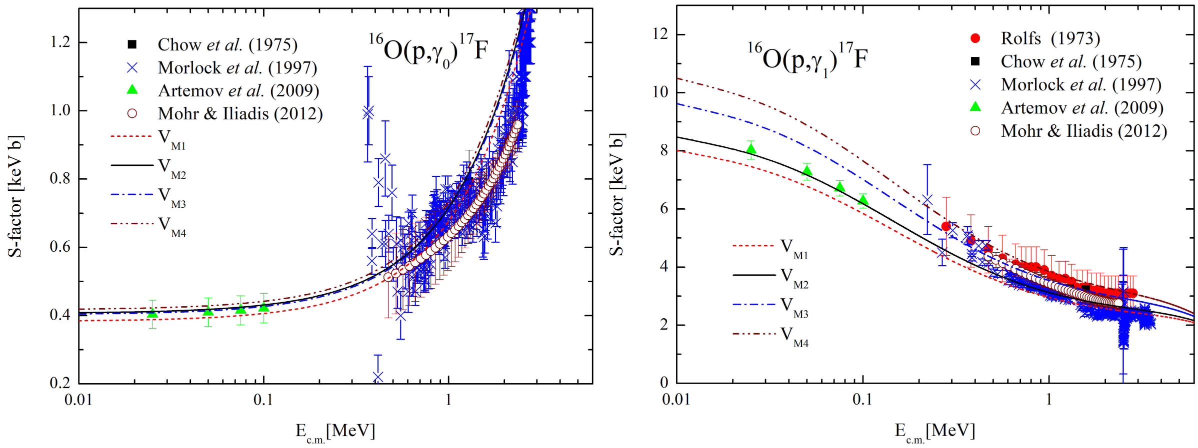

Fig. 1. Astrophysical S factors for the ground and first excited bound states within the different sets of proposed potential models in comparison with the available experimental data.

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CLASSIFICATION OF TAU-NEUTRINO EVENTS IN THE SCATTERING AND NEUTRINO DETECTOR USING KINEMATIC INFORMATION

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The SHiP (Search for Hidden Particles) experiment is a new fixed-target experiment to be installed at the CERN SPS ring with a 400 GeV proton beam energy. The primary goal of the experiment is to detect signals from the Hidden Sector particles, introduced to describe dark matter, baryon asymmetry, and small neutrino masses. To suppress background, an iron magnetized hadron absorber and a muon shield are utilized, along with several veto systems, aiming to reduce the experiment's overall background to zero over 5 years of operation.

SND (Scattering and Neutrino Detector) is the SHiP detector project designed to detect neutrinos of all flavors and direct signals from Light Dark Matter (LDM) interactions. An updated design for SND@SHiP includes a high-granularity hadron calorimeter achieved using scintillating fibers (SciFi) and scintillator layers (Sci).

This work aims to verify the possibility of classification:

- Signal from inelastic interaction of tau-neutrinos via charged current on nuclei followed by tau lepton decay in the leptonic channel (CC DIS $\nu_\tau N \to \tau + X \to \mu\nu_\tau\nu_\mu + X$) against the background of signal from inelastic interaction of muon neutrinos via charged current on nuclei (CC DIS $\nu_\mu N \to \mu + X$).
- Signal from inelastic interaction of tau-neutrinos via charged current on nuclei followed by tau lepton decay in the hadronic channel (CC DIS $\nu_\tau N \to \tau + X \to \text{hadrons} + X$) against the background of signal from inelastic interaction of muon neutrinos via neutral current on nuclei (NC DIS $\nu_\mu N \to \nu_\mu + X$).

The search for tau-neutrino signal was performed using reconstructed kinematics of secondary particles and detector response. Inelastic neutrino interaction events from the SHiP experiment spectrum on nuclei were simulated using the GENIE package, and secondary particles were passed through the detector using the GEANT4 package. A classifier was developed using machine learning methods trained on kinematic variables, capable of accurately classifying event types. To assess the required accuracy and resolution of the detector, the model was tested on blurred data and demonstrated stability under the assumed detector resolution.

NEUTRINO MAGNETIC MOMENTS AND HIGH-ENERGY NEUTRINOS FLAVOUR COMPOSITION

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Neutrino propagation in the Galactic magnetic field is considered. To describe neutrino flavour and spin oscillations on the galactic scale baselines an approach using wave packets is developed. Evolution equations for the neutrino wave packets in a uniform and non-uniform magnetic field are derived. Analytical expressions for neutrino flavour and spin oscillations probabilities accounting for damping due to wave packet separation are obtained for the case of uniform magnetic field. It is shown that for oscillations on magnetic frequencies $\omega_i^B = \mu_i B_\perp$ the coherence lengths that characterizes the damping scale is proportional to the cube of neutrino average momentum p_0^3. Probabilities of flavour and spin oscillations are calculated numerically for neutrino interacting with the non-uniform Galactic magnetic field. Flavour compositions of high-energy neutrino flux coming from the Galactic centre are calculated accounting for neutrino interaction with the magnetic field. It is shown that for neutrino magnetic moments $\sim 10^{-13}\mu_B$ and larger these flavour compositions significantly differ from ones predicted by the vacuum neutrino oscillations scenario.

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SATURNE: CURRENT STATUS AND PHYSICS POTENTIAL

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The Sarov tritium neutrino experiment (SATURNE) is part of the scientific program of the National Center for Physics and Mathematics (NCPM) [1] that was founded in Sarov in 2021. The experiment is under preparation, with the first taking of data expected for 2025 and the data collection expected to be completed by 2032.

SATURNE is motivated by fundamental problems in neutrino physics. Specifically, it will primarily search for neutrino electromagnetic interactions [2,3] in elastic and ionizing neutrino-atom collisions. The experiment will employ a high-intensity tritium neutrino source, with an initial activity of at least 10 MCi and possibly up to 40 MCi. The tritium source will be used in combination with the He-4, Si and SrI_2(Eu) targets in order to study the elastic and ionization channels of neutrino-atom collisions at unprecedentedly low energies.

The Si and SrI_2(Eu) detectors with record low-energy thresholds for such detector types will measure the ionization channel of neutrino-atom collisions. With the 1-year data from either detector, one may expect to achieve a sensitivity on the order of $\sim 10^{-12}\,\mu_B$ at 90% C.L. to the neutrino magnetic moment μ_ν, which is the most studied theoretically and actively searched experimentally among the neutrino electromagnetic properties.

The measurements with the liquid He-4 detector in a superfluid state are expected to provide the first observation of coherent elastic neutrino-atom scattering (CEνAS) [4,5]. This will bring the experimental studies of coherent elastic neutrino-nucleus scattering (CEνNS) [6] to a qualitatively new level, namely when one will be able to explore the neutrino elastic scattering not only on a nucleus as a whole, but also on an atom as a whole. With the 5-year data using the liquid He-4 detector, it is also expected to achieve a record-high μ_ν-sensitivity of $\sim 10^{-13}\,\mu_B$ at 90% C.L.

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RICCI-GAUSS-BONNET GRAVITY, COSMOLOGY, AND NUCLEAR ASTROPHYSICS

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Ricci-Gauss-Bonnet (RGB) gravity based on a pure geometric Lagrangian that is defined by a specific dimensionless combination of the Ricci (R) and Gauss-Bonnet (G) scalars is suggested and discussed as a possible viable generalization of the General Relativity (GR). Within the Parameterized Post-Newtonian (PPN) formalism it is shown that RGB gravity has the same values of PPN parameters as in the GR. As well in RGB gravity there is no ghosts, or unstable perturbations. With no need in cosmological constant and dark matter RGB gravity well agrees with the solar system data, cosmological data, and with the spectral scalar index defined by evolution of the random metric fluctuations at the inflation stage of the primordial Universe. The physics of the gravitational field arising from RGB gravity is considered in contexts of the cosmology, black holes, supernovae stars, neutron stars, compact binary systems, galaxy rotation curves, and weak-field gravity. Finally, RGB gravity is shown to exhibit a number of interesting phenomena in each of the topics mentioned above, and it is discussed for prediction of new possible experiments.

EFFECTS OF NEUTRINO ELECTROMAGNETIC PROPERTIES AND SPIN STATE IN ELASTIC NEUTRINO-NUCLEON SCATTERING

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Electromagnetic neutrino properties can be a manifestation of new physics [1]. We study electromagnetic contribution to elastic neutrino-nucleon scattering processes. Following our approach developed for the case of elastic neutrino-electron [2] and neutrino-proton [3-6] collisions, in our formalism we account for possible electromagnetic form factors of massive neutrinos: the charge, magnetic, electric, and anapole form factors of both diagonal and transition types. Considering Dirac neutrinos from an astrophysical source arriving at a detector on Earth, we assume them to have arbitrary spin polarization due to effects of neutrino spin oscillations induced by neutrino magnetic moment interactions with magnetic fields both in the astrophysical source and in the interstellar environment. When treating the nucleon electromagnetic vertex, we take into account not only charge and magnetic form factors of a nucleon, but also its electric and anapole form factors. We numerically examine how the effects of electromagnetic properties and spin polarization of the cosmic neutrinos can influence the differential cross sections of their elastic scattering on nucleons in the detector.

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APPLICATIONS OF NUCLEAR METHODS IN SCIENCE TECHNOLOGY, MEDICINE AND RADIOECOLOGY

ИЗМЕРЕНИЕ КОНЦЕНТРАЦИИ АЛЬФА-ИЗЛУЧАЮЩИХ НУКЛИДОВ В РАСТВОРАХ С ПОМОЩЬЮ АЛЬФА-СПЕКТРОМЕТРИИ

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Данная работа относится к применению методов ядерной спектроскопии для онлайн контроля гидрометаллургических процессов при переработке ОЯТ. Описывается опыт прямого измерения альфа-излучающих радионуклидов в жидкостях с использованием поверхностно барьерного полупроводникового планарного кремниевого диодного детектора и обработки данных методами математического моделирования. Рабочие характеристики и долговечность диодных Si детекторов позволяют напрямую обнаруживать альфа-частицы в образцах жидкости путем размещения диодного детектора непосредственно в объеме образца жидкости, а математическое моделирование позволяет интерпретировать данные, полученные в условиях сильного рассеяния альфа-частиц в жидкости. Было проведено сравнение с результатами, полученными на жидкостном сцинтилляционном спектрометре и спектрометре с PIPS детектором и вакуумной камерой.

При переработке ОЯТ важно, как общее содержание актинидов, так и количественная оценка концентраций соответствующих изотопов, особенно на этапе экстракции/реэкстракции гидрометаллургического передела, для контроля технологического процесса. Так же альфа-активность ОЯТ важна, поскольку изотопы актинидов обладают длительным периодом полураспада, высокой радиологической и химической токсичностью и влияют на оценки критичности технологического оборудования.

Прямой анализ альфа-излучателей с помощью «погружных» Si- детекторов представляет значительную проблему из-за сложных процессов формирования функции отклика альфа-частиц для «толстых» образцов [1]. С помощью расчета переноса альфа частиц в растворе и Si детекторе были определены функции отклика детектора на альфа-частицы радионуклидов урана и трансуранов (U, Np, Am, Pu, Cm). Программа расчета переноса альфа-частиц методом МК основана на приближении непрерывного замедления и использует данные NIST/ASTAR по тормозной способности материалов. В коде используется простейший геометрический пакет, позволяющий проводить расчет для плоских цилиндрических фигур.

Рассчитанные функции отклика позволили оценить значения эффективности регистрации альфа-частиц различных нуклидов и, при обработке экспериментальных энергетических спектров альфа-частиц образцовых растворов изотопов Pu и Am восстановить содержание альфа излучающих нуклидов с точностью лучше 10 %.

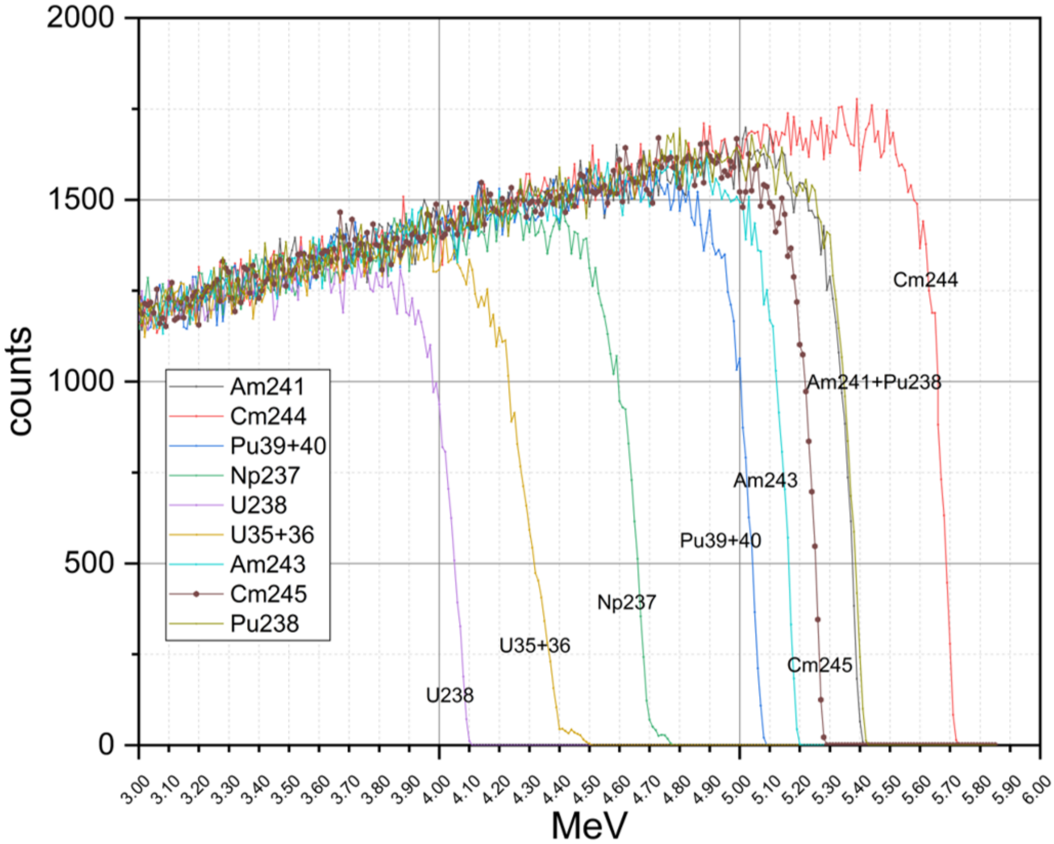

Рисунок 1 – Расчетные функции отклика полупроводникового детектора погружного типа, слой водного раствора 100 микрон. Результат нормирован на одинаковое число историй.

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PROJECT BECQUEREL AT PORTAL OF NUCLEAR KNOWLEDGE BELNET

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Since beginning of the XXI century the International Atomic Energy Agency (IAEA) gives big attention to the nuclear knowledge management (NKM), based on research and development as well as industrial applications of nuclear technologies. NKM by the IAEA involves the nuclear science in the educational process through creation and development of different educational networks and portals.

Belarusian Nuclear Education and Training Portal (BelNET https://belnet.by/) was created in 2016 by scientists of the Institute for Nuclear Problems of Belarusian State University (INP BSU) to implement NKM principles. Currently it is the only major portal of nuclear knowledge in Belarus with about 5000 records in the main NK fields including current news, glossaries, monographs, textbooks, preprints, materials of international conferences, analytical reviews, special laboratory works for students etc.

At the end of 2023, mutually beneficial cooperation between the Laboratory of analytical research of INP and the JINR Nuclotron BECQUEREL experiment began.

The purpose of this experiment is to study the clustering in light stable and radioactive nuclei in the relativistic approach with the method of nuclear track emulsion. The investigated events of interaction of relativistic nuclei including complex multiparticle states allow to understand whether it is possible in the laboratory to reproduce the conditions of nuclear matter corresponding to nuclear astrophysics. The BECQUEREL experiment team working at the JINR Laboratory of High Energy Physics named after V.I. Veksler and A.M. Baldin has its own site http://becquerel.jinr.ru/.

The portal BelNET now contains a large number of records devoted to the BECQUEREL experiment. These include review articles and works on the study of nuclear reactions during irradiation of a nuclear emulsion in beams of various relativistic isotopes. Materials can be found in the portal section “Basic science” (https://belnet.by/elib/?i=121) → “Relativistic nuclear physics” → “Study of relativistic fragmentation of nuclei using the nuclear photoemulsion method”.

In this report, the scientific results of cooperation between portal BelNET and BECQUEREL experiment are presented and discussed.

МЕХАНИЗМ УТОЧНЕНИЯ ЭНЕРГЕТИЧЕСКИХ ПОТЕРЬ ИОНОВ В ОБЛАСТИ НИЗКИХ ЭНЕРГИЙ С ПОМОЩЬЮ ИЗМЕРЕНИЯ ЭФФЕКТА ДОПЛЕРА

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Ниже 100 кэВ на нуклон потери энергии согласно LSS модели пропорциональны скорости, однако ниже 10 кэВ на нуклон электронная оболочка иона-снаряда начинает восстанавливаться, поэтому значение степени пропорциональности электронных потерь скорости при уменьшении энергии иона может иметь иную степенную зависимость от скорости. Измеренные потери тяжелых ионов с энергией меньше 100 кэВ на нуклон оказались значительно ниже, чем считалось раньше, поэтому ионные каскады распределяются по большему объему, чем ожидалось, что приводит к увеличению времени кластеризации дефектов и увеличению ошибки моделируемой радиационной стойкости материалов. В работе предлагается методика, позволяющая использовать результаты измерения доплеровских ширин гамма-линий, инициированных радиационным захватом нейтронов, для оценки энергетической зависимости электронных потерь ионов малых энергий.

Из формы и ширины доплеровской линии, обусловленным снижением импульса от p_0 до p_1 за время Δt, можно оценить энергетическую зависимости электронных потерь:

$$\frac{p_1}{p_0} = \left(1 - \frac{\Delta t}{\tau_{\alpha<0.5}} \left(\frac{\epsilon}{E_0}\right)^{0.5-\alpha}\right)^{\frac{1}{1-2\alpha}}$$

где t – время жизни иона на уровне, E_0 – начальная энергия иона, α – показатель степенной зависимости от скорости ($\alpha_{LSS} = 0.5$) и ϵ – нормировка электронных потерь.

На Рис. 1 для реакции ^{48}Ti(n, γ)^{49}Ti продемонстрировано, что аппроксимация имеющихся экспериментальных данных МАГАТЭ со степенной зависимостью $\alpha = 0.4$ (по экс. точкам) лучше описывает интерференционным спектрометром GAMS4, чем LSS аппроксимация, использованная в Geant4

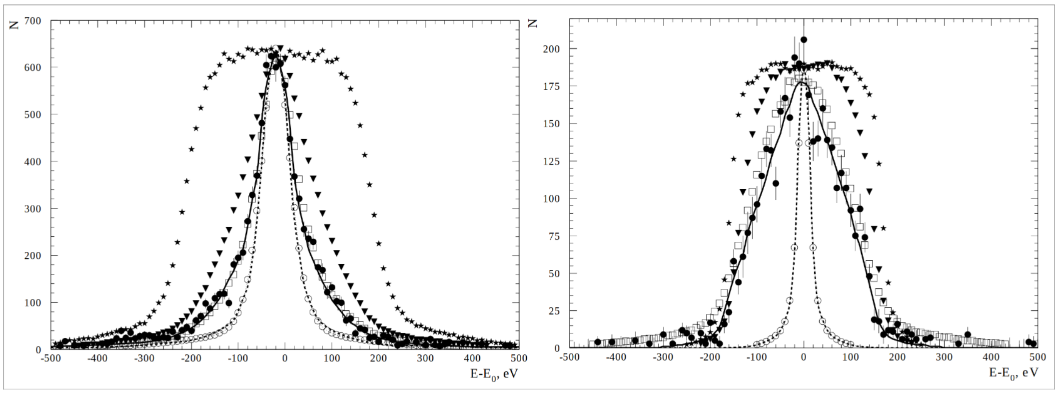

Рис. 1 Моделирование доплеровского уширения в реакции ^{48}Ti(n, γ) ^{49}Ti для указанных табличных времён жизни уровней. Кружки – разрешение GAMS4 спектрометра (большое время жизни), звезды – газовое приближение, треугольники – Geant4 (LSS модель потерь), квадраты – моделирование с использованием данных МАГАТЕ.

В работе обсуждается, как варьируя величину и наклон электронных потерь можно описать ширину и форму допплеровской линии

INCREASING THE ACCURACY OF DOSE DELIVERY TO CTV DURING PBS PROTON THERAPY

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Currently, the proton therapy (PT) method, which uses a thin scanning beam, is one of the most ef-fective and modern methods for creating a conformal (shape-matching with the tumor) distribution of the absorbed dose in the tumor. A highly conformal dose distribution is achieved by optimizing thousands of thin proton beams. In order to prevent the occurrence of clinically significant errors, increased requirements are placed on the accuracy of delivery of each individual thin beam.

The advantages provided by the Bragg peak allow for more accurate dose distribution, but also require greater precision in patient positioning. Incorrect patient positioning during PT can lead to serious errors, including underexposure of tumors and overexposure to healthy tissue. To neutralize this effect, the concept used is to irradiate an area that exceeds the size of the subclinical spread of the tumor. The clinical volume of a tumor, including the microscopic spread of cancer cells around it, is called CTV. Planned target volume (PTV) is CTV plus some margin. It is assumed that some of the normal tissue surrounding the CTV within the irradiated area may be included in the irradiation to ensure adequate coverage of the target with a uniform dose, taking into account possible geometric uncertainties.

In radiotherapy, the presence of various inhomogeneities in the path of the proton beam (e.g., bone, lung, air cavities) can lead to a significant deterioration in the predictability of the final dose distribu-tion in the event of errors in beam delivery. Before each PT session, it is necessary to check the pa-tient's position using two orthogonal images and then evaluate the position correction. In the Russian Federation, standards for PTV margins for PT have not yet been established. Therefore, generally ac-cepted margins applied for photon therapy are used. Typically, the CTV-PTV margin ranges from 3 mm to 20 mm.

When comparing PT to conventional photon therapy, a different approach must be taken to determine the margin between the CTV and PTV. Especially in the case of PT using PBS for fixed targets surrounded by bone structures, it is possible to determine a minimum margin that takes into account the accuracy of dose delivery of a particular PT system. There is no mention in the literature of meth-ods for assessing the accuracy of PT systems and the impact of the results of such assessment on the accuracy of radiation dose delivery to tumors of various locations.

The Proton Center of the Federal Scientific Clinical Center for Medical Radiology and Oncology of FMBA of Russia (FSCCRO of FMBA of Russia) uses the IBA Proteus Plus PT system, based on the IBA C235-V3 cyclotron. In 2011-2012, the cyclotron was assembled and tested at the Joint Institute for Nuclear Research in Dubna, then delivered to Dimitrovgrad. Given the characteristics of the system and the organization of clinical processes, the accuracy of dose delivery to the CTV can be influenced by various factors, such as radiation output, accuracy of narrow beam delivery, energy choice and collinearity of X-ray and PT systems. To speed up the process of morning measurements (quality assur-ance QAs), a combination of the IBA LynxPT scintillation detector and the IBA Sphinx phantom was chosen, which made it possible to significantly reduce the time of daily morning QA checks from 2-2.5 hours to 20-30 minutes. This optimization increased efficiency in the use of clinical time and allowed additional patients to be treated, increasing PT center throughput capacity by 18%.

The dimensions of the CTV-PTV margins established by the FSCCRO of FMBA of Russia are based on clinical recommendations developed for the use of photon devices in radiation therapy, and are 3 mm for the case of intracranial tumors. However, to take into account errors in dose delivery to the CTV, it is necessary to calculate the minimum required CTV-PTV margin. This calculation requires analyzing the stability of the dosimetric parameters of the PT system, such as the constancy of the size and position of the narrow beam, the collinearity of the central axes of the proton and X-ray systems, as well as the stability of the energy selection system.

PT system parameters measurements were recorded in the IBA MyQA software database, including date and measured values. This data was exported into a spreadsheet format for further analysis. Daily morning checks of the PT system parameters were carried out over a period of 11 months. Measure-ments were taken at different gantry angles (0°, 90° or 270°) on weekdays. As a result, over three working weeks, 5 measurements were made at each gantry angle.

The position of the narrow beam was set to $pm10\%$ of the reference value to ensure a constant beam penumbra within 1 mm. The position of the narrow beam remained within $pm1$ mm throughout all meas-urements in both PT rooms. The average deviation of the narrow beam position from the reference val-ue did not exceed 0.4 mm. Analysis of the images obtained on the LynxPT screen as part of the morn-ing checks also showed that the fluctuations in the position of the narrow beam were insignificant. The range of deviations of all studied parameters of the PT system from the reference values remained within the limits recommended in TG-224.

There is no mention in the literature of methods for assessing the accuracy of PT systems and the impact of the results of such assessment on the accuracy of radiation dose delivery to tumors of various locations. Therefore, it was decided to adapt the well-known approach to calculating the margin to take into account geometric uncertainties to the results of an 11-month monitoring of the stability of the parameters of the PT system.

Errors in the lateral direction come from errors in narrow beam position and collinearity, and in the axial direction from errors in energy parameters. Based on the standard orientation of the patient on the treatment table, lateral errors in the X direction are used to calculate the margin in the head-foot direc-tion, and in the Y direction for left-right and abdomen-back. Axial errors are used to calculate the mar-gin along the beam axis. In the lateral directions relative to the beam axis, the calculated margin was 0.8 mm, along the beam axis – 0.4 mm.

The calculated values represent the minimum indentations in the corresponding directions for plan-ning PT in the FSCCRO of FMBA of Russia. Their use, taking into account the accuracy of dose de-livery by the PT system, ensures CTV coverage of 95% of the prescribed dose. This is especially im-portant for stationary targets surrounded by inert structures, for example, for brain tumors, where in-trafractional movement of the target can be neglected.

After studying the methods for conducting morning QAs of the parameters of the PT system, the optimal set of parameters was determined that should be measured as part of the daily quality assur-ance program for the PT system IBA Proteus Plus, used in the Proton Center of the FSCCRO of FMBA of Russia.

The methodology for morning checks of the PT system parameters was optimized using the LynxPT+Sphinx complex, which led to a reduction in the time of inspections by 7.5 times and an in-crease in the throughput of the PT center by 18%. These tests include all recommended tests from TG-224 for PBS systems.

The constancy of the relative dosimetric parameters of the PT system affecting the calculation of the CTV-PTV margin was analyzed. Over nine months, no significant deviations from reference values exceeding acceptable limits were detected. The total mechanical error exceeded 1 mm in 1.3% of cases, the maximum value was 1.3 mm.

Using the approach known from the literature for calculating the CTV-PTV margin taking into ac-count the patient positioning error, the CTV-PTV margin was calculated taking into account the dose delivery error of the PT system. The obtained minimum margin values, taking into account the accuracy of dose delivery, can be applied both for single-field (0.8 mm in the lateral directions relative to the beam axis, 0.4 mm in the direction along the beam axis) and for multi-field (0.8 mm in all directions) irradiation. It is proposed to use this margin calculation method, which takes into account the accuracy of dose delivery by the PT system, in new PT centers.

ESTIMATION OF BIOLOGICAL PROTECTION AT THE NEW CYCLOTRON COMPLEX DC-140 USING MONTE CARLO METHOD

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Currently, the Laboratory of nuclear reactions, Joint Institute of Nuclear Research (JINR), is working on the creation of a new cyclotron complex DC-140, designed to solve a wide range of applied tasks. The main objectives of the project include research in solid-state physics, radiation resistance of materials, surface modification, production of track membranes, as well as testing of avionics and electronic component base under heavy charged particles [1].

The declared parameters of the new cyclotron are as follows: ion energy 2.1 and 4.8 MeV/u; ions of elements from O to Bi or U; intensities: 2.1 MeV/u (up to Xe 10^{12} s-1, Bi: 1×10^{11} s-1, U $> 10^{9}$), 4.8 MeV/u (up to Xe $> 10^{11}$ s-1, Bi: 1×10^{10} s-1).

An important aspect of designing/engineering and exploitation/operation of accelerators is estimation of the radiation situation in the building. Estimation is performed by calculations that allow us to assess the possible radiation risk to the personnel, as well as to materials and equipment.

One of the methods of calculation is Monte-Carlo method, which is based on statistical modeling processes of interaction of particles with matter. Specialized simulation package FLUKA [2], which is based on this method, emerges as a powerful instrument for modeling the interactions of particles with matter and carrying out calculations of biological protection.

The new accelerator of heavy ions will be installed in the building previously occupied by the outdated cyclotron, hence requiring refinement of the radiation shielding. The simulation package FLUKA was utilized for computation. Performed computations allow us to evaluate the radiation situation of the building and indicate the maximum doses of ionizing radiation at various locations.

In [3], an estimate of the yield and angular distribution of neutrons has already been presented for calculating the biological protection of reconstructed heavy ion accelerators with an energy from 1 to 6 MeV/nucleon.

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THE EFFECT OF X-RAY RADIATION AND ACCELERATED ELECTRONS ON POTATO YIELD

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Worldwide, there is an increase in demand for the use of radiation technologies for economic purposes. They can be introduced into agriculture to accelerate the development and increase crop yields, improve product quality, and destroy pathogenic microflora [1]. The technology of pre-planting irradiation of seed tubers is based on the ability of ionizing radiation to accelerate plant growth and development, and the possibility of improving crop quality is shown [2].The values of stimulating doses (from 3 Gy to 20 Gy) for most crops, as well as conditions affecting the effectiveness of pre-sowing irradiation, have been determined [3-5].

In this study, Gala potato tubers were irradiated from two opposite sides at the electron accelerator UELR-1-25-T-001 with a maximum energy of 1 MeV and the 1BSV-23 X-ray machine with a RAD 100-10 X-ray tube equipped with a molybdenum anode. The radiation doses ranged from 5 to 30 Gy.

It was found that the treatment of planting material with accelerated electrons and X-ray radiation in doses from 5 Gy to 30 Gy affected the phenology, phytosanitary condition of the agrocenosis and, accordingly, the productivity and quality of potatoes. Irradiation with accelerated electrons at doses of 10 Gy and 15 Gy increased the yield of healthy tubers (with respect to Rhizoctonia solani Kuhn.) by 33.8-43.9%, compared with the control, and doses of 5 Gy and 15 Gy were more effective in weight equivalent, where the yield of healthy tubers was 2.5-2.8 t/ha, but did not exceed the reference value.

X-ray radiation at doses of 15 and 30 Gy increased the yield of healthy tubers (with respect to Rhizoctonia solani Kuhn.) by 27.1-35.2%, compared with the control, and doses of 5 Gy and 25 Gy were more effective in weight equivalent, where the yield of healthy tubers was 2.8-3.0 t/ha, but in the first case it was not exceeded the control value.

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RESEARCH OF THE FLASH EFFECT AT THE PROTON ACCELERATOR OF INR RAS

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The flash effect, which consists in better sparing of normal cells at mean dose rates $\dot{D}$m > 100 Gy/s, has been experimentally established quite confidently. However, its practical application requires further study of the regularities and biological nature of this effect. To this end, we studied the change in various manifestations of the flash effect with an extreme increase in the mean proton dose rate $\dot{D}$m > 104 Gy/s. This possibility is provided by the INR high-current linear proton accelerator, which in single-pulse flash (splash) mode allows increasing $\dot{D}$m up to 106 Gy/s when biological targets are irradiated with a single pulse up to 100 µs long with an instantaneous proton current up to 10 mA. We studied [1] the dependence of the response of cells and living organisms on $\dot{D}$m in the widest range: in the conventional mode with $\dot{D}$m < 1 Gy/s, in the flash mode with $\dot{D}$m 102 Gy/s and in the splash mode with $\dot{D}$m > 104 Gy/s. Dosimetry in high dose-rate modes was provided with EBT-XD films [2,3] and with an original detector using Cherenkov radiation [4]. In continuation of previous work [1], we irradiated tumor cells HT29 and HCT116 and normal cells - fibroblasts (ADSC) in all three irradiation modes both at the SOBP and on the plateau. As living organisms for study, we used live fertilized quail eggs. Cell response was studied using the following methods: flow cytometry, fluorescence microscopy, PCR analysis of gene expression, clonogenic analysis of cell survival etc. To study the response of live embryos to irradiation in different modes, their development and properties were studied before and after hatching from eggs. The analysis of new data is still ongoing, but the following results can be stated with sufficient statistical significance ($p<0.01$). In the single-pulse mode with extreme dose rates (splash), compared to the usual flash mode, the following effects are observed at the same values of the absorbed dose: further reduced apoptosis of normal cells compared to tumor cells; increased expression of some important genes; reduced embryonic mortality. These results allow us to make a cautious conclusion that the flash effect does not yet reach saturation upon irradiation by protons with $\dot{D}$m in the region of 102 Gy/s. Confirmation and biological substantiation of these results may initiate a further development of new accelerator techniques for application in oncology.

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ОПРЕДЕЛЕНИЕ ТОРМОЗНОЙ СПОСОБНОСТИ ИОНОВ УГЛЕРОДА В ОРГАНИЧЕСКИХ СОЕДИНЕНИЯХ ПРИ ПОМОЩИ ЯДЕР ОТДАЧИ

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Применение пучков тяжелых ионов для радиотерапии является одним из перспективных направлений при лечении онкологии. Пучок тяжелых ионов позволяет получить хорошую локализацию дозы [1]. Однако, существуют и проблемы, одна из которых неопределенность тормозной способности, в особенности в области низких скоростей ионов. Согласно базе данных МАГАТЭ [2], существуют значительные расхождения в величине тормозной способности ионов C-12 в органических соединениях, при этом имеется только ограниченный набор экспериментальных данных. В данной работе мы предлагаем метод определения тормозной способности ионов C-12 в органических соединениях при помощи резонансной реакции образования протонов отдачи. Измерения тормозной способности были выполнены для полипропилена и полиметилметакрилата.

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SILICON PIXEL SENSORS FOR DETERMINATION OF CHARACTERISTICS OF PROTON BEAMS IN THE ENERGY RANGE 100 – 1000 MeV FOR THEIR USE IN TRACKING DETECTORS

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Silicon pixels detectors may be used in proton computed tomography for tumor treatment planning in hadron therapy. In the context of this task it seems important to obtain the characteristics of the proton beam used for diagnostics and for therapy with high precision. It is also important to study the properties and influence on the beam of various materials that make up tomography detector systems. In this work the characteristics of proton beams of different energies using experimental setup of silicon pixels detectors system have been studied. The study of properties of carbon composite supporting structures used for digital track calorimeter will also be presented.

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ОЦЕНКА ТОЧНОСТИ ДОЗИМЕТРИИ ПРОТОНОВ С ПЛЁНОЧНЫМИ ДЕТЕКТОРАМИ

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На сильноточном линейном ускорителе протонов ИЯИ РАН имеется возможность использовать максимально широкий диапазон средней мощности дозы $\dot{D}$, от конвенционального режима с $\dot{D} < 3$ Гр/с до одноимпульсного режима FLASH (SPLASH) с $\dot{D} > 10^4$ Гр/с. В данной работе мы продолжили анализ согласованности и корректности расчетов и измерений дозовых распределений вблизи пика Брэгга, где характерен быстрый рост ЛПЭ. Исследования показали, что отклик плёночных детекторов ухудшается в области высокого градиента ЛПЭ, что не характерно для ионизационных камер. В то же время показана нелинейность отклика ионизационных камер в областях мощностей доз характерных для FLASH-режима. В силу невозможности использования ионизационных камер для абсолютной дозиметрии при максимально высоких значениях мощности дозы нами было проведено исследования влияния мощности дозы и ЛПЭ на отклик плёночных детекторов в референтных условиях при фиксированной дозе протонного излучения.

В продолжение предыдущих работ [1], были исследованы теоретические и экспериментальные характеристики глубинных дозовых распределений протонов в области пика Брэгга. Использованы расчеты по Монте-Карло с пакетом TOPAS MC и экспериментальные данные, полученные с помощью пленочных детекторов, ионизационных камер и оригинального черенковского монитора пучка [2]. Рассмотрены взаимосвязь полученных значений поглощенной дозы и корректность применения детекторов для ее измерения. В частности, получено хорошее совпадение рассчитанных и измеренных с помощью ионизационных камер дозовых распределений для начального и модифицированного пика Брэгга в конвенциональном режиме облучения и показана возможная взаимосвязь значения линейной передачи энергии и точности измерения дозы с пленочными детекторами.

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ЭКСПЕРИМЕНТЫ ПО ОБЛУЧЕНИЮ БИОЛОГИЧЕСКИХ МОДЕЛЕЙ В ПРОТОННОМ ПУЧКЕ

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Протонная терапия с высокой мощностью дозы или флэш-терапия является одним из актуальных и перспективных направлений развития методов лечения онкологических образований. Современные исследования показали, что превышение мощности дозы облучения свыше 40 Гр/с снижает негативные последствия воздействия на нормальные клетки, сохраняя эффективность лечения новообразований. Работа посвящена подготовке и проведению экспериментов по облучению биологических моделей на примере оплодотворенных яиц японского перепела (Coturnix japonica) в широком диапазоне мощности дозы.

Подготовка к экспериментам состоит из оценки действующей модели симуляции установки комплекса протонной терапии ИЯИ РАН [1], написанной с использованием библиотек Geant4 и Topas MC и проведения последующих симуляций геометрий включающих сборки перепелиных яиц, а также их крепления, устанавливаемых на глубине модифицированного пика Брэгга. Рассмотрены возможные варианты положения сборок с мишенями в пучке, а также влияние линейной передачи энергии и других характеристик, влияющих на биологическую эффективность радиационного воздействия.

Данная работа выполнена при поддержке гранта РНФ № 24-15-00040 «Разработка ядерно-физических и радиобиологических методов протонной флэш-терапии».

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ПОЗИЦИОННО-ЧУВСТВИТЕЛЬНЫЙ ЧЕРЕНКОВСКИЙ МОНИТОР МОЩНЫХ ПУЧКОВ ПРОТОНОВ

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Цель данной работы – разработка позиционно-чувствительного монитора, работающего в широком диапазоне интенсивностей и длительностей импульса протонного пучка, в условиях сильного низко-энергичного электромагнитного фона. Монитор, предложенный в работе [1] позволяет измерять в on-line режиме временную структуру, число протонов и положение центра пучка в каждом отдельном импульсе протонного пучка. Этот монитор протонного пучка предназначен для работы на медицинском канале центра коллективного пользования ИЯИ РАН в широком диапазоне интенсивностей протонного пучка. В настоящее время монитор используется для исследования флэш-эффекта при облучении биологических объектов пучками протонов высокой мощности дозы, достигающей значений более 10 кГр/с [2,3]. Конструкция черенковского монитора протонного пучка позволяет преобразовать монитор в позиционно-чувствительный детектор заменой фотоумножителя (XP2020) на позиционно-чувствительный многоканальный кремниевый фотоумножитель (SiPM). Для пучков протонов с энергией 160 МэВ и импульсным средним током 1 мА получено хорошее согласие измерений монитора с данными пленочного детектора Gafchromic и индукционного датчика тока. При этом, в отличие от индукционного датчика тока, данный монитор находился в обычной атмосфере, а не в вакууме. Проведены стендовые измерения координаты положения светового потока, имитирующего световой образ протонного пучка в радиаторе 2х координатного монитора. Представлен анализ алгоритмов восстановления координаты положения светового пучка с результатами моделирования монитора.

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АНАЛИЗ КЛЕТОЧНОЙ ГИБЕЛИ И ПРОЛИФЕРАТИВНОЙ АКТИВНОСТИ КЛЕТОЧНЫХ КУЛЬТУР ПРИ ОБЛУЧЕНИИ ПРОТОНАМИ В РЕЖИМЕ ФЛЭШ

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Главным достоинством протонной флэш-терапии является повышенная выживаемость нормальных тканей по сравнению с опухолевыми. Протоны имеют дополнительное преимущество по сравнению с электронами и фотонами из-за большей конформности распределения дозы облучения тяжелыми частицами и дополнительных эффектов, связанных с высокой линейной передачей энергии (ЛПЭ) в области модифицированного пика Брэгга (SOBP). Именно поэтому изучение протонной флэш-терапии актуально для дальнейшего развития лучевой терапии.

В данной работе представлены результаты серии экспериментов по облучению клеточных культур на сильноточном линейном ускорителе протонов средних энергий ИЯИ РАН. В этих экспериментах в водном фантоме облучались опухолевые клетки - рака толстой кишки (HCT116) и аденокарциномы толстой кишки человека (HT-29). В качестве нормальных клеток были взяты мезенхимальные стволовые клетки (ADSC) жировой ткани человека – фибробласты. Доза подводилась в трех разных режимах: конвенциональный режим (мощность дозы $\dot{D} < 3$ Гр/с), флэш-режим ($\dot{D} \sim 100$ Гр/с) и одноимпульсный флэш - режим ($\dot{D} > 10^4$ Гр/с) в области модифицированного пика Брэгга и на плато до пика. За время инкубации для клеточной гибели были взяты 24 и 48 часов после облучения. Пролиферативный потенциал оценивался в течении 10 дней после облучения. Для анализа клеточной гибели производилась окраска йодистым пропиедием и аннексином. Для пролиферативного потенциала воспроизводился EdU-тест. Анализ проводился с помощью флуоресцентной микроскопии.

Среди полученных результатов анализа можно выделить повышенный уровень позднего апоптоза у опухолевых клеток в одноимпульсном режиме облучения по сравнению с флэш и конвенциональным режимами спустя 24 часа. Также наблюдается высокий уровень некроза опухолевых клеток во всех режимах. Замечены явные различия в репликации ДНК у опухолевых и нормальных клеток в зависимости от режима облучения и величины поглощенной дозы.

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THE INAA AND ICP-MS AND TRACK ANALYSIS OF THE BONE FINDS AND SOME PROBLEMS WITH RADIOGENIC DATING

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The use of combination Instrumental Neutron Activation Analysis (INAA) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and also track detector analysis (TDA) by type of CR-39 are very efficient for element analysis of the prehistoric and ancient bone samples.

By the INAA and ICP-MS were analyzed contents of 25 and 64 elements with $\leq$ 15 % errors, respectively. And a high concentration of uranium were detected in the bones of dinosaurs (122 mg/kg), mammoth (220 mg/kg) and archanthrope (1.5 mg/kg) compared to surrounding soils (3.7-7.8 mg/kg) and standard bones ($<$0.01 mg/kg).

It has been established that the concentration of migrant elements and nuclear fission products K, Sc, As, Sr, Mo, Ba, La, Ce, Nd, Sm, Eu and Yb have been 3-30 time more in prehistoric and ancient bones than in standard bone. It is follows the radiogenic dating methods with $^{14}C/^{14}N$, $^{40}K/^{40}Ar$, $^{89}Rb/^{89}Sr$, $^{147}Sm/^{147}Nd$, $^{238}U/^{206}Pb$ are not absolutely correct and reliable for bone finds, due to increasing values of radioisotopes in skeletons depending on the environment and being period.

For estimating the ages of bone finds was proposed determination of the ^{226}Ra activity by registration α-particles of ^{222}Rn, by using a CR-39 track detector in an isolated chamber. The comparison of the ^{226}Ra concentration in the bones of archanthropus, mammoths, dinosaurs between standard bones showed are being direct correlation between age and ^{226}Ra concentration in skeletons.

STUDY OF THE RADIOECOLOGICAL SITUATION AT THE SITES OF EMERGENCY UNDERGROUND NUCLEAR EXPLOSIONS IN THE ^{70}S IN YAKUTIA

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In the 70s of the XX century, 12 underground nuclear explosions (UNE) were carried out in the Yakut Autonomous Soviet Socialist Republic (ASSR, now the Republic of Sakha (Yakutia) – RS(Ya)). Two UNE became emergency – “Kraton-3” with a capacity of 22 kt produced on August 24, 1978, and “Crystal” with a capacity of 1.7 kt produced on October 2, 1974. The explosion of “Kraton-3” was produced 40 km from the village of Aikhal on the border between Oleneksky and Mirninsky regions on the banks of the Markha River, which flows through the Vilyui region. As a result of the accident, radionuclides were released into the atmosphere and onto the soil surface. The explosion of the “Crystal” was made 2.5 km from the town of Udachny near the border of Mirninsky region. Rehabilitation works were carried out on the burial grounds of both facilities, which were built in 1981 for the first time after the explosions: in 2007, a protective screen was installed at the “Kraton-3” facility and soil 1.5 m thick was poured without fencing the area; In 1992, the “Kristall” explosion site was filled up to twenty meters high with a fence and a protective drainage shaft with a height of 0.9 m was erected to prevent the burial ground from being washed away by spring meltwater and summer rainwater. And 3 control wells were drilled with a diameter of 132 mm and a depth of 3 m below the burial ground [1]. In this paper the study of the migration of radionuclides from the cavity of the explosions “Crystal” and “Kraton-3” into the environment. In July 2023, an expedition was organized to the sites of emergency UNE, during which measurements of the radiation background and collection of environmental samples were carried out: samples of soil and local vegetation: moss, lichen, cypress (Ivan tea). To determine the degree of contamination of the environment with radionuclides and identify the approximate boundaries of the radioactively hazardous zone, an ORTEC semiconductor gamma spectrometer with a detector made of extremely pure germanium GEM-40 and a low-background liquid scintillation alpha-beta spectrometer HIDEX SL-300 were used.

Artificial radionuclide ^{137}Cs and natural radionuclides such as ^{212}Pb, ^{214}Pb, ^{214}Bi, ^{228}Ac, ^{232}Th were found in soil and vegetation samples from both sites of the UNE. The ^{241}Am, traces of ^{60}Co were found in samples from the “Kraton-3” locality. The values of the specific activity of ^{137}Cs in soil samples from the “Craton-3” explosion sites exceed the permissible levels by more than 10 times. The obtained values for the volumetric activity of tritium in water samples from both localities correspond to background values, taking into account the influence of thermonuclear reactions on the Sun, generating tritium rain for northern latitudes. According to 2004 data, the value of the exposure dose rate (EDR) in the area of the “Kraton-3” nuclear power plant reached 1.6 mSv/h [2], and as a result of dosimetric measurements carried out during the 2023 expedition, the maximum value of the EDR turned out to be 1.2 mSv/h. I.e., the EDR exceeds the value of the EDR of a safe gamma background by 2.5 times in the area of the Kraton-3".

Thus, currently there is a high level of radiation pollution in the area of "Kraton-3 unlike "Crystal which may be explained by insufficient rehabilitation work. In the nearby regions from the area "Kraton-3 the incidence of malignant neoplasms (MN) and mortality from them are higher than the average for RS(Ya). Perhaps the increase in MN is a long–term consequence of emergency UNE - additional dose loads leading to an increase in MN. The results of this study, in conjunction with the level of heat, can be considered as a basis for recognizing the need to develop recommendations and regulations as measures to comply with radiation safety when conducting similar tests in the future and during mining with the release of radionuclides to the surface.

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PERFORMANCE OF THE MASS TESTING SETUP FOR ARRAYS OF SILICON PHOTOMULTIPLIERS IN THE TAO EXPERIMENT

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Modern neutrino physics detectors often employ thousands, and sometimes even hundreds of thousands, of Silicon Photomultipliers (SiPMs). The TAO experiment is a notable example that utilizes a spherical scintillator barrel with a diameter of 1.8 meters, housing approximately 130,000 SiPMs organized into 4,100 tiles. Each tile with size of 5×5 cm^2 consists of a 32-SiPM array functioning as a single detector unit. To achieve an unparalleled energy resolution of 2% at 1 MeV within this volume, the SiPMs must possess cutting-edge parameters, including a photon detection efficiency (PDE) exceeding 50%, cross-talk of approximately 10%, and an extremely low dark count rate (DCR) below 50 Hz/mm^2. Maintaining the setup at a negative temperature of -50°C is necessary to achieve the desired DCR. This talk presents the setup and methods employed to individually characterize the mass of SiPMs across all 4,100 tiles at the specified negative temperature.

THE DEVELOPMENT OF CRITERIA FOR EXPRESS DETERMINATION OF TYPES OF ORE MINERALIZATION BASED ON GAMMA-SPECTROSCOPIC ANALYSIS OF THE CONTENTS OF ^{238}U, ^{232}Th, POTASSIUM

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Gamma-spectroscopic studies of the contents of ^{238}U, ^{232}Th, potassium and the values of their indicator ratios are considered as an express method for classifying rocks to a particular type of ore mineralization. Approbation of work on the identification of ore zonality of the Riphean and Neogene-Quaternary formations of Southern and Middle Timan by gamma-spectroscopic parameters in combination with the associations of elements was carried out in the subsurface areas named Verkhneukhtinsky and Bobrovy, as well as in the adjacent territory. As a result of the investigation of core samples using a gamma spectrometer with a highly sensitive germanium detector, a number of values characterizing certain types of mineralization in terms of contents in g/t were obtained, which were recalculated from the experimentally obtained values of activities of ^{238}U, ^{40}K and ^{232}Th [1]. A variety of mineralization types and characteristic associations of related elements were obtained from the results of core research using the following methods: X-ray fluorescence method, X-ray spectral method, semi-quantitative spectral analysis, method of mass spectrometry data with inductively coupled plasma (ICP MS). The comparisons made it possible: firstly, to detail the values of relation of uranium to thorium proposed earlier as determining values in relation to sections of Riphean strata revealed by wells; secondly, to establish measurement ranges of the indicator uranium-thorium relation U/Th corresponding to certain types of mineralization; finally, thirdly, these comparisons made it possible to propose a new indicator - the uranium–thorium relation, normalized for potassium (U/Th/K) and to determine the ranges of changes in its values for different types of mineralization.

The greatest differences in the contents and values of the indicator relations of U/Th indicator were found for rare-earth mineralization in the zone of volcanism development and in the zone of carbonatite development. In the first case (volcanism), minerals with a phosphate group (monazite) predominate, and in the second case (carbonatites), minerals with a carbonate group (bastnesite) predominate. It has been established that ore specialization is due to the superimposed influence of fluids of different compositions: for example, rocks with superimposed CO2 influence differ in the highest values of the uranium-thorium relation and the values of the same relation normalized for potassium. The inflow of ore matter in the form of fluids with hydrogen sulfide (sulfide mineralization) is characterized by average values of U/Th indicator and U/Th/K indicator. At the volcanogenic (explosive) source of the substance, the lowest values of the U/Th indicator and the U/Th/K indicator were noted, which is associated with an increase in the content of thorium and potassium. It is precisely this distribution that is associated with the differentiated nature of the inflow from the bowels of ^{238}U, ^{232}Th and ^{40}K, which, in our opinion, determines the universal character of the above gamma-spectroscopic criteria for ore mineralization and depends, presumably, on the composition of ascending and/or migrating fluids through the strata.

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CONTRIBUTION OF PHOTOELECTRIC EFFECT TO THE DOSE ENHANCEMENT FACTOR IN PHOTON ACTIVATION THERAPY

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Radiation therapy is fundamental method for treating cancer, however depositing precise dose to the target and preventing damage of vitally important healthy tissue surrounded by cancer cells remains challenging. Potential solution for this might be to inject high-Z containing elements into a tumor just before radiation therapy. In our research, we quantitatively evaluated the potential of biocompatible elements with different atomic numbers (Z) to act as radiation dose enhancers. Among these, Ag utilized in the form of nanoparticles to robust antimicrobial properties. Ag nanoparticles exert their antimicrobial effects through multiple mechanisms: they disrupt microbial cell membranes, induce apoptosis, and exhibit synergistic effects when combined with other antimicrobial agents. Sm in the form of a pharmacological drug (^{153}Sm preparations) have been used for a long time in the radiation therapy of metastases. Gd contrast agents, as Magnevist; Au nanoparticles are useful for contrast imaging, drug delivery, or radiation therapy enhancement. Bi metallic nanoparticles having preclinical proofs for theranostic applications [1-3].

Evaluating the contribution of the photoelectric effect to the dose enhancement factor (DEF) is calculated via the analytical approach developed in [4]. The photoelectric effect depends on the accumulation of radiosensitizer nanoparticles with a certain concentration and nanoparticle dimensions on the surface of the cells. The X-ray spectrum is generated by SpecPy, a tool for modeling X-ray tube spectra in [5]. The calculation is derived by taking into account the interaction of Ag, Au, Bi, Gd, and Sm nanoparticles with incident photons produced by the X-ray tube (1 mA current, 100 kV voltage, 3 mm thick aluminum filter, rhodium anode (W) with a 12° angle, and a 1 m distance from the tube focus).

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PROSPECTS AND DIRECTIONS FOR IMPROVING RADIATION STERILIZATION TECHNIQUES

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Sterilization is an essential process to ensure the integrity and safety of bone materials, regardless of whether they are used in medical procedures, in solving forensic tasks, or in conducting research on fossil fragments. However, the use of "monomethods such as chemical treatment and even radiation, is not always effective, unlike the use of two-stage combined radiation sterilization methods.

At the first stage of combined radiation sterilization, methods such as chemical treatment, microwave exposure, sterilization with an ozone-oxygen mixture, etc., can be used, depending on factors such as the type and level of initial contamination. After completing the first stage of sterilization, the samples are subjected to a second stage using radiation exposure. Radiation sterilization is effective for eliminating microbial contamination and residual biological load preserved after the first stage [1].

The choice of the type of radiation exposure is crucial to provide the safety and effectiveness of bone implants. Factors to be considered include the type of radiation (e.g. gamma radiation or electron beam treatment), the dose required to achieve the desired level of sterilization, and any potential impact on the physical and mechanical properties of implants.

Choosing the appropriate methods at each stage of combined sterilization is an important step in ensuring the quality of bone implants. Taking into account the specific requirements for each sample and the optimal sterilization options will ensure the manufacture of implants according to the highest standards of safety and efficiency.

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APPLICATION OF COMBINED RADIATION TECHNOLOGIES FOR STERILIZATION OF CULTURAL HERITAGE ARTIFACTS

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A set of studies was carried out to establish patterns of changes in the surface characteristics of bone materials as a result of combined sterilizing effects. The results confirmed the possibility of using a combined technique of radiation sterilization of biological tissues for processing tissue samples of fossil biological objects such as mammoths and other ancient animals. Consecutive treatment of bone fragments at the first stage with an ozone-oxygen mixture of low concentration and ionizing radiation with a relatively low absorbed dose at the second stage makes it possible to achieve the required degree of sterility while maintaining the original morpho-mechanical characteristics of the treated objects.

Exposure to ozone at the first stage of the combined sterilization process does not lead to morphological changes in the surface, mechanical properties, or characteristics of bone collagen. The oxygen content increases significantly, which in turn helps to increase the efficiency of radiation exposure at the second stage of sterilization, and, consequently, to further reduce the dose load. Thus, the synergistic effect of exposure occurs due to the effective weakening of the pathogen population and a decrease in their radioresistance under ozone exposure, which enhances the subsequent effect of radiation.

Combined (ozone + radiation) exposure at an absorbed dose of 12 kGy does not lead to significant changes in the collagen content in bone tissue. Noticeable changes in collagen content were recorded at high (20 kGy) values of the absorbed dose during radiation exposure.

The results obtained open up the possibility of using a new promising method for processing biological samples of ancient animals, ensuring the minimum possible changes in their structure, properties and characteristics, and establishing optimal parameters for the sample sterilization process. This technique can be used in the future to work with various samples of fossil biological objects.

EVOLUTION OF THE NEUTRON SPECTRUM DURING PROPAGATION OF THE NEUTRON FLUX IN SOLID BODIES

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The results of numerical modeling of leakage spectra, diffusion time and absorption spectra during propagation of neutron fluxes in solid bodies are presented. The spherically symmetric task of neutron flux diffusion from a central source to the outer surface of spheres, made of various materials, is reviewed. The simulation was carried out using the Monte Carlo method with ABBN-78 neutron group constants.

The task was carried out within the framework of modeling the spectrum of a tungsten-water proton beam target of the pulsed neutron source RADEX,which is used as a proton beam target of the INR RAS proton linear accelerator. Modeling was carried out in order to determine the effect of the target material choice on the neutron spectrum, value of neutron flux and it's diffusion time. Possibility to reconstruct capture spectrum, using experimentally measured leakage spectrum, is discussed.

DOSIMETRIC ANALYSIS OF THE VVR-SM RESEARCH REACTOR WITH ENHANCED MONTE CARLO TECHNIQUES

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This study presents a comprehensive simulation of the dosimetry for the VVR-SM research reactor of the Institute of Nuclear Physics in Tashkent[1], utilizing the Monte Carlo code OpenMC [2]. The simulation incorporates advanced modeling techniques including detailed geometric configurations, material specifications, and source term definitions that closely mirror the operational characteristics of the reactor. To enhance the accuracy and efficiency of our simulations, sophisticated variance reduction techniques such as importance mapping, weight windows, and particle splitting/russian roulette were applied.

The simulation framework was rigorously tested for convergence and accuracy, comparing computed results against available experimental data to validate the model. Our results provide critical insights into the neutron flux distribution, reaction rates, and radiation transport within the reactor, contributing valuable data for safety analysis and operational planning.

This work details the methodology employed in constructing the reactor model, the computational strategies to handle the complex neutron transport phenomena, and the analysis of dosimetric parameters critical for reactor safety and research applications. The findings demonstrate the potential of advanced Monte Carlo simulations in enhancing the understanding and management of nuclear reactor operations.

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DOSIMETRIC PLANNING OF RADIATION TREATMENT OF BIO-OBJECTS AND MATERIALS

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Today more than 70 countries of the world have industrial centres of radiation sterilization of food products and medical devices [1]. Compared to classical approaches, radiation sterilisation has a number of advantages: ionising radiations suppress microorganisms more effectively, the temperature of products does not change during processing, and they can be processed immediately in the package (which excludes the possibility of re-contamination). Today, when planning radiation treatment, all attention is focused on the integral released dose [2, 3], while recent studies [4 - 6] show that the efficiency of radiation treatment also depends on the nature of its distribution over the volume of the object.

The integral absorbed dose is unambiguously determined by the amount of delivered radiation and can be easily measured in practice (e.g., using dosimetric films or alanine dosimetry). The nature of the volume distribution of absorbed dose depends on several factors, including the type of radiation, the shape of the object and the energy spectrum of the beam. In order to take all these factors into account when planning radiation treatment, computer modelling is used [7]. And if the type of radiation and the shape of the treated object are reliably known, the exact energy spectrum of the beam is unknown and difficult to measure in practice. Replacing the exact spectrum by the "effective energy"can lead to an error of up to 20% in the estimation of processing uniformity.

In this paper, we propose a method for recovering the energy spectrum of an electron accelerator beam from the experimentally measured depth distribution of the dose produced by the beam. To implement the algorithm, the depth distributions of absorbed dose in various reference materials under irradiation with monoenergetic beams of accelerated electrons with energies from 100 keV to 20 MeV with a step of 100 keV are pre-calculated using the Geant4 software code [8, 9]. Experimental verification of the algorithm was carried out on the Varian TrueBeam medical electron accelerator in the radiosurgery and radiotherapy department with a day hospital at the Burdenko Neurosurgery Centre, operating in the 6 MeV and 9 MeV modes. The depth dose distributions in aluminium, water and polymer RW3 Slab Phantom were measured. The spectra reconstructed from the measured distributions showed agreement with each other, the discrepancy was not more than 5%.

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OPTIMIZATION OF RADIATION SHIELDING FOR SMALL MODULAR REACTORS (SMRs) USING OpenMC

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In the pursuit of advancing nuclear energy technology, Small Modular Reactors (SMRs) present a promising pathway due to their potential for scalability and reduced on-site construction risks [1]. However, the design and optimization of effective radiation shielding remain critical to ensuring safety while minimizing costs and material usage [2]. This study introduces a comprehensive shielding optimization analysis for SMRs, utilizing a Monte Carlo-based simulation approach. A three-dimensional and precise modeling of the source term, reflecting the actual conditions of the SMR core is conducted. Utilizing the Monte Carlo calculation code OpenMC [3], enhancement calculations of the radiation shielding systems of SMRs have been performed.

This approach facilitates the fine-tuning of the thickness of various shielding layers, which are specifically engineered to mitigate the mixed-radiation fields of neutrons and gamma rays emitting from the reactor. The core of the optimization effort in this work focuses on achieving a shield design that is both compact and lightweight, thereby reducing material use and cost while maintaining structural integrity.

Additionally, the optimization calculations have been evaluated to ensure compliance with existing safety standards, particularly through normalized dose rate assessments. The results highlight the effectiveness of the method in optimizing shield thickness across different layers, thereby setting a new benchmark in SMR shielding solutions that harmonize safety, efficiency, and economic viability.

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DOSES OF INTERNAL HUMAN RADIATION FROM RADON DURING HEATING OF RESIDENTIAL BUILDINGS WITH NATURAL GAS IN THE CONDITIONS OF THE NORTH

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Some sources contain information [1,2] that natural gas may contain radon, but there are no detailed studies of the emission of radon from network natural gas, and this problem of radon emanation from natural gas is of important practical importance in connection with the implementation of the gasification program for populated areas points of Yakutia [3]. Radon is one of the main causes of cancer, including most often lung cancer. Studies conducted in different countries have shown that even low concentrations of radon detected in residential areas create health risks and contribute to the development of lung cancer. It is known, that prolonged exposure to radon with an average concentration increased by 100 Bq/m^3 increases the likelihood of developing lung cancer by 16% [4]. This paper presents the results of experimental studies of equivalent equilibrium volumetric activities (EEVA) of radon ^{222}Rn and maximum annual dose loads for the heating season (from September to May) in residential premises of the city of Yakutsk, the central regions of the Republic of Sakha (Yakutia). The measurements were carried out using radon radiometers RRA-01M-03 and Alpha Guard PQ2000. Calculation of the individual annual effective dose of internal irradiation of residents of a populated area due to short-lived daughter products of radon isotopes in the air is carried out according to the data of measurements of EEVA of radon isotopes ^{222}Rn in indoor and outdoor air using the following formula [5]:

$$E_{internal.Rn} = 9.5 \cdot 10^{-6} \left(0.2 \cdot EEVA_{outdoor} + 0.8 \cdot EEVA_{indoor}\right), \mathrm{mSv/N},$$

where 9.5×10^{-6} is the dose coefficient (in units (mSv·m^3)/(hour·Bq)); t – number of hours in one month; 0.2 and 0.8 – the proportion of time spent indoors and outdoors, respectively; if there are no $EEVA_{out}$ values for the outside air on the territory of a populated area, then for calculations of radiation doses it is necessary to take $EEVA_{out} = 6.5$ Bq/m^3 in accordance with data on the world average $EEVA_{out}$ values of radon isotopes in the ground layer of atmospheric air, N is the number of months of the heating season ($N = 9$ months).

The EEVA of radon for a nonequilibrium mixture of short-lived daughter decay products in the air is calculated using the following formula [6]:

$$EEVA_{Rn} = VA_{Rn} \cdot F$$

where VARn is the volumetric activity of radon, F is the equilibrium coefficient between radon and its decay products, which can take values from 0 to 1. In the absence of experimental data on the average value of this coefficient, F=0.5 is taken.

The table provides examples of the results of calculated dose load readings depending on the season.

Table. Dose loads

Locality	Gas boiler type	VA_{Rn}, $\frac{Bq}{m^3}$ (max, value)	$EEVA_{Rn}$, $\frac{Bq}{m^3}$ (max, value)	$E_{internal.Rn}$, mSv/N
Yakutsk, three-story residential building	Rinnai (made in Japan)	205 ± 50	102.5 ± 25.0	5.2
Oy village, Khangalassky ulus	Wolf (made in Germany)	126 ± 36	63.0 ± 18.0	3.2
Oy village, Khangalassky ulus	AOGV (made in Russia)	229 ± 53	114.5 ± 26.5	5.7
Oy village, Khangalassky ulus	KSG-10 (made in Russia)	73 ± 24	36.5 ± 12.0	1.9
Oy village, Khangalassky ulus	KSG-7 (made in Russia)	103 ± 32	51.5 ± 16.0	2.6

To assess the possibility of an increase in radon concentration due to emanation from the soil, the release of radon from soils selected from the subfloor of houses was measured using semiconductor gamma spectrometry and using a test chamber. Measurements have shown that radon emanation from the underground (24 Bq/m^3) makes an insignificant contribution to the concentration of radon in residential premises.

The results of the studies show that the dose load from radon does not exceed the permissible value (10 mSv/year). Basically, the obtained values of $VA_{Rn} > 200$ Bq/m^3 and $EEVA_{Rn} > 100$ Bq/m^3 exceed the standard values that are recommended for residential premises under construction. As can be seen from the examples of results shown in the dose load table, there is a dependence of VARn and EEVARn on the types of boilers: dose load readings correspond to standard values only in the case of using Russian-made KSG-10. In accordance with the data obtained, EEVA values may depend on several factors, such as ventilation systems, thermal insulation, on which the volume of gas used depends, on types of boilers, etc. Thus, there is a need to control EEVA in residential premises to prevent dose loads from radon and take measures to reduce them at different stages: 1) ventilation systems during construction; 2) commissioning of a gas heating system. To achieve this, uniform standards must be adopted based on research such as this work. In addition, the high dose rates presented in this work may be the reason for the increase in the level of malignant neoplasms in the localities in which these studies were conducted since the time of their gasification.

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DETERMINATION OF THE PARAMETERS OF PROTOTYPE OF "GAMMA" INSTALLATION AT THE IREN FACILITY

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On the flight bases of the 4th (11 meters) channels of the IREN facility, neutron flux density measurements were performed in the neutron energy range from 0.4 eV to 1500 eV. The neutron fluxes (thermal and resonance) were determined using gold foils. The parameters of the resolution function have also been determined and their values, obtained from experimental measurements for several neutron energies, are in good agreement with the calculations.

MEASUREMENT OF THE PHOTO-PEAK EFFICIENCY AND COVARIANCE ANALYSIS OF γ-RAY DETECTORS OF TANGRA PROJECT USING ^{22}Na, ^{60}Co, ^{133}Ba, ^{137}Cs, ^{152}Eu, ^{228}Th AND COMPARISON WITH THE GEANT4 AND MCNP SIMULATION

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Conducting thorough research on the inelastic scattering of 14.1 MeV neutrons on atomic nuclei using the tagged neutron technique is the main objective of the TANGRA project at the Frank Laboratory of Neutron Physics (FLNP) of the Joint Institute for Nuclear Research (JINR) in Dubna, Russia [1,2,3]. We tested the respective photo-peak efficiency of the HPGe and LaBr3(Ce) gamma-ray detectors in a recently built experimental facility as part of this ongoing programme of study. We have conducted our experiment with some common gamma-ray radioactive point sources such as ^{22}Na, ^{60}Co,^{133}Ba, ^{137}Cs, ^{152}Eu, and ^{228}Th. Furthermore, we used the GEANT4 code to do Monte Carlo (MC) simulations in order to determine these efficiencies. The simulations showed that the outcomes of the Monte Carlo computations and the experimental data agreed rather well. Our study results might be helpful for scientists using HPGe and LaBr3(Ce) detectors for gamma-ray spectroscopy, as well as for processing and analysing data collected during TANGRA project tests [4,5]. The agreement between our experimental data and the Geant4 (MC) simulation result is excellent. We have also compared our results with others' data and MCNP result and found our results are more consistent. The propagation of error or micro-correlations takes into account various sources, including source activity, gamma ray abundance, gamma ray counts, and the half-life of radioactive nuclides. These correlations are thought to be the source of covariance information for the efficiency of the HPGe and LaBr3(Ce) detectors at various γ-ray energies. This study aims to provide a thorough analysis of photo-peak efficiencies together with covariance matrix data. In many different domains, such as nuclear physics, environmental science, medicine, geology, archaeology, and more, gamma-ray spectroscopy is an essential analytical method.

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NEW BEAM DYNAMICS SIMULATION FOR THE UPDATED COIL DESIGN OF MSC230 CYCLOTRON FOR MEDICAL-BIOLOGICAL RESEARCH

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JINR is conducting development of the isochronous cyclotron MSC230 for the new JINR's international biomedical research center, which will be the successor of the medical beam line of currently discontinued Phasotron. The project is entering the production stage. The latest compatibility checkup of the systems showed that the current distance between coils is not sufficient for the insertion of the systems of internal elements' operation. Therefore, the coil distance was increased, that heavily affected magnetic field and required its reshape. This talk concerns the peculiarities of field correction and results of proton beam tracing from ion source to the extraction from cyclotron.

STUDY OF THE YIELD OF POSITRON EMITTERS AFTER IRRADIATION WITH 100 AND 200 MeV PROTONS OF NATURAL CALCIUM TARGETS

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The most powerful means of achieving high conformality dose distributions is currently proton therapy. It allows a significant reduction in radiation exposure to normal tissues compared to traditional photon beam radiotherapy methods. This can be achieved even when the target is close to critical body structures. The energy of the beams used in proton therapy is in the range of 50–300 MeV. This range of proton energies corresponds to a Bragg peak depth of ∼3–30 cm and is determined by the possible depth of the tumour in the patient's body. Traditionally, analytical calculations of the dose rate neglect the contribution of nuclear reactions on the accelerated protons. However, the interaction of protons of such energies with light nuclei in biological tissue produces a large number of radionuclides that decay by emitting positrons. According to some estimates, they can increase a patient's dose by more than 20% [1].

We have investigated the activity yields of ^{34m}Cl ($T_{1/2} = 32$ min) and ^{38}K ($T_{1/2} = 7.6$ min) when irradiating natural calcium targets with accelerated protons of energies of 100 and 200 MeV. The irradiation was performed at the Prometheus proton therapy complex of the Physical-Technical Center, Lebedev Physical Institute of the Russian Academy of Science. The irradiated targets were measured using Ortec and Canberra semiconductor spectrometers with ultrapure germanium detectors having an energy resolution of 1.8–2.0 keV for 1333 keV ^{60}Co gamma radiation. The detection efficiency of the spectrometers was determined using standard calibration sources ^{152}Eu, ^{226}Ra, ^{137}Cs.

The gamma transitions accompanying the decay of ^{34m}Cl and ^{38}K were reliably determined in the measured gamma spectra. For 100 MeV protons, the cross sections of these processes were found to be (σ^{nat}Ca(p, XpYn)^{34m}Cl)=6.5±0.6 mbn, (σ^{nat}Ca(p, 2p1n)^{38}K)=9.3±1.0 mbn. For protons with energies of 200 MeV, the activity ratios of ^{34m}Cl and ^{38}K were found to be similar within the measurement error.

The activity yields of ^{34m}Cl were (3.1±0.2)10^{-8} Bq/proton for 100 MeV and (3.2±0.2)10^{-8} Bq/proton for 200 MeV. The results are discussed.

ТРАНСМУТАЦИЯ ^{99}Tc ПРИ ВЫСОКИХ ЭНЕРГИЯХ

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Ранее авторами были выполнены экспериментальные и вычислительные работы на синхроциклотроне ПИЯФ, в которых были определены нейтронные потоки для различных объемов замедлителя (легкой воды) [1], предварительно были проведены численные расчеты нейтронных полей в программном пакете PHITS. Также был проведен эксперимент по трансмутации ^{241}Am. Работа по трансмутации технеция является продолжением этих работ. Основная цель работы продемонстрировать преимущество использования нейтронов высоких энергий для объемных образцов.

Имеющаяся на синхроциклотроне ПИЯФ внутренняя свинцовая мишень позволяет получить потоки нейтронов с энергией до 1 ГэВ, а при помощи различных конфигураций замедлителя можно получить в разных точках пространства потоки с разным энергетическим спектром и интенсивностью.

На рисунке 1 приведена схема численного эксперимента, а в таблице 1 приведены расчетные количества продуктов для каждого из образцов при облучении свинцовой мишени (параллелепипед 102) протонами: ток 2,5 мкА, время облучения 24 часа.

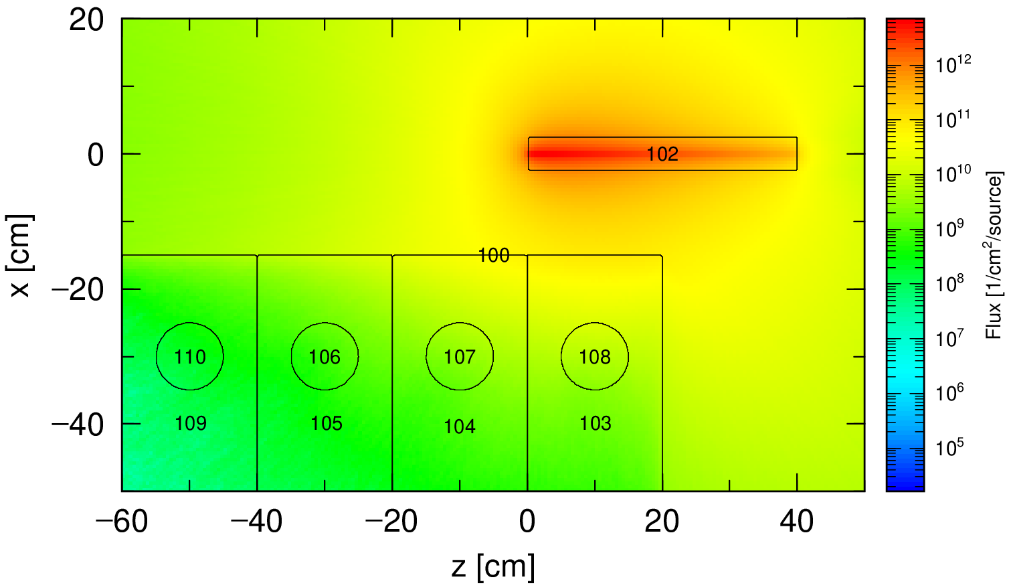

Рис. 1 Результаты расчета транспорта нейтронов в виде 2D графика для энергий от 100 кэВ до 1 ГэВ

Таблица 1. Расчетное количество продуктов реакции для 4-х объемных мишеней из ^{99}Tc (сферы 110, 106, 107 и 108) — число образовавшихся атомов

Облучение	**Мишень**	**Продукт**	**110**	**106**	**107**	**108**
+	Чистый ^{99}Tc	^{99}Ru	6.30×10^{14}	6.30×10^{14}	6.31×10^{14}	6.36×10^{14}
		^{100}Ru	2.19×10^{15}	1.00×10^{16}	4.36×10^{16}	8.26×10^{16}
	Tc+полиэт.	^{99}Ru	1.08×10^{14}	1.08×10^{14}	1.09×10^{14}	1.09×10^{14}
		^{100}Ru	1.66×10^{15}	7.6293×10^{15}	3.35×10^{16}	6.44×10^{16}

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ASSESSMENT OF SOME UNACCOUNTED CONTRIBUTIONS TO THE ABSORBED DOSE DURING RADIATION THERAPY

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Radiation therapy is widely used in the treatment of various types of cancer today. However, a number of factors are not taken into account at the planning stage of radiation treatment. This may be the reason for the additional dose load on the patient.

When medical electron accelerators operate at energies above 8 MeV, fluxes of secondary neutrons can be generated. The contribution to the dose from secondary neutrons is not estimated and is not taken into account in modern planning systems. To evaluate this contribution, a computer model of the medical linear accelerator head, verified based on the depth dose distribution in water, is used. As a result of Monte Carlo simulation, spectra of secondary neutrons were obtained and their contribution to the absorbed and equivalent doses was assessed.

Secondary neutrons can also be produced on structural elements of proton accelerators and even in the patient's body during proton and hadron therapy. A simulation was carried out and an estimate of the additional dose load from neutrons produced on the modulator wheel of a proton accelerator was obtained. In addition, to assess the risks for personnel and accompanying personnel, the parameters of neutron radiation generated in the water phantom during irradiation with proton beams were calculated.

Another factor not taken into account is distortion of MR images. It can lead to radiation treatment not meeting the plan. As a result of various experiments on MRI machines with a magnetic field induction of 0.5 T and 1.5 T, the distortion of images of homemade phantoms was assessed. Based on the images obtained, a radiation treatment plan was constructed and compared with a similar plan based on CT images, and the unaccounted dose was assessed.

PROGRAM FOR QUICK CALCULATION OF ABSORBED DOSE DISTRIBUTION BY DEPTH IN HOMOGENEOUS OBJECTS

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The use of electron accelerators has become widespread throughout the world, becoming an integral part of scientific and technological development. Currently, accelerator-based installations are used not only in science, but also in medicine, industry, and agriculture. An important parameter for the efficiency of using accelerated electrons is the uniformity of the distribution of the absorbed dose over the volume of the object being processed. Therefore, the development of planning and quick calculation methods is relevant.

Despite the fact that the Monte Carlo method has become widespread for modeling the interaction of ionizing radiation with matter, its use has some limitations. To obtain accurate results and obtain satisfactory event statistics, computer simulation will be required, which can take from several hours to several days depending on the estimated power of the computer used.

It seems interesting to develop a program that allows, based on a database prepared using previously performed modeling, to obtain in a few seconds the distribution of the absorbed dose over depth in an object with a given size and density. Such a program will significantly reduce the planning time for scientific research in the field of application of accelerated electrons.

The goal of this work was to develop a program for calculating the depth distribution of the absorbed dose in a model phantom when irradiated by an electron beam with an energy spectrum in the range from 0.1 MeV to 20 MeV based on a database obtained through detailed modeling using GEANT4. A solution to the inverse problem has also been implemented, when using given distributions of the absorbed dose in water, plastic and aluminum it is possible to reconstruct the energy spectrum of the electron beam.

A comparison was made of the values of the distribution of the absorbed dose over the depth of the object obtained as a result of the created program with the values obtained by direct computer modeling using GEANT4. It is shown that the maximum deviation from the simulation results is no more than 3% over the entire range of energies, thicknesses and materials considered. At the same time, calculations using the developed program were performed on average in 2 seconds, while calculations using GEANT4 took about 7 hours using an average-power personal computer.

The research was carried out within the framework of the Development Program of the Interdisciplinary Scientific and Educational School of Moscow University “Photon and Quantum Technologies. Digital medicine".

TECHNOLOGICAL STATE AND PROSPECTS OF PRODUCTION OF MODERN X-RAY DIAGNOSTIC SYSTEMS

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The report is devoted to the general review of technologies and prospects of development of modern X-ray diagnostic devices. In the course of progressive qualitative movement of scientific and technological progress there is a development of technologies and improvement of medical equipment, which certainly has a positive impact on the development of world medicine in general and domestic medicine in particular. Research and innovations in the field of medical equipment contribute to the development of X-ray diagnostic systems. Among the main areas of development are: achieving more accurate diagnostics, increasing resolution, improving image quality while minimising X-ray dose, automation and introduction of artificial intelligence and machine learning technologies, improving ergonomics and functionality of X-ray diagnostic systems.

Structurally, a typical X-ray diagnostic system is a single independent product developed on the basis of X-ray diagnostic apparatus with a teleoperated table-tripod for standard and special X-ray diagnostic examinations in the modes of radiography and fluoroscopy.

The basic principle of operation of a typical X-ray diagnostic system is as follows: the X-ray power supply unit (PSU) supplies power to the X-ray emitter unit with the X-ray tube, as a result of which the X-ray tube generates braking ionising X-ray radiation in the direction of the patient located on the tripod table. Thanks to the collimator, the X-ray radiation is geometrically corrected for the size of the field and is directed towards the patient's anatomical region to be examined. After the X-rays pass through the patient's body, the X-rays reach the detector inside the tripod table and are converted into electrical signals, which are then processed by a digital computer station to form a clinical image. The tripod table is rotatable, which allows the patient to be examined in various inclined positions, and is remotely controlled (i.e. teleoperated), allowing medical staff to stay in the control room to avoid exposure to ionising radiation. Clinical images are visualised on monitors. Thanks to the laboratory technician's automated workstation (AWS), the images can be edited, archived and transmitted over the network in DICOM format to the PACS system or to the hospital intranet.

Currently, there is a tendency to develop the technological side of X-ray diagnostic devices, for example, the creation of a new generation of X-ray tubes for projection radiography. Clinical practice of the past years has shown that for successful implementation of the projection radiography method the size of the focal spot of the used X-ray tubes should not exceed 0.1 mm or 100 µm. According to GOST 22091.9-86 such X-ray tubes belong to the class of microfocus tubes. Long-term studies have shown that in case of using microfocus X-ray tubes a number of peculiarities (effects) appear during X-ray image formation. The main ones are: the effects of increasing the depth of field and contrast, the effects of pseudo-volume image and phase contrast, the effect of reducing the exposure dose. However, due to the limited power supplied to the target of a microfocus X-ray tube by an electron beam of small cross-section, the intensity of the radiation generated by it is small in comparison with a "conventional"X-ray tube. This significantly limits the scope of application of microfocus radiography in such socially important areas of medical diagnostics as angiography, mammography, fluorography, tomography, etc. The intensity of radiation can be increased both by increasing the tube current and the tube voltage, so both directions were used in the development of a new generation of microfocus X-ray tubes [1].

The problem of performing X-ray diagnostic studies in non-specialised settings, such as at the patient's home, should be highlighted separately. Obviously, it is impossible to use traditional stationary X-ray devices in the home. Accordingly, the issue of ensuring radiation safety for the personnel conducting the study and for others who may also be involved in the study, for example, when laying the patient, becomes important. However, it is practically impossible to use special means of protection from unused X-ray radiation - screens, booths, etc., as well as to remove the surrounding people to a safe distance at home. Therefore, it is necessary to apply such techniques of X-ray imaging that will significantly reduce the exposure dose of radiation in comparison with imaging with stationary devices. In this case, it is extremely important to obtain image quality of the examined organ, necessary and sufficient to make a decision on the presence or absence of pathology.

The diagnostic efficiency of portable chest radiography (defined as the number of chest radiographs showing new findings or changes in known findings divided by the total number of chest radiographs) for patients admitted to the ICU is 84.5%. These conclusions were reached by Palazzetti V. et. al, (2013) in a study of the effectiveness of mobile radiography in the ICU [2]. Portable technical means in radiography are now also proposed for use in dental practice [3,4].

When using 'hand-held' X-ray machines, there is a small increase in the dose level for X-ray laboratory technicians. However, the dose remains well below the recommended levels. The position of the machine relative to the X-ray technician has a significant effect on the total absorbed dose. The availability of individual dosimeters to monitor exposure levels is recommended. In addition, guidance, training and protocols for exposure levels should be available on site and strictly adhered to; regular checks are necessary to ensure that all regulations are being followed [5].

From the prospects of development of X-ray diagnostic devices, we can separately emphasise the direction of tomography and dual energy. In general purpose radiography traditional linear tomography allows to obtain layer-by-layer images of the object, but during one pass of the radiator only one slice is imaged. As a result, in case of necessity to obtain a layer-by-layer image of all lungs the procedure is performed not less than 10 times, which leads to significant increase of radiation load on the patient and duration of the procedure. Computed tomography method allows to obtain information about the whole volume of the thorax, but significantly increases the dose load on the patient [6]. Tomosynthesis technology is at the junction of linear and computed tomography (CT), combining high informativeness (compared to linear tomography) and low dose load (compared to CT). The use of modern tomosynthesis and dual-energy technologies makes it possible to significantly increase the informativeness of the examination and improve the diagnosis of pathology at early stages. The main advantage of these technologies is that they can be used on teleoperated tripod tables with a digital flat panel dynamic detector without significant modifications of the hardware, as well as on modern devices for two workplaces [7,8].

It is expected that the introduction of dual-energy and tomosynthesis technologies into medical practice will, in a number of cases, make it possible to eliminate the need for follow-up examinations in CT rooms. This will help to relieve CT rooms of routine examinations and provide access to them for more patients.

Based on the above, it can be concluded that the development of X-ray technology at the present stage should be assessed not as the final milestone of evolution, but as the transition of X-ray technology to a qualitatively new digital level, the potential capabilities of which are enormous.

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CHEMICAL TRANSFORMATIONS OF VOLATILE ORGANIC COMPOUNDS IN ANIMAL-DERIVED PRODUCTS AFTER IRRADIATION

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Radiation technologies are actively used to extend the shelf life of food products and ensure their microbiological safety [1]. However, radiation exposure can cause a variety of physicochemical and organoleptic changes in animal-derived products. This is caused by the intense oxidation of biomacromolecules, such as proteins and lipids, which can change the texture, color, and smell of meat [2]. The intensity of physicochemical processes occurring in biological objects can be assessed by the presence and concentration of volatile organic compounds (VOCs) [3].

This work of scientists from Moscow State University is aimed at identifying and analyzing the physical and chemical changes in products after their radiation processing. In this study, a series of of products - beef, turkey and salmon - was irradiate using the UELR-1-25-T-001 accelerator with a maximum energy of 1 MeV. Also, to explain the dose behavior of the concentrations of volatile organic compounds in products, a series of model studies were carried out on the irradiation of standard samples of volatile organic compounds - 1-hexanol. The concentrations of volatile compounds were determined using a gas chromatography-mass spectrometer Shimadzu GCMS-QP2010 Ultra (Shimadzu, Japan).

Based on the results of the study, a mathematical model was developed that describes the dependence of the concentrations of standard volatile compounds and VOCs identified in food products on the radiation dose.

It was found that aldehydes make it possible to assess how radiation affects the product's lipid and protein components. It has been established that ethanol may indicate a decrease in microbial enzymatic processes occurring in meat products during storage [4].

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OPTIMIZATION OF RADIATION TREATMENT OF BIOLOGICAL OBJECTS

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To meet the demands of irradiation centers and extend the range of biological objects which can be irradiated for different purposes, our research team has conducted a series of experimental studies to estimate the influence of irradiation parameters as well as physical and chemical properties of bio-objects on the irradiation efficiency. The study focuses on determining the criteria for choosing optimal dose range which would destroy pathogens while preserving essential molecules, such as proteins, lipids, and enzymes.

The study uses real-life objects, such as beef, turkey, chicken, salmon and trout, potato tubers, cereal and oil seeds as well as model objects, such as bacteria, fungi, phytopathogens, standard samples of volatile organic compounds and bovine serum albumin. The methodology of the research involves irradiation of bio-objects using the 1 MeV electron accelerator UELR-1-25-T-001 (SINP MSU, Russia) and X-ray apparatus DRON YM-2 with X-ray tube BSV 23 with copper anode and X-ray apparatus RAP 100-10 with X-ray tube 1BPV 23-100 with molybdenum anode (Burnazyan Federal Medical Biophysical Center of FMBA, Russia). Irradiation of bio-objects is simulated using GEANT 4 toolkit to estimate the dose uniformity and linear energy transfer (LET) throughout the objects in order to find the most effective irradiation method depending on the objective of irradiation and the distribution of irradiation parameters in the objects.

To determine the optimal dose range limits we applied current physical methods to investigate the biochemical and biophysical changes in biological objects after irradiation. Gas chromatography-mass spectrometry method was used to trace the change in the concentrations of volatile organic compounds in bio-objects since some of these concentrations are highly sensitive bio-markers of lipid, protein oxidation as well as bacterial activity in the irradiated objects. To estimate the change in the native structure of proteins we used high-performance liquid chromatography-mass spectrometry method with tandem mass spectrometric detection and spectrophotometric method for estimation of myoglobin derivative concentrations. Microbiological analysis of bio-objects was carried out to estimate the efficiency of suppressing pathogens by irradiation. The lack of cost-efficient express methods for detecting irradiated objects with a high-water content caused us to apply the kinetic fluorometric fingerprinting technique for recognition of irradiated and non-irradiated bio-objects.

The experiments involved pre-planting irradiation of seeds and root crops to assess the effect of irradiation on the growth and phytosanitary status of agricultural crops. The plants grown from irradiated seeds and root crops were planted and monitored at the experimental sites of the Siberian Federal Scientific Center of Agricultural-Biotechnology of the Russian Academy of Sciences to determine the optimal dose range limits for crops irradiation.

Following the experiments performed by our team it was established that the efficiency of irradiation of biological objects is determined as a function $F(D) = F(K1(D), K2(D), K3(D))$, where $K1$ is a value determined by the dose uniformity throughout the object and the dose needed to suppress pathogens to the required degree; $K2$ determines the fraction of pathogens which are suppressed in the biological object irradiated with a certain dose; $K3$ is radiosensitivity heterogeneity of pathogens across the statistical ensemble.

We have found clear dose and time dependencies of the concentration of lipid and protein oxidation aldehydes as well as the concentration of ethanol alcohol. With a higher irradiation dose ranging from 250 Gy to 10000 Gy a higher peak of lipid and protein oxidation derivatives is detected on day 1 and day 2 after irradiation. On the contrary, the higher the dose the lower ethanol content in biological objects during 4 days of storage after irradiation. Therefore, the concentrations of lipid and protein oxidation aldehydes can serve as markers of lipid and protein peroxidation, while the concentration of ethanol is a marker of efficiency of bacterial suppression as a result of irradiation. For example, when beef tenderloin is irradiated with 1 MeV electron beam with the dose rate of 4 Gy·sec–1, lipid and protein peroxidation is observed in the beef samples irradiated with the doses of 500–1000 Gy and higher, while in the beef samples irradiated with 250–350 Gy the ethanol concentration is 2 times lower than in the non-irradiated beef samples. Therefore, as dose and time dependencies of volatile organic compound markers suggest, the lowest limit of the optimal dose range is 250–350 Gy, and the highest limit is 500–1000 Gy.

The spectrophotometric method for calculating the metmyoglobin concentration in bio-objects containing myoglobin as well as the trypsin hydrolysis of the native structure of bovine serum albumin allow us to quantify the impact of electron beam and X-ray irradiation with different physical parameters, such as dose, dose rate, and the type of irradiation, on protein native structure.

Counting of viable cells in bio-objects after irradiation and assessment of the quantitative damage of protein native structure by irradiation show that the limits of the optimal dose range for beef tenderloin irradiated with 1 MeV electron beam with the dose rate of 4 Gy·sec–1 is 220-854 Gy assuming that the upper limit is determined by the myoglobin oxidation. At the same time, the optimal radiation dose range for beef is 204-755 Gy assuming that the upper limit is determined by the damage of protein native structure. Therefore, the dose ranges determined by measuring the number of viable cells in bio-objects and the damage of protein native structure align well with the ranges obtained by measuring the volatile compound concentrations.

Considering that the rate of indicator reactions involving carbocyanine dyes and oxidizing agents varies depending on physical and chemical properties of bio-objects, kinetic fluorometric fingerprinting technique, which measures the absorption spectrum and fluorescence intensity of extracts made from bio-objects, has proved to be the most suitable express method for recognition of non-irradiated and irradiated animal and plant biological tissues.

Our experimental studies allow to develop practical recommendations on how to improve the efficiency of the bio-object irradiation.

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MONTE CARLO SIMULATION TECHNIQUES IN RADIATION DOSIMETRY: ADVANCEMENTS AND APPLICATIONS

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Monte Carlo methods have revolutionized the field of radiation dosimetry by providing a robust framework for simulating the intricate interactions between ionizing radiation and matter. These methods, rooted in probabilistic sampling techniques, offer unparalleled accuracy and flexibility in modeling radiation transport, energy deposition, and dose distribution in diverse applications ranging from medical imaging to radiation therapy[1].

At the heart of Monte Carlo simulations lies the concept of random sampling, where individual interactions of photons, electrons, or other charged particles with tissues and materials are stochastically simulated. The trajectory of each particle is governed by the laws of classical or quantum mechanics, depending on the energy regime and particle type. The probability of interaction events, such as photoelectric absorption, Compton scattering, and pair production, is described by interaction cross-sections derived from fundamental physics principles.

The transport of particles through a medium can be described by the Boltzmann transport equation, which accounts for processes such as scattering, absorption, and production of secondary particles[2]. In a Monte Carlo simulation, the trajectory of a particle is tracked through successive interactions until it is either absorbed or exits the medium. The absorbed dose, defined as the energy deposited per unit mass, is calculated by tallying the energy deposited by all particles within a defined volume.

Validation and benchmarking of Monte Carlo codes are essential to ensure their accuracy and reliability in practical applications. This often involves comparing simulated results with experimental measurements and established dosimetric protocols[3]. By iteratively refining simulation parameters and adjusting models to better match experimental data, researchers can improve the fidelity of Monte Carlo simulations and enhance their predictive capabilities.

In summary, this review provides a comprehensive overview of Monte Carlo methods in radiation dosimetry, emphasizing their foundational principles, applications, validation techniques, recent advancements, and future prospects. By elucidating the role of Monte Carlo simulations in quantifying radiation dose distributions, this review aims to contribute to the ongoing dialogue surrounding radiation safety, treatment planning, and dosimetric accuracy in medical and industrial settings.

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МОДЕЛИРОВАНИЕ ДОЗНЫХ ПОЛЕЙ ГАММА-ЛУЧЕВОЙ ТЕРАПИИ ПОЛОСТИ РТА

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Актуальной задачей лучевой терапии является обеспечение требуемой (планируемой) поглощенной дозы – D тканями часто неконтролируемо смещаемого органа, в частности, языка. В работе получены оценки распределения значений поглощенной дозы D и их отклонений от плана в пределах 5%. Измерения выполнены с помощью пальчиков гаммы-камеры, тканеэквивалентного фантома из «твердой воды» формой соответствующей языку со средней электронной плотностью 0 HU, стоматологический фантом челюсти с электронной плотностью зубов 300 HU, болюс со средней плотностью – 4 HU.

Линейный ускоритель обеспечивал пучок энергии 6 МэВ, расстояние до изоцентра 100 см, отпускаемая доза 2 Гр. Кантри устанавливался при 270°, 315°, 0°, 45°, 90° градусов.

Полученные данные поля позволяют считать возможные отклонения от плана облучения не более 5%.

DESIGN OF NEW EXPERIMENTAL FACILITIES

MICROTRON BASED VEGA-M SPECTROMETER FOR STUDY OF THE SHAPE ISOMERS DECAYS

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In the series of experiments performed at the beam of the MT-25 microtron in FLNR, JINR, the break-up of fission fragments (FFs) while they pass a solid-state foil in the timing detector, placed at four meters from the actinide target was observed [1-3]. The results were obtained using the VEGA (V–E Guide based Array) setup. The FFs from photo-fission reactions were captured by an electrostatic guide system (EGS). The guide is a cylindrical capacitor of four meters long with a thin wire as a central electrode. Some part of the FFs were captured in EGS and transported to the time-of-flight mass-spectrometer at the opposite side of the guide, where the break-up of part of the FFs took placed. The mean time-of-flight of the FFs in the EGS exceeded 400 ns. The effect was treated as a break-up of the FF born in a long-lived shape isomer state at the stage of binary fission of mother nucleus in the target and was observed for the first time.

The main problem that was encountered during the experiment was the background noise from the accelerator. To radically improve the situation, a new VEGA-m project is underway. The guide of about 6 meters long will now be positioned vertically and therefore will enter the second floor of the microtron hall, passing about 2 m of concrete, which will protect from the radiation. Essential upgrade of both the spectrometer electronics and data processing is also being planned.

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IP VERTEXING – A NOVEL IDEA

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A new vertexing algorithm is presented, applicable to IP determination, based on the linear extrapolation of tracks in the vicinity of the IP. The algorithm considers the tracks as infinitely elongated ellipsoids, reducing the problem to the vertexing of a set of points of given ellipsoid error matrices. We have implemented the idea in C++, which works with our previously reported NXV4 package for vectors and matrices (available in JINRLIB).

MISALIGNMENT INFLUENCE ON THE TRACK RECONSTRUCTION IN THE MPD TPC

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A method of determining the position of the readout sectors of a time projection chamber using experimental data is proposed. Considering the results of modeling the response of sensitive elements of the time projection chamber of the multipurpose detector (MPD), three types of tracks were reconstructed: cosmic muons, beams of the laser detector system, and muons from the interaction of nuclei. The accuracy of the MPD TPC alignment finding is investigated in MC events with different types of tracks. For the Time Projection Camera, a measure of deviation of the used alignment from the real one is introduced. The simulation of track reconstruction shows the dependence of track parameter errors on the accuracy of knowledge of the real alignment of the detector. The found dependencies allow to correct systematic errors during track reconstruction.

ПРОЕКТ УСТАНОВКИ ДЛЯ ИЗУЧЕНИЯ ВЗАИМОДЕЙСТВИЯ БЫСТРЫХ НЕЙТРОНОВ С ЛЕГКИМИ ЯДРАМИ СО СПЕКТРОМЕТРОМ ПАР ЭЛЕКТРОНОВ И ПОЗИТРОНОВ

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Описан проект установки для исследования взаимодействия быстрых нейтронов с энергией свыше 1 МэВ с легкими ядрами ^{10}B, ^{11}B и ^{9}Be с вылетом ядра ^{3}H или ^{4}He и электрон-позитронной пары. Установка включает в себя позиционно-чувствительные детектор нейтронов на основе слоя с исследуемым ядром и пропорциональной камеры, постоянного дипольного магнита и позиционно-чувствительных кремниевых детекторов. Пространственная реконструкция событий позволит исследовать редкие внутриядерные процессы с рождением пар электронов и позитронов внутренней конверсии.

DETECTOR SETUP OPTIMIZATION BASED ON TRAINING ARTIFICIAL NEURAL-NETWORKS

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We apply artificial neural networks (ANN) to event-wise analysis of simulated data from a microchannel plate detector (MCP)[1] being considered for installation in future experiments on NICA collider [2]. We have demonstrated, that neural networks can estimate the parameters of the collision not only from spatial distribution of particles, but also benefit from high resolution time-of-flight distributions that can be obtained from MCP. From this data we estimate the impact parameter and the collision point of an event. We have performed the analysis based on several Monte-Carlo models of the event. Even though the quality of the existing event models is not sufficient for a reliable model-independent estimation of the event parameters, the proposed parameter reconstruction procedure allows us to evaluate - and to optimize - the technical characteristics of the detector. These characteristics include the geometry of the device, its placement, the number of sensors, and the time resolution.

In [3, 4, 5] we have demonstrated that – subject to the detector geometry – the collision point and the impact parameter of each event can be estimated quite accurately only from the raw detector data. Our approach exploits Monte-Carlo models of high energy collisions. As we have demonstrated in [3, 4, 5], the data from QGSM generator [6] allows us to estimate the impact parameter within an uncertainty of about 1 fm, and to reconstruct the collision point with uncertainty about 1 cm. This result, however, is model-dependent, and processing data from alternative generators [7, 8] leads to different ANN parameters. Despite this model dependence of the ANNs, the detector parameters providing the best reconstruction of the event parameters do not depend on the Monte-Carlo model of the event.

We report the results of ANN training and suggest the optimal MCP configuration which is model-independent and, thus, can be used in future detector specification.

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INTEGRATION OF THE HGND READOUT INTO THE BM@N EXPERIMENT DATA ACQUISITION SYSTEM

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The new high granular time-of-flight neutron detector (HGND) is being developed for the BM@N (Baryonic Matter at Nuclotron) experiment to identify neutrons and to measure their energies in heavy-ion collisions at ion beam energies up to 4 AGeV. The HGND consists of about 2000 scintillator detectors (cells) with a size of $40 \times 40 \times 25$ mm^3 and with individual light readout with EQR15 11-6060D-S photodetectors. The readout board with a 100 ps FPGA-based TDC (Time to Digital Converter) is currently under development. The HGND will have eight such readout boards, each comprising three Kintex 7 FPGAs for reading out 252 channels. The TDC operates on the standard LVDS 4x asynchronous oversampling and is synchronized with the experiment timestamp using the White Rabbit link. The two-channel TDC prototype demonstrates a time resolution of 42 ps. The FPGA-TDC principle of operation and tests results, readout board topology, and the readout software architecture will be discussed.

ИССЛЕДОВАНИЕ НАНОУГЛЕРОДНЫХ ЦЕНТРОВ СПОНТАННОЙ ЭМИССИИ НА КАТОДАХ МНОГОПРОВОЛОЧНЫХ ПРОПОРЦИОНАЛЬНЫХ КАМЕР МЮОННЫХ ДЕТЕКТОРОВ LHCB

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Практика работы экспериментов на Большом адронном коллайдере (БАК) показала, что основной проблемой эксплуатации многопроволочных пропорциональных камер (МПК) являются спонтанные самоподдерживающиеся токи (ССТ) [1,2]. Их появление вызывает либо аварийное отключение детекторов, либо понижение значений поданного на них напряжения, что приводит к уменьшению эффективности соответствующих детекторных систем.

Исследование МПК, работавшей в составе Мюонной системы эксперимента LHCb на БАК, где регулярно возникали ССТ показало, что причиной эффекта являются точечные центры эмиссии электронов на катодных плоскостях [3]. Причиной возникновения центров эмиссии оказалось образование на катодах МПК островковых наноструктур, включающих в себя углерод, фтор и кислород. Представленная работа демонстрирует сформировывавшиеся путем осаждения из газовой фазы на катоды МПК наноструктуры. Поиск и исследование центров эмиссии проводились путем последовательного применения методов атомно-силовой микроскопии, начиная с полуконтактных фазовых и топографических измерений, и заканчивая измерениями токовых характеристик на предварительно выделенных участках поверхности катода МПК.

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CRYOGENIC GAS STOPPING CELL TESTING WITH ALPHA SOURCE AND MONTE CARLO SIMULATIONS

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The new experimental setup for the high-precision mass measurement of the heavy and the superheavy nuclei is being built in the Flerov Laboratory of Nuclear Reactions (Dubna). The crucial part of the setup for stopping and thermalization of the reaction products is the cryogenic gas stopping cell (CGSC). The CGSC consists of the stainless steel outer and inner chambers. The outer chamber is at the vacuum pressure and works like the thermal insulation. It also reduces the radiation heat transfer to the inner chamber by the insulation foil. The temperature inside of the outer chamber is the room temperature (293 K). The inner chamber is filled by the helium buffer-gas and it is also platted from the outside by the copper for the homogenous distribution of the temperature. The inner chamber is cooled to the 40 K by the cryocooler. The set of the cylindrical and the conic electrodes are installed inside of the inner chamber. The isotopes for the testing of the CGSC is possible to get from the alpha source with the intensity below the minimally significant activity according to the radiation safety rules. There are stopped in the active volume of the inner chamber and guided by the electrical field to the supersonic nozzle and then extracted and filtered by the radio frequency quadrupole. The alpha source ^{227}Th decays by alpha decay to the ^{223}Ra, ^{219}Rn, ^{215}Po and ^{211}Bi. The measuring is performed at the pressure 50 Torr for the room temperature (293 K) and the 5 Torr for the 40 K. The simulations of the extraction time from the CGSC were performed. The internal software using the Monte Carlo method and based on the SRIM and the Geant4 was used in the simulations.

PERFORMANCE OF THE TIME-OF-FLIGHT SYSTEM AT THE BM@N EXPERIMENT

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The BM@N is the first experiment at the NICA accelerator complex. It is focused to study baryonic matter at high density which provides the opportunity to investigate both the EOS, and to explore the degrees-of-freedom of this matter, including the search for new phases of high-density matter. For the purpose of charged particle identification in the BM@N, two time-of-flight systems TOF400 and TOF700 are used. To perform particle identification, it is necessary to measure the time of flight as precisely as possible. To maintain the systems' good time resolution, a sequence of calibrations has to be done. Firstly, it is the calibration of the integral nonlinearity of TDC channels, secondly, it is cable length correction, thirdly it is geometry alignment of the system, then time-amplitude correction using Time-Over-Threshold method and finally "time shift" correction. The procedure for calibration and final performance of TOF400 and TOF700 systems will be presented.

ЭКСПЕРИМЕНТАЛЬНАЯ УСТАНОВКА ДЛЯ ПРЕЦИЗИОННОГО ИЗМЕРЕНИЯ ЗАРЯДОВОГО РАДИУСА ПРОТОНА

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Представлена экспериментальная установка для прецизионного измерения радиуса протона в упругом *ep*-рассеянии с регистрацией протона отдачи в активной водородной мишени в диапазоне по $Q_2 \sim 0.001$–0.04 GeV^2. Установка включает в себя активную водородную мишень – время-проекционную камеру (TPC – time projection chamber), разработанную для регистрации протонов отдачи, совмещенную в одном корпусе с высокоточным трекером рассеянных электронов на основе многопроволочных пропорциональных камер (MWPC – multiwire proportional chamber). Установка, работающая при давлении газов 20 bar, позволяет измерять в TPC угол и энергию отдачи протона одновременно с углом рассеяния электрона в MWPC. Одним из ключевых элементов эксперимента является трековая система MWPC, работающая в аргон/метановой смеси высокого давления. Трекер из восьми детекторов измеряет с высокой абсолютной точностью X и Y координаты трека электрона, а также формирует быстрые сигналы для триггерной системы. Результаты испытаний трекера и регистрирующей электроники приведены в докладе.

FRONT-END ELECTRONICS AND MECHANICAL DESIGN OF THE HGND FOR BM@N EXPERIMENT

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High Granularity (time-of-flight) Neutron Detector (HGND) is the newest addition to the BM@N (Barionic Matter (at) Nuclotron) experiment, designed to identify neutrons and to measure their energies in heavy-ion collisions at ion beam energies up to 4AGeV. This work covers the mechanical design, developed to host 2000 individual scintillatior cells with a size of $40 \times 40 \times 25$ mm^3, together with their readout electronics, data gathering equipment as well as power and monitoring devices. This work also includes a discussion on the design of the front-end analog electronics, responsible for photo-electronic conversion, based on the EQR15 series SiPMs, and implementation of the Time-over-Threshold (ToT) conversion.

ПРИМЕНЕНИЕ МИКРОСТРИПОВЫХ КРЕМНИЕВЫХ ДЕТЕКТОРОВ ДЛЯ ИССЛЕДОВАНИЯ РАСПАДОВ С ИСПУСКАНИЕМ ПРОТОНОВ

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Исследование различных механизмов распадов лёгких нестабильных ядер с испусканием протонов либо нейтронов представляет значительный интерес для современной ядерной физики, поскольку эти процессы пока мало изучены. Некоторые из них, такие как истинный четырёхпротонный распад, до сих пор не регистрировались в экспериментах.

Проект EXPERT (EXotic Particle Emission and Radioactivity by Tracking) является частью коллаборации SuperFRS (Super-conducting FRagment Separator) Experiment, который реализуется в рамках FAIR (Facility for Antiproton and Ion Research). Основной целью проекта является исследование малоизученных ядерных систем, находящихся вблизи границ нейтронной и протонной стабильности, а также изучение экзотических распадов, таких как испускание нескольких протонов или нейтронов. В рамках проекта EXPERT используются различные детекторные системы, включая кремниевые микростриповые детекторы FOOT (FragmentatiOn Of Target).

Одним из изотопов, который до сих пор не был обнаружен, является ^{7}C. В нём ожидается наблюдение истинного четырёхпротонного распада. В следующем году на фрагмент-сепараторе FRS (FRagment Separator) в GSI планирутся проведение эксперимента по получению данного изотопа и регистрации продуктов распада с помощью метода трекинга на лету. Последующее изучение угловых корреляций продуктов его распада также поможет лучше понять свойства зеркального ему изотопа ^{7}H. В недавнее время был проведён тестовый эксперимент со вторичным пучком ^{9}C, предназначенный для отладки всей схемы эксперимента.

В данной работе представлены предварительные результаты по симуляции предстоящего эксперимента во фреймворке ExpertRoot, а также по сравнению симуляционной модели и экспериментальных данных, полученных в ходе тестового эксперимента.

THE FIRST RESULTS OF TEST OF THE SPD BEAM-BEAM COUNTER SCINTILLATION DETECTOR PROTOTYPE

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The Spin Physics Detector is a collider experiment at NICA designed to study the spin structure of the proton and deuteron and other spin-related phenomena using polarized beams. One of the subsystems of the SPD is the Beam-Beam Counters (BBC). Two scintillator-based BBC detectors will be installed symmetrically upstream and downstream the interaction point and will serve as a tool for beam diagnostics including local polarimetry. The BBCs will be designed as high granularity scintillation detector.

In this talk, we present the tests of a BBC prototype based on the scintillation tiles produced by Uniplast (Vladimir). The prototype was equipped with the Saint-Gobain Crystals green wavelength shifter, 1×1 mm^2 SensL SiPM, and CAEN FERS-5200 front-end readout system. The first obtained results are disscussed.

ЭКСПЕРИМЕНТАЛЬНОЕ ОБОСНОВАНИЕ НЕОБХОДИМОСТИ ИССЛЕДОВАНИЯ РАДИАЦИОННЫХ СВОЙСТВ МАТЕРИАЛОВ: ГРАФИТ, ТАНТАЛ, ВИСМУТ, ЗОЛОТО, УРАН, ТОРИЙ, АКТИНИДЫ, ЛЕНТЫ ВТСП, С ЦЕЛЬЮ СОЗДАНИЯ ТЕХНОЛОГИЙ ДЛЯ РАБОТЫ РЕАКТОРОВ, РАБОТАЮЩИХ В ЭЛЕКТРОЯДЕРНОМ (АДС) ВАРИАНТЕ

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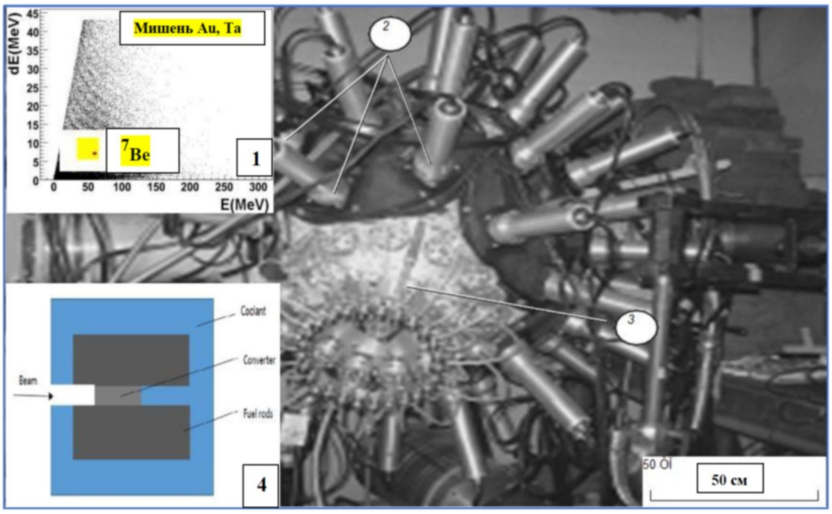
Эксперименты проводились в рамках программы электроядерных исследований на ускорителях ОИЯИ на экспериментальных комплексах ЛЯП и ЛФВЭ ОИЯИ, созданных на базе ускорителей, в «on-line» и «off-line» режимах. В докладе описана методика экспериментов, как при использовании урановой сборки «Квинта», так и при облучении на прямом пучке ускорителей ОИЯИ, описана работа и полученные результаты на многодетекторном спектрометре ФАЗА.(см. рис.)



Многодетекторный спектрометр «ФАЗА». (1-спектры продуктов реакций, 2-3 детекторы и датчики режимов работы спектрометра, 4- схема «гепотетической» активной зоны реактора в режиме ADC).

Рассматриваются протекающие реакции, а также структура образующихся и исследуемых ядер. Особое внимание уделено реакциям мультифрагментации идущих при больших (более 1 ГэВ) энергиях. Представлены результаты исследований с мишенями графита, золота, урана, актинидов. В докладе делаются экспериментальные оценки образования и наработки быстрых нейтронов необходимых для протекания реакций деления. Рассматриваются планы дальнейших экспериментов.

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POSTER SESSION

PHOTON-NUCLEUS INTERACTION AND ILLUSIVE NATURE OF LIGHT

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The nature is quite a mystery until and unless we recognize it. Around 95% of the universe is unrealized, which contains dark matter and dark energy. But the illusive nature of photons is a possible new hope to resolve the mystery of the dark sector. While photon interacts with matter (nuclei to bulky objects) create mass illusions and hide their energy. For this reason, photons do not carry any fixed rest mass. It shows zero and non-zero rest mass in certain circumstances, and this nature of light is a reason for wave-particle duality. This research exercise has been studied in recent years. However, this has not been done in the Quantum Field Theory's perspective; we need to move forward beyond the Standard Model. Hence, the interactions of the nucleus and photon might be changed by the era of Astrophysics and Cosmological throne.

MODELING THE EFFECT OF α-RADIATION ON DETERMINATION IN DROSOPHILA IMAGINAL DISCS

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Currently, Drosophila is used as a model object in studying the influence of various environmental factors, such as high and low temperatures, the inclusion of active oxygen in metabolism, nutritional habits, and diabetes mellitus on longevity and fertility, as well as the effect of radiation on health and life expectancy. The annual dose load from natural radiation sources is mainly due to radon gas and its decay products (DP) and amounts to more than 50%. Radon is released from the earth's crust, and its concentration varies significantly and can range from several Bq/m^3 to several thousand Bq/m^3 (the norm for residential buildings is 200 Bq/m^3). The energy range of alpha particles in the region of 5.5 MeV is of particular interest because it is in this region that the energies of all alpha particles emitted during the radioactive decay of three natural isotopes of radon are located – ^{219}Rn, ^{220}Rn, ^{222}Rn, and their DP. The study of radiation damage from radon is an urgent task due to the fact that, according to the International Commission on Radiological Protection, the main share of oncological diseases of the lungs and bronchi is caused by radon isotopes and, in particular, their DP.

In this work, the epigenetic effects of alpha particles, which in the environment are mainly generated by radon isotopes, were investigated. The object of the study was the X-linked genetic lines of Drosophila melanogaster (Winsley), Möller-5 (Basc), and the white (w) system. In the irradiation experiment, calibration alpha sources with alpha particle energies from 4.8 to 7.7 MeV were used. Radiation exposure ranged from 20 to 72 hours under controlled conditions, and the equivalent dose was up to 3 mSv per Drosophila larva.

In the experiment, in the first generation (F_1), deformities or morphoses were discovered, which can be called "radiation syndromes" or mutations, the manifestation of which is similar to the pleiotropic action of genes. The teratogenic properties of α-radiation in Drosophila flies of the first and second generations are expressed in the manifestation of the following morphoses, which looked like black spots or melanomas on various parts of the adult body: "generalized" melanomas; curled, curved wings: shortened wing; bubble on one wing; absence of one wing, deformation of the thorax, interruption and disruption of tergite patterns, disturbance of the distribution of ocular facets and hairs; lack of pigmentation of the second and third legs. The proportion of morphoses in the experiment was 1.8%, and in the control - 0.4%. Statistical analysis using the Chi-square method showed a significant difference between the experiment and control at $P \leq 0.01$. Based on this, we can assume that alpha particles (with the help of which the situation in radon-hazardous territories was modeled) have a mutagenic effect, manifested mainly in the formation of morphoses or deformities.

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NEW RESULTS ON THE pp-SCATTERING SIMULATION FOR THE BEAM-BEAM COUNTER AT NICA SPD

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The results on the pp-scattering simulation at the total energy 10 and 27 GeV for the Beam-Beam Counter at SPD are presented. The simulation has been performed using the Pythia8 generator under SPDRoot framework. The estimations of the magnetic field influence on the inclusive charged particles production asymmetries and on the Beam-Beam Counter loads have been obtained.

MONITORING THE DISTRIBUTION OF RADON ISOTOPES AND THEIR DECAY PRODUCTS IN THE SURFACE GROUND ATMOSPHERIC AND EARTH LAYERS OF ALMATY

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The UN, among its 17 Sustainable Development Goals, calls for healthy lives and the promotion of well-being for all at all ages. Radon measurements to assess the health effects of this radioactive gas support the Sustainable Development Goals and target 3.4 on noncommunicable diseases [1]. Radon is classified by WHO and IARC as a Group I carcinogen [2, 3]. The proportion of lung cancer cases caused by radon is estimated to range from 3% to 14% [3]. In Kazakhstan, lung cancer has occupied first place in the structure of mortality from cancer in recent years [4]. In Almaty, the problem of radon hazard in the territory, despite the presence of a large number of tectonic faults (the concentration of radon in the human eco-environment, residential buildings located above such zones can reach high values), has not been sufficiently studied. The decay of radon isotopes produces alpha, beta, and gamma radionuclides, which are easily sorbed by substances in various phase states. Radionuclides can be found in air, water, and soil as a result of natural and man-made pollution, which may increase short-term and/or long-term effects on human health. Therefore, the search and monitoring of local radon “flares” in Almaty is a relevant area of research.

In this work, radiometric measurements of the equivalent equilibrium volumetric activity of radon in the air were performed in residential and administrative premises located at various distances from tectonic faults; beta and gamma spectrometric measurements of soil samples. The measurements were carried out at different distances from tectonic faults using a radon radiometer "RAMON-02"in temporary and long-term buildings. Soil samples were taken near these buildings and measured using gamma and beta spectrometric installations SKS-99 SPUTNIK. The measurement exposure on the spectrometers was at least 10,000 events per sample.

The results of the study showed that the content of beta and gamma activity of natural radionuclides in the soil correlates with the equivalent equilibrium volumetric activity of radon in the air; this in turn reflects the increased concentration of radon decay products in the samples. The radon activity concentration averaged 73.85 Bq$\cdot$m^{-3} and ranged from 4.93 to 405.21 Bq$\cdot$m^{-3}. Local foci have been identified in which the obtained values exceed by more than twice the established standards for the average annual equivalent equilibrium volumetric activity of the decay products of radon and thoron in the air of residential premises (200 Bq$\cdot$m^{-3}) [5]. These results will make it possible in the future to develop protective measures aimed at reducing the entry of radon into indoor air and improving indoor ventilation.

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DIFFRACTION PROCESSES IN ELASTIC SCATTERING OF 4n NUCLEI ON LIGHT AND MEDIUM NUCLEI

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Due to the fact that the influence of cluster states, both excited and ground, quite strongly influences the properties of the light nuclei under study, the study of such multicluster nuclear structures is an urgent task [1-2]. Within the framework of the diffraction theory and under the assumption of complete absorption within the interaction sphere, in this work the results obtained earlier in [3-5] were systematized, and new data were obtained on the expansion of the total amplitudes of the angular distributions of the differential cross sections for elastic scattering of light 4n nuclei (^{4}He, ^{12}C, ^{16}O) on nuclei up to ^{40}Ca. Studying such diffraction processes using the method [3] makes it possible to identify partial scattering amplitudes and their contribution to the total amplitude, which characterize the multicluster structure of nuclei of either 4n-nuclei or 4n$\pm$1 nuclei. For a comprehensive analysis of the multicluster structure of nuclei, an experimental technique for direct detection of cluster structures in a nucleus was proposed in [4]. For other nuclei, the manifestation of cluster states is strongly suppressed by others, for example, shell effects or collective states of nucleons, so that analyzing the contribution of cluster partial amplitudes within the framework of this method does not seem trivial, and for some nuclei, it is not possible.

From the analysis of previous results and the results of this work, it was obtained and shown that basically the interference between cluster partial amplitudes and the amplitude responsible for scattering on the nucleus as a whole has maxima at interaction radii from 0.5 to 1.5 fm.

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DECAY PROPERTIES OF THE ^{260}Sg ISOTOPE

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An experiment on the study of the ^{260}Sg decay properties was conducted using the SHELS separator. The isotope was synthesized in the complete fusion reaction of ^{54}Cr beam ions and ^{207}Pb target nuclei.

The alpha-spectrum was investigated and its fine structure was discovered.

The neutron multiplicities of ^{260}Sg spontaneous fission ($\nu = 4.66 \pm 0.14$) were obtained for the first time using the SFiNx detector system. The multiplicity distribution of emitted prompt neutrons was restored using the Tikhonov method of statistical regularisation.

PROMPT NEUTRONS FROM THE SPONTANEOUS FISSION OF ^{244}Fm

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An experiment on the study of the ^{244}Fm spontaneous fission was conducted using the SHELS separator. The isotope was synthesized in the complete fusion reaction of ^{40}Ar beam ions and ^{206}Pb target nuclei.

The neutron yields of ^{244}Fm spontaneous fission ($\nu = 3.62 \pm 0.12$, $\sigma\nu 2 = 1.79$) were obtained with the best precision using the SFiNx detector system.

The multiplicity distribution of emitted prompt neutrons was restored using the Tikhonov method of statistical regularisation. The experimental data were compared with scission point model predictions.

MULTICHANNEL ANALYZER FOR ALPHA SPECTROSCOPY

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The multichannel analyzer is used to identify the source of alpha radiation. Silicon detectors and scintillators are used for registration.

The system for alpha spectroscopy should consist of silicon detectors, NaI(Ti) crystal scintillators, charge-sensitive preamplifier units, a discriminator, an amplifier, a coincidence circuit and a multichannel analyzer[1,2,3].

The goal of the work is to create an alpha spectrometric system at low cost for use in experimental physics and in teaching students. For this purpose, microcircuits were selected and an analog signal processing circuit was created. Simulation of analog signal processing circuits was carried out on the NI MultiSim 14 program.

The multichannel analyzer is created on the basis of the well-known, commercially available and cheap STM32 microcontroller.

The microcontroller has fast multichannel ADC's with sampling rates of 2.5 - 5 million samples per second. However, this speed is not sufficient to accurately measure the peak of a signal using digital signal processing methods such as in digitizers, where ADC speeds reach 250-500 million samples per second. The use of an analog peak detector circuit allows you to save the signal peak before recording the ADC, which allows you to use any slow ADC built into microcontrollers[4,5].

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ДЕТЕКТОР iDREAM: ТЕКУЩИЙ СТАТУС И МОДЕРНИЗАЦИЯ

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Эксперимент iDREAM направлен на изучение свойств нейтрино от промышленного реактора. Детектор расположен в 20 метрах от активной зоны реактора третьего энергоблока Калининской АЭС в потоке электронных антинейтрино, которые регистрируются на основе процесса обратного бетта-распада. На конференции будет представлен текущий статус эксперимента iDREAM, основные результаты модернизации детектора и последние данные результатов эксперимента.

THE MEASUREMENT OF THE ^{6}Li(n, t)^{4}He REACTION CROSS-SECTION IN THE ENERGY RANGE OF 4.25–7.50 MeV

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The measurement of the total cross-section of the ^{6}Li(n,t)^{4}He reaction was carried out over the energy range of 4.25-7.50 MeV by a time-of-flight method relative to the cross-section of the ^{235}U fission. The Cs_2LiYCl_6:Ce based scintillation detector was used as a lithium containing target. The scintillation detector was placed in an axially symmetrical geometry relative to a monitor fission chamber containing ^{235}U layers. The pulsed quasi-monoenergetic neutron beam from the ^{2}H(d,n)^{3}He reaction was used as a neutron source. The total systematic uncertainty in the experiment was 4.6-6.7% with the statistical uncertainty of 2.0-3.7%. The obtained data do not support the evaluated cross-section of the ^{6}Li(n,t)^{4}He reaction from the ENDF-B/VIII.0 library. At the same time, the average difference between the evaluated cross-section from the JENDL-5.0 library and the experimental data obtained in this work also exceeds the total systematic uncertainty of the measurements.

THE KLEIN-GORDON EQUATION WITH DISSIPATION AND ITS APPLICATION TO THE DESCRIPTION OF SECONDARY PARTICLE EMISSION IN HEAVY ION COLLISIONS

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The equations of quantum relativistic hydrodynamics can be obtained from the Klein-Gordon equation [1]. Taking into account dissipation and temperature using additional equations to the effective Klein-Gordon equation allows us to consider the dynamics of the process of collisions of heavy ions and calculate the yields of secondary particles. This allows us to include both light and heavy nuclei into consideration. This makes it possible to more adequately describe the cumulative processes of the formation of high-energy particles in collisions of light heavy ions of intermediate energies [2-4]. The spectra of the resulting cumulative protons, pions, kaons, antiprotons, as well as light fragments, calculated by us using the Klein-Gordon equation, are in agreement with the available experimental data obtained at the U-70 accelerator IHEP (Serpukhov) [5,6] at the collision of carbon nuclei with an energy of 20 GeV per nucleon. Reducing solutions of the Klein-Gordon equation and quantum hydrodynamics equations to solutions in the form of quantum shock waves has not previously been considered. and can be used in other areas of physics when calculating the nonlinear dynamics of oscillations of complex systems.

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FLASH-ALGORITHM FOR HELIX FIT

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Helix fits are of primordial importance for track reconstruction in particle detectors. For certain online applications speed is critical. We present a flash-algorithm helix fit with a latency the order of 300 ns, which is more than twice as fast as the Stratix-10 FPGA solution developed for the ATLAS HTT in trig.LVL1. The fit expects "xyz"-hits and uses a third order helix approximation. The code will be made available in JINRLIB.

ON THE DETECTION OF NEW PARTICLES FROM DATA AT ACCELERATORS AND ULTRA-HIGH ENERGY COSMIC RAYS

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The search for new particles beyond the Standard Model at accelerators is undoubtedly one of the main tasks of modern nuclear physics. On the other hand, the interpretation of the spectra of soft photons in collisions of high-energy elementary particles is also a mystery for elementary particle physics.

Here we have proposed a development of the approach [1, 2] for interpreting the spectra of soft photons based on the transverse momentum in pp collisions with an incident proton momentum of 450 GeV/c [3]. The spectrum of soft photons [3] cannot be explained by the traditional bremsstruhlung mechanism. It can be explained taking into account the X17 boson with a mass of 17 MeV - a new particle, a possible candidate for the role of dark matter particles, discovered in the experiment [4]. The X17 boson was discovered in the ATOMKI experiment [4] in atomic transitions with Be, which requires independent confirmation. Here we propose to improve the agreement with experimental data [3] in order to more convincingly isolate the signal about the detection of the X17 boson. Our interpretation of photon momentum spectra is to use the formula for temperature [2]. The corresponding temperature is T =3.8 MeV. Unlike [2], here we take into account the isentropic decrease in temperature according to the formula $T^3V = {T_0}^3V_0$, where T_0 is the initial temperature before expansion, $V_0/V = G$ is the Lorentz contraction of volume. The corresponding excess of the spike over the undisturbed curve is 4 standard deviations. This can be verified after subtracting the corresponding values of the unperturbed curve from the experimental data [3]. In the spectra of photons emitted in the reactions of protons with carbon nuclei at a momentum of incident protons of 5.5 GeV/c [5], a boson with a mass of 38 MeV appears. Based on the combination of two-dimensional quantum chromodynamics and quantum electrodynamics in the tube model, we found the masses of these particles [2] with $m \sim \sqrt{\alpha}$, where α is the coupling constant, which is compatible with the resulting meson masses for the hadronic string-tube at $\alpha = 0.5$. That is, such an interpretation of the spectrum of soft photons can serve as further evidence in favor of the existence of a new particle of the X17 boson. The contribution of the X38 boson, predicted in the experiments carried out in Dubna [5], is also compatible with our approach. And based on temperature analysis for high-energy particle collisions, the contribution of the decay of the X17 and X38 bosons into two photons can be seen by relativistic kinematics to have an effect on the spectrum of emitted photons. It's a matter of subsequent experiments. These new particles may manifest themselves in ultra-high-energy cosmic rays on the order of 10^{11} GeV, unattainable with modern accelerators. We were able to reproduce the burst detected in experiments [6,7] due to the X17 and X38 bosons. The corresponding formulas used an approximation of the experimental spectrum of cosmic rays, proportional to E^{-3} , and the contribution of the decay of X-bosons to photons according to the black body radiation formulas.

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MANIFESTATION OF THE FISSION DYNAMICS IN MUON-INDUCED PROMPT FISSION

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In muonic atoms of ^{238}U, the nuclei can undergo prompt fission through non-radiative transitions [1] of the muon: 2p – 1s, 3p – 1s, 3d – 1s etc. Main features of the fission dynamics are studied in prompt fission: augmentation of the barrier, dynamics of the saddle-to-scission descent, muonic conversion and characteristic X-rays from fission fragments supply information on the multipolarity of electromagnetic transitions and charge distribution, structure of nuclear transition currents. Revision of the non-radiative transition probabilities comprises my present purpose.

It is commonly accepted that the probability of the non-radiative nuclear excitation in the muonic transition can be expressed in terms of the photoexcitation cross-section and resonance internal conversion coefficients [2]. In this way, satisfactory agreement is attained with experiment [3] for non-radiative transition widths for the 2p–1s transitions in ^{238}U. However, the 3p–1s radiative transition width turns out to be by a factor of 15 larger that experimental one. I undertake detailed analysis of this circumstance on the basis of Ref. [4]. First, this broadening is not only due to the additional contribution of the non-radiative transition, but also the admixed GDR nuclear width gives a contribution. And that width is of the order of MeV. Second, there is level doubling due to the non-radiative interaction, with the related broadening of the second radiative component within MeV scale due to the GDR total width. Moreover, the nucleus gets excited, properly speaking, not in the 3p–1s transition, but rather in the preceding cascade transition to this state, like 4d–3p, even 3d–3p (virtually) or similar. Correspondingly, some missing intensities should manifest themselves in these transitions.

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COMMISSIONING OF FORWARD WALL DETECTOR IN THE HADES EXPERIMENT

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The Forward Wall (FW) is subdetector of HADES (High Acceptance Di-Electron Spectrometer) experiment located in GSI/FAIR in Darmstadt, Germany. The HADES detector is a complex experimental apparatus designed for studying the QCD phase diagram at high baryonic densities and low temperatures, primarily via the di-lepton decay of vector mesons. FW is critical for determination of the collision centrality and event plane orientation in nucleus-nucleus collisions. FW setup consists of 288 cells of three different sizes and utilizes photomultiplier tubes (PMTs) with NE109 plastic scintillators. This talk will report the upgrade, reparation, and calibration before the February/March 2024 experiment. Calibration was done using developed iterative algorithm, which allowed to calibrate all the cells of the detector at once. FW detector was firstly pre-calibrated using cosmic muons, the final calibration was done at C+C and Au+Au experiment.

ОПРЕДЕЛЕНИЕ СПЕКТРА ЭНЕРГИИ ВОЗБУЖДЕНИЯ ^{6}Li В РЕАКЦИИ n+^{6}Li

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На нейтронном канале РАДЭКС ИЯИ РАН на созданной установке для исследования свойств высоко возбужденных состояний легких ядер [1] проведен эксперимент по определению спектра энергии возбуждения ядра ^{6}Li в реакции $n + {}^6\mathrm{Li} \to n + {}^6\mathrm{Li}^* \to n + {}^3\mathrm{He} + t$. В эксперименте, проведенном при энергии нейтронов $40 - 60$ МэВ, регистрировались в совпадении рассеянные нейтроны и ядра гелия-3. Энергия и угол вылета не детектируемой частицы ^{3}H, а также энергия первичных нейтронов, вызвавших реакцию, восстанавливались из законов сохранения энергии и импульса. По углам вылета и энергиям продуктов развала высоко возбужденных состояний $^6\mathrm{Li}^*$ получен спектр энергии возбуждения $E_\mathrm{x}(^6\mathrm{Li})$ в интервале от пороговой энергии развала (15.79 МэВ) по каналу $^6\mathrm{Li} \to {}^3\mathrm{He} + t$ до 29 МэВ.

Исследование выполнено в рамках научной программы Национального центра физики и математики, направление №6 «Ядерная и радиационная физика».

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WHY DO NUCLEI EXIST?

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It is one thing to discover the atomic nucleus but it is quite another matter to explain why this entity exists at all in Nature. The way from the Rutherford fundamental discovery to our days clearly shows that the essence of the so called nuclear forces can not be understood without such explanation.

Only own Laws of Nature that is Laws of Natural Physics, independent from the observers and an act of observation, can distinguish the sense from a nonsense and explain why Nature is just the way it is. From the Laws of Natural Physics it follows that all nuclei are the different states of the unique inextricable connected natural system of fields that is defined by the new natural representations about time, charge, internal symmetry and spin. We establish the Lagrangian of this system and outline the simple scheme of possible applications.

OPTIMIZATION OF THE QUANTITATIVE COMPOSITION OF SCINTILLATION ADDITIVES FOR A TELLURIUM-LOADED PLASTIC SCINTILLATOR

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The paper describes the optimization of the composition of a tellurium-loaded plastic scintillator (Te-PS) for experiments on the search for neutrinoless double beta decay. Polystyrene was used as a scintillation base for Te-PS and 2,5-diphenyloxazole (PPO) and 1,4-bis(5-phenyloxazol-2-yl)benzene (POPOP) were used as scintillation additives. Complex compound of diphenyltellurium oxide and di-(2-ethylhexyl)phosphoric acid in a concentration corresponding to 1% tellurium content was used as tellurium-containing additive. The light yield and transparency of the scintillators were measured.

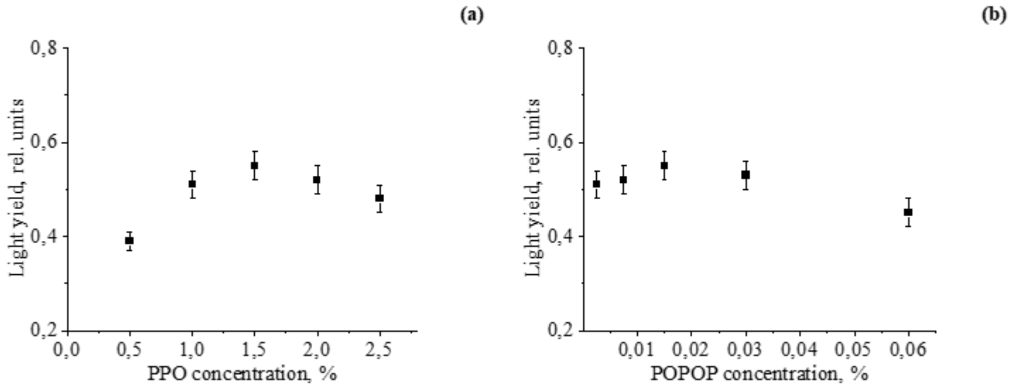

Fig.1. Light yield as a function of PPO concertation with 0.015% POPOP (a), POPOP concentration with 1.5% PPO (b) for tellurium-loaded plastic scintillators (relative to the light yield of unloaded PS)

It has been shown that the optimal PPO concentration in the scintillator is 1.5%, and varying the amount of POPOP in the studied concentration range has practically no effect on the light yield. This work is supported by a grant from the Russian Science Foundation for fundamental research and exploratory research by small individual research groups (project no. 23-22-00214).

ВЕСОВОЙ АЛГОРИТМ TPT3 МОДЕЛИРОВАНИЯ ПОДКРИТИЧЕСКИХ И СВЕРХКРИТИЧЕСКИХ УСТАНОВОК

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Программа TPT3 разработана во ВНИИА им. Духова для высокопроизводительного параллельного моделирования задач переноса радиации и взаимодействия излучения с веществом на современных многоядерных центральных процессорах и графических ускорителях, поддерживающих векторные инструкции. Одной из её ключевых особенностей является использование упрощённой воксельной геометрии, идеально подходящей для параллельных вычислений и совмещения с программами гидродинамического моделирования. Физические модели программы TPT3 покрывают практически все аспекты взаимодействия ионов и нейтронов с веществом в широком диапазоне энергий и приспособлены для использования весового метода.

Применение весового метода позволяет моделировать цепные реакции ядерного деления с большими постоянными размножения практически для любых сборок, которые при этом описываются геометрическими моделями, состоящими из миллиардов декартовых ячеек (вокселей), каждая из которых характеризуется своим элементным составом и концентрацией. При возрастании весов моделируемых частиц программа TPT3 позволяет учитывать выгорание ядерного топлива и изменение окружения моделирования в результате образования продуктов деления.

В настоящем докладе обсуждаются результаты применения программы TPT3 для моделирования цепной реакции ядерного деления в критических сборках, а также особенности разработанного алгоритма весового деления нейтронов на эквивалентные весовые частицы меньшего веса в существенно подкритическом режиме цепной реакции.

THE ALIGNMENT OF THE ^{20}Ne(2^+; 1.63 MeV) NUCLEUS FORMED IN ^{19}F(α, T) ^{20}Ne REACTIONS AT $E_\alpha = 30.3$ MeV

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Experimental and calculated the $F_2(\theta_t)$ and $F_4(\theta_t)$ alignment angular dependences of the ^{20}Ne nucleus in the excited state 2^+ (1.63 MeV), formed in the reactions $^{19}F(\alpha,t)^{20}Ne$ at energies $E_\alpha = 30.3$ MeV are presented. The orientation parametersF_k $(k = 1, \ldots, 2J)$ are polynomials in the mean values of the powers $\langle J_z \rangle$ and are included in the expression for the interaction energy of nuclei with an electromagnetic field [1]. Since the method of angular correlations used in this work makes it possible to experimentally determine only even components, we consider the parameters of the quadrupole F_2 and hexadecapole F_4 orientations. In the case of an isotropic spin distribution, the alignment is zero. The maximum value of the parameters is achieved at the maximum value of the spin projection $M = J$ onto the quantization axis:

$$F_2 = \frac{2J+1}{\sqrt{5}} \sqrt{\frac{(J+1)(2J+3)}{J(2J-1)}} \langle T_{20} \rangle,$$

$$F_4 = \frac{2J+1}{6} \sqrt{\frac{(2J+3)(2J+2)(2J+4)(2J+5)}{J(J-1)(2J-1)(2J-3)}} \langle T_{40} \rangle,$$

where

$$T_{K0} = \frac{1}{2J+1} \frac{\rho_{K0}}{\rho_{00}} = \frac{1}{\sqrt{2J+1}} (-1)^{J-M} \langle JMJ-M|K0 \rangle,$$

and $\rho_{k0}(\theta_t)$ is the spin tensor component of the density matrix of the nucleus.

Experimental information was obtained on the basis of previously retrieved [2] spin-tensors $\rho_{k\kappa}(\theta_t)$ density matrices of the ^{20}Ne nucleus (2^+ 1.63 MeV) by measuring of the angular particle-gamma correlations. The experimental orientation parameters are compared with the calculated ones under the assumption of CCBA taking into account the mechanisms of nucleon stripping and the coupled channel method (FRESCO code [3]). The calculated alignments are in satisfactory agreement with the experimental ones.

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DIRECT PHOTON PRODUCTION IN Pb-Pb COLLISIONS MEASURED WITH ALICE

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Hot and dense nuclear matter produced in relativistic heavy-ion collisions has been extensively studied in the past decades. The space-time properties of such nuclear matter can be comprehensively described by Quantum Chromodynamics (QCD). At LHC energies, QCD predicts a phase transition to Quark-Gluon Plasma (QGP). Hence, the number of experimental observables have been established to study QGP, including direct photon that comes from thermal expansion of QGP. Photons are not coupled with the strong interaction, which makes them one of a key probe of QGP, especially at the earliest stages of its evolution. In the ALICE experiment, it is possible to measure photons down to 0.4 GeV/c of transverse momentum (p_{T}) with the tracking system using photon conversion to $e^{+}e^{-}$ pairs in the detector material. Photons of higher p_{T} are measured with EMCal and PHOS electromagnetic calorimeters. We report the results of the ALICE experiment on the direct photon production in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV and $\sqrt{s_{NN}} = 2.76$ TeV.

APPLICATION OF EPOS4 AND URQMD (LHC) EVENT GENERATORS TO ANALYSE 7 TeV pp COLLISIONS

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In the study of heavy ion collisions, pp collision modeling plays an important role. We have carried out modeling of 7 TeV pp collisions using the EPOS4 [1] and UrQMD [2] event generators (LHC).

We found that both baryon and lepton charges B and L, as well as energy, are conserved when simulating scattering events using UrQMD. However, there is a small non-conservation of the electric charge, and there is a significant deviation in the distribution of events by the number of outgoing charged particles from that experimentally obtained at the ALICE detector [3].

We found that the EPOS4 simulation results show noticeable tails in the distributions of B-L,electric charge Q, and energy. With a number of generated events of several thousand, the EPOS4 generator poorly describes the multiplicity distribution of charged particles. With a sufficiently large number of events (about 20 thousand) the generator gives a distribution of events by the number of outgoing charged particles close to that observed experimentally at the ALICE detector [3]. For UrQMD generator, increasing the number of generated events to the same value did not improve the distribution.

Discarding events in which conservation laws do not hold significantly worsens the multiplicity distribution for both generators. Therefore, such filtering is impractical.

The study was carried out within the framework of the St. Petersburg State University project ID 94031112.

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STUDY OF THE STRUCTURE OF ^{12}C AND ^{6}Li NUCLEI IN THE ALPHA-CLUSTER MODEL BY HYPERSPHERICAL FUNCTIONS AND FEYNMAN'S PATH INTEGRALS

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The light nuclei ^{12}C and ^{6}Li used as target and projectile nuclei in the many experimental studies of the nuclear reactions, including Flerov Laboratory of Nuclear Reaction (JINR). The study of the structure of these nuclei is necessary for theoretical description of such reactions. Wave functions of the ground state of the ^{12}C and ^{6}Li nuclei in the alpha-cluster model are calculated using Feynman's path integrals and hyperspherical functions [1]. Cubic spline interpolation is applied for solving hyperradial equations [1]. The alpha-alpha interaction in the ^{12}C nucleus is changed in comparison with well-known Ali-Bodmer potential [2]. As a result, the energy of separation to alpha-particles and the charge distributions were calculated and agreement with experimental data [3–5] was obtained (Fig. 1). The alpha-cluster model may explain the strong oblate deformation of the ^{12}C nucleus (with $\beta_2 = -0.59$ [6]). In addition, the shell model of the deformed nuclei is used to calculate the nucleon states in the ^{12}C nucleus for comparison against alpha-cluster model.

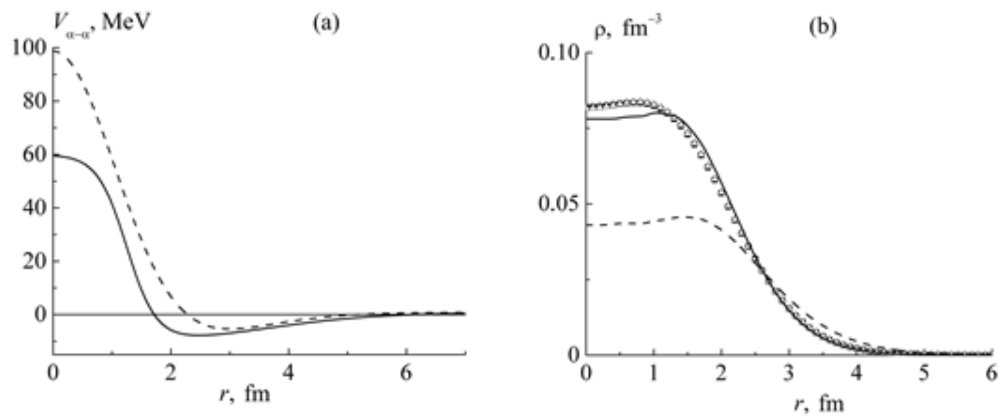

Fig.1. (a) The Ali-Bodmer potentials of the interaction between free α-particles [2] (dashed curve) and potentials between α-clusters in the ^{12}C nucleus (solid curve); (b) The charge distribution in the ^{12}C nucleus: experimental data [3–5] (symbols), results of calculations with Ali-Bodmer potentials from [2] (dashed curve) and with potentials between α-clusters in the ^{12}C nucleus (solid curve).

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NEUTRINOLESS DOUBLE ELECTRON CAPTURE STIMULATED BY X-RAYS

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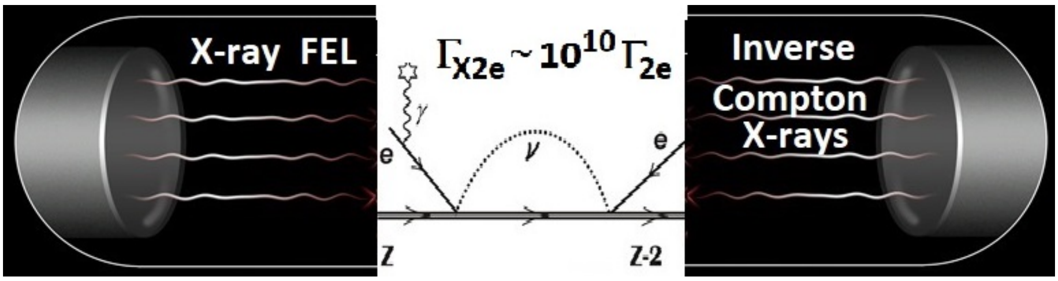
The possibility of exposure of electromagnetic radiation on the nuclear processes is considered on an example of a neutrinoless double-electron capture - 0ν2ec. Expected lifetimes of the 0ν2e capture are several orders of magnitude longer than those of the 0ν2beta-decay that strongly retards development of experiments, requiring many tons of the bulk target matter. Hence, any way of acceleration of the 0ν2ec would be of great interest. For cases of X-ray free electron lasers – X-ray FEL and/or inverse Compton X-ray sources it is shown that such a decay can be significantly enhanced due to tuning the system to the resonant conditions through an absorption and/or emission of a photon with the decay resonance defect energy Δ. In this case the 0v2ec decay rate Γ2eX of nuclide Z grows linearly with field intensity - S/Sz - up to the X-ray flux power Sm Z6, while Sz Z6 (Γ/Δ)2 with decay width Γ of a daughter atom. For a case of ^{78}Kr $\rightarrow$ ^{78}Se - 0ν2ecL1L1 capture we find Sz $\sim$ 108.5 W cm-2 and Sm $\sim$ 1017.5 W cm^{-2} which indicate a possibility of increasing decay rate to ten orders of magnitude or even larger.



PRODUCTION OF Σ BARYONS IN pPb AND pp COLLISIONS AT THE LHC WITH ALICE

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The strangeness production has been widely studied through measurements of kaons, Λ, Ξ and Ω baryons from small to large collision systems. However, a strange baryon has not been fully studied yet - the Σ baryon. Σ baryons contain a single strange quark and form a triplet, with the charge (+, 0, -) depending on the light quark content. However, the experimental measurement is a challenging task. Only Σ^0 in 7 TeV pp collisions have been measured by ALICE, while few other experiments have measured the charged states at lower pp(p$\bar{\text{p}}$) collision energies.

During the LHC Run 2 several methods to identify charged Σ have been developed by ALICE. The decay $\Sigma^+ \to p + \pi^0$ can be reconstructed via the direct detection of the proton and the two gammas from the π^0 decay. Gamma can be also identified via conversion into e^+e^- pairs.

The latest addition is a method to detect anti-neutrons in the Photon Spectrometer (PHOS), allowing the $\bar{\Sigma}^{\pm} \to \bar{n} + \pi^{\pm}$ decays to be reconstructed. We present the transverse momentum spectra of Σ^+ and its charge conjugate anti-particle, in both minimum bias and high-multiplicity triggered pp collisions at $\sqrt{s} = 13$ TeV, $\bar{\Sigma}^{\pm}$ spectra in pPb and pp collisions at $\sqrt{s} = 5.02$ TeV and Σ^0 spectrum in 7 TeV pp collisions, compared with predictions from state-of-the-art Monte Carlo models. In addition, integrated yields are compared with Thermal model predictions.

РАСЧЕТ СПЕКТРОМЕТРА ПАР ЭЛЕКТРОНОВ И ПОЗИТРОНОВ В УСТАНОВКЕ ДЛЯ ИССЛЕДОВАНИЯ РЕАКЦИЙ БЫСТРЫХ НЕЙТРОНОВ С ЛЕГКИМИ ЯДРАМИ

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Выполнено моделирование движения электронов и позитронов в спектрометре на основе постоянного магнитного диполя с последующей их регистрацией в позиционно-чувствительных кремниевых детекторах. Получено разрешение по энергии и углу вылета электронов и позитронов. Данный спектрометр является составляющей частью установки для исследования редких внутриядерных процессов в легких ядрах с рождением пар внутренней конверсии.

ELLIPTICAL AND TRIANGULAR AZIMUTHAL FLOWS IN HEAVY-ION COLLISIONS WITH HYDJET++ MODEL AT THE LHC ENERGIES

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We are generating the production of particles in Xe–Xe, Pb–Pb and O-O collisions using Monte Carlo HYDJET++ model which simulates collisions of heavy ions as a mixture of two independent components: the soft hydrodynamic part and the hard part with multipart processes. A comparison of the model results for elliptical and triangular azimuthal flows of charged particle at the LHC energies with the CMS experimental data is presented. In addition, the predictions are given for azimuthal flows for new energies and new nuclei.

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STATUS OF EXPERIMENTAL AND EVALUATED DISCRETE γ-RAY PRODUCTION IN (n,x) REACTIONS AT $E_n = 14.1$ MeV FOR ^{12}C, ^{16}O, ^{28}Si

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Cross-sections of the γ-ray production in neutron-induced reactions are needed in many practical fields: design of nuclear and thermonuclear reactors, elemental analysis and modeling of various nuclear setups. Besides this they provide valuable information base for understanding the nuclear structure and mechanisms of nuclear reactions. In the Frank Laboratory of Neutron Physics, the international project TANGRA is being implemented to study the scattering of tagged 14.1 MeV neutrons on atomic nuclei. For this project it is very important to have a comprehensive and detailed information of present status of experimental and evaluated data on photon production cross sections, showing for what nuclei and with what accuracy the γ production cross-sections have been measured and how they are predicted by widely used evaluated data libraries.

To date, the most comprehensive compilation for this kind of information was created in 1998 [1], so it is important to include and review results of modern experiments. A promising way to do that is analysis of data from EXFOR [2]. In this work we have developed spiecific techniques for extraction and processing data available in EXFOR. As a result of the work we will provide our review of experimental data for ^{12}C, ^{16}O and ^{28}Si nuclei and updated recommended values of γ-ray production cross-sections.

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ALGORITHM OF NEUTRON IDENTIFICATION WITH THE HGND AT THE BM@N EXPERIMENT

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Fixed target BM@N experiment at Nuclotron (JINR, Dubna) is aimed at study of heavy ion collisions at beam energies up to 4 A GeV. The High Granular Neutron Detector (HGND) is being developed in addition to existing BM@N detectors. It provides a possibility to carry out unique measurements of direct and azimutal flow of neutrons and measure their energy spectrum. Such measurements allow to study the isospin term of the equation of state of hadronic matter.

The HGND has two arms, each consisting of 8 layers of plastic scintillator with copper absorber plates in between. The first layer is used for rejection of the charged particles. Each scintillation layer is assembled from 11x11 matrix of individual cells (1936 cells in total).

This report is dedicated to the development of algorithm of HGND data analysis. This algorithm includes cluster recognition, selection of clusters corresponding to neutrons and determination of their energy by the time of flight. The energy resolution, efficiency and purity of neutron selection based on Monte-Carlo simulation will be discussed.

PERFORMANCE STUDY OF GLOBAL POLARIZATION OF LAMBDA HYPERONS IN HEAVY NUCLEI COLLISIONS AT THE MPD EXPERIMENT

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Global hyperon polarization is an important observable phenomenon for studying the properties of strongly interacting matter produced in of relativistic heavy ion collisons. The magnitude of polarization carries information about the collective response of the medium formed in collisions to the development of large angular momentum and the formation of a strong magnetic field in non-central collisions of heavy nuclei. At NICA collider energies, global polarization has a strong energy dependence and is predicted to increase with decreasing energy, which will allow it to be studied in detail as a function of energy, centrality, and kinematic characteristics. The report will present the results of studying the possibility of measuring the global polarization of lambda hyperons in Bi+Bi collisions at an energy of 9.2 GeV per nucleon pair at the MPD experiment.

ANALYSIS OF THE REGULAR PART OF THE TOTAL SCATTERING AMPLITUDE IN THE GENERALIZED THEORY OF FINITE FERMI SYSTEMS

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In the sequential microscopic theory of the nucleus, using the formalism of Green's functions (GF), it is necessary to consider the full amplitude of the interaction (scattering amplitude) Γ [1,2], which contains the regular part of Γ^r. First of all, this is due to the inclusion of two-phonon configurations in addition to the 1p1h+phonon configurations [2], i.e. we are talking about the sequential consideration (in the language of GF) of two-phonon configurations.

The equation for the regular part of Γ^r was obtained by A.B. Migdal [1] and, as far as we know, has never been studied quantitatively. To solve it, it is necessary to find the second free term F_1 containing the square of the phonon creation amplitude g (the first free term is the well-known interaction F in the theory of finite Fermi systems [1])

We transformed both these equations for g and Γ^r in the approximation for the interaction of F in the form of separable forces, see [3], with the parameters of these forces found by us for ^{208}Pb for $E2$ transitions, used the corresponding experimental data for g and solved the equation for Γ^r. Calculations showed a rather unexpected result: the ratio of two free terms F_1/F = -6.0, and the ratio Γ^r/F=-31.2. Apparently, these estimates mean that the microscopic theory of two-phonon nuclear excitations must be substantially refined.

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A NEW APPROACH TO ESTIMATE THE NUCLEAR TEMPERATURE IN LOW-ENERGY FISSION

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The phenomenon of isoscaling has been studied mostly in low-energy heavy-ion reactions during the past decades until the present time [1]. It was confirmed in various reaction processes, among others also concerning fragments in low-energy fission.

The isoscaling behavior of reaction products is related to properties of equilibrated matter e.g. the nuclear temperature. In this regard we treated fission yields stored in the IAEA Nuclear Data Services [2], assigned to certain classifications of low-energy fission processes. We analyzed the compiled fragment yields covering an extended range of Z associated with fissioning nuclei from Th to Fm. The obtained isoscaling parameters α and β are related to the neutron and proton chemical potentials, i.e the nucleonic compositions of the nuclei undergoing fission as well as to the related nuclear temperatures. Therefore, the corresponding temperatures can be evaluated by using only one parameter, namely the symmetry energy coefficient C_{sym}. Its value is well-known from fits of experimental binding energies achieved within the Liquid Drop Model. In our calculations we used the mean value $C_{sym} = 23$ MeV [3]. It is obvious that possible deviations from this value can be served as a measure of the accuracy of the obtained results.

The found nuclear temperatures corresponding to low-energy fission processes are located in the interval from 0.5 to 0.8 MeV. This result is in a fair agreement with corresponding values derived from the isotope thermometry [4].

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MODEL OF NUCLEON CLUSTERING AND FRAGMENT FORMATION IN HEAVY NUCLEI FISSION

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The fission of heavy nuclei plays an important role as the most striking example of large-amplitude collective motion in a quantum many-body system. Reconstructing the detailed sequence of events leading to rupture remains a challenge for both experimentalists and theorists [1, 2, 3].

In this paper, we consider the problem of theoretical description of the fission fragment formation within the framework of an extended Vicsek-type collective model. The non-mean-field approach, first proposed in [4, 5], is based on microscopic modelling of the nucleon clustering as a phenomenon of collective behavior inside the many-body nuclear system. The new algorithm is aimed at modeling the occurrence of collective nucleon aggregation due to short-range mutual interaction. The developed method leverages an algorithm coming from the field of agent-based computing models.

Numerical computer simulations were carried out for the main clusters, observed experimentally in the multimodal fission of heavy and superheavy nuclei, starting with doubly magic nuclei ^{132}Sn and ^{208}Pb.

In superheavy nuclei, a new mode is clearly visible now – a super asymmetric mode under the influence of the ^{208}Pb shell [6]. This mode was predicted using multidimensional potential energy surface calculations in [7].

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PROSPECTS OF ION-PLASMA TECHNOLOGY FOR NUCLEAR ENERGY

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Today, one of the challenging tasks of nuclear energy are decommissioning of nuclear power plants (NPP), decontamination of irradiated reactor graphite and metal structures of NPP, reprocessing of spent nuclear fuel (SNF) and closing the nuclear fuel cycle, creation of new energy sources: beta-voltaic batteries. To solve this wide range of problems in various nuclear materials processing we develop a new approach: ion-plasma deactivation technology. At present time 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 250 thousand tons) and the challenging problem of uranium-graphite reactors decommissioning period. There is no effective method for decontaminating reactor graphite and circuit equipment of NNPs; known chemical decontamination methods based on acid solutions lead to an increase in the volume of secondary liquid radioactive waste.

Proposed ion plasma decontamination technology is based on the inert gas (argon) ion-plasma sputtering and thermo-treatment deactivates surfaces. Argon plasma is iginited between the deactivated rector graphite or metal surface (the cathode) and electrode-collector (the anode) under operating parameters discharge current (0.001 - 1 A / cm^2), voltage (300-1000V), inert gas pressure (0.01-1 atm.), gap between the treated graphite surface and the anode (1-5mm). In our research we experimentally demonstrate the efficiency of ion-plasma technology on non-irradiated samples of reactor graphite and metal alloys. The sputtered layer of radioactive contamination atoms in the mass transfer mode in the solid form is deposited on the anode surface. One of the possible contamination mechanisms of graphite masonry surfaces is the neutron activation of nitrogen atoms from the cooling gas mixture, as well as the process of intercalation of nitrogen migrating inside graphene-graphene layers of graphite. This leads to the fact that the RBMK graphite masonry acquires significant activity due to the ^{14}C isotope localized on and inside of the surface layers of micron depth. Ion plasma technology during the decontamination make it possible the sputtering of atoms layer enriched by the ^{14}C isotope from the irradiated reactor graphite surface and deposit this sputtered layer on the surface of the anode. The layer enriched by the ^{14}C isotope can be used to create a new type of beta-voltaic batteries. Ion-plasma technology is patented in collaboration with Concern Rosenergoatom JSC and Rosatom [1] and is suitable for Fukushima NPPs accident dismantling efforts.

Additionally, some modification of ion-plasma technology can be used for a new scheme of spent nuclear fuel (SNF) reprocessing and closed circulating fuel cycle – ion sputtering-thermal separation (IS-TS) technology that also make it possible to the extraction of the beta-emitting ^{90}Sr from SNF. The ^{90}Sr isotope can be used for the fabrication of a new type of vacuum beta-voltaic cell (VBC) with output electric power 1 W/cm^3.

The advantages of ion-plasma technology are the absence of liquid radioactive waste, a 10-fold reduction in the volume of secondary radioactive waste and economic costs, a “dry” method of decontamination of NPP and a reduction in decommissioning costs by 400 billion rubles, separation of uranium and plutonium from fuel fission products, the possibility of extracting the ^{90}Sr isotope during SNF reprocessing to create a new type of power source VBC.

The study was supported by the Russian Science Foundation grant No. 24-29-00321, https://rscf.ru/project/24-29-00321/

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TWO-CENTER SINGLE-PARTICLE MODEL OF NUCLEAR FISSION

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Nuclear fission is a pronounced example of collective motion having multidimensional and nonlinear dynamics. A direct determination of dynamical coordinates has not been done due to the complexity of such a problem, which leads to the impossibility of describing a strict sequence of nucleus shapes during fission. The description of the dynamics of nuclear fission is a pending issue that requires modern computing solutions.

Nuclear models and parameterization is a specific feature of nuclear theory essential to solve the many-body problem with strong interaction. At present, there is no unambiguous approach to selecting deformation parameters, and various ways of specifying a function that describes an axially symmetric surface have been developed [1]. The deformation parameters included in the form of this function are collective dynamical variables in describing the fission dynamics.

The single-particle model as a stage in the program for describing the dynamics of nucleus fission separation serves as a basis for calculating fission barriers, level densities, and excitation schemes. The paper presents the created basis with calculations and demonstrates its features. The program allows to perform calculations for axially symmetric nuclei, whose shape can change within wide limits, up to splitting into two fragments. The shape of the nucleus is specified in the lemniscate coordinate system [2]. Unlike most methods, the proposed parameterization allows describing a wide range of nucleus shapes.

The stage of descending from the saddle point to the point where the nucleus breaks into fragments is the most fascinating in terms of nuclear dynamics [3]. The non-adiabatic effects of this stage are a promising problem, and our program will be a tool for solving it.

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EXPERIMENTAL STUDIES OF A MODEL OF SPACE PROPULSION ON A NEW PHYSICAL PRINCIPLE

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A new principle of motion is briefly outlined, using a new non-gauge force of nature in the form of thrust, but physical space (dark matter - the quantum medium of special objects in Byuon's theory [1,2]) in the form of a support medium, which can be used to move astronauts and space ships. The results of some experiments carried out in Italy during 2012 - 2015 are presented on the use of a new principle of movement using a new non-gauge force of nature [1.2.3] in the form of object thrust. The results of the latest experiments conducted during 2021-23 are shown in Russia [4] with a model of space propulsion operating on a new physical principle. Experiments recorded thrust at a level of 15 - 30 grams with a specific energy consumption of (5 - 6) W/g and a model weight of about 100 kg.

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НОВАЯ АППРОКСИМАЦИЯ СЕЧЕНИЙ РЕАКЦИЙ СИНТЕЗА

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В задачах, связанных с расчётом термоядерных процессов, используются оценённые данные по сечениям реакций синтеза. Во многих случаях эти данные удобнее использовать не в табличной форме (с необходимостью интерполяции промежуточных значений), а в виде аналитических выражений, аппроксимирующих табличные значения. Для сечений четырёх реакций синтеза с участием дейтронов разными авторами предложено несколько аппроксимирующих выражений: Duane-1972 [1], Bosch-1992 [1], Li-2008 [2], Gaganov-2017 [3]. Для указанных выражений проведено сравнение качества аппроксимации сечений четырёх реакций синтеза ^{3}H(d,n)^{4}He, ^{2}H(d,n)^{3}He, ^{2}H(d,p)^{3}H, ^{3}He(d,p)^{4}He из современной библиотеки оценённых данных ENDF/B-VIII [4]. Результаты сравнения показали, что в диапазоне значений кинетической энергии дейтрона от 6 кэВ до 350 кэВ новое аппроксимирующее выражение [3] обеспечивает наиболее точное описание оценённых данных с отклонением менее 0.5%.

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DETERMINATION OF TARGET THICKNESSES USED ON THE GNEIS TIME-OF-FLIGHT SPECTROMETER

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This paper presents a method for determining the number of atoms of specific isotopes present in targets used in the GNEIS time-of-flight spectrometry system when measuring the angular distribution of fragments and the fission cross section. This method is based on determining the total number of alpha particles emitted by a target using surface barrier detectors in a well-defined geometry.

TRACKING MODULES WITH DSSD SENSORS FOR THE BM@N EXPERIMENT

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Modules with a double-sided silicon microstrip sensors are the back-bone components of the future wide-aperture Silicon Tracking System of BM@N experiment. The main features of this module are the fast readout electronics based on STS-XYTER ASIC and the usage of low mass (0.23% X0) aluminum micro-cables for the transfer of analog signals from the sensor strips to the input channels of the readout electronics. The results of tests of the tracking modules with 1 GeV proton beams at the SC-1000 accelerator at PNPI are presented. Stable operation of the readout electronics at occupancies, which are close to the maximum values - 360 kHz sec^{-1} cm^{-2} was demonstrated. The Signal-to-Noise ratio for the module is more than 23. The measured coordinate resolution of the modules within the beam telescope is 17 ± 0.4 μm, and the detector registration efficiency for protons with energy of 1 GeV is more than 99%.

MEASUREMENT OF FORWARD NEUTRON YIELDS WITH A HIGH GRANULAR NEUTRON TIME-OF-FLIGHT DETECTOR PROTOTYPE FROM ELECTROMAGNETIC DISSOCIATION AND NUCLEAR INTERACTION IN Xe+CsI@3.8 AGeV COLLISIONS AT THE BM@N EXPERIMENT

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The High Granular Neutron Time-of-Flight Detector (HGND) prototype was used for the first time in Xe+CsI@3.8 AGeV run at the BM@N experiment. The multilayer longitudinal structure (absorber/scintillator), high granularity and good time resolution of the HGND prototype makes it possible to identify and measure the energies of neutrons produced in nucleus-nucleus collisions by time-of-flight. A comparison of forward neutron yields on the HGND prototype from electromagnetic dissociation in ultraperipheral collisions and from nuclear interaction in central collisions is presented. The fraction of background events outside the target is estimated. Taking into account the acceptance and efficiency of neutron detection by the HGND prototype, the ratio of neutron yields from a nuclear reaction to EMD is in a good agreement within the errors with simulations.

LIGHT HYPERNUCLEI AT THE BOUNDARY OF NEUTRON STABILITY

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Modern nuclear physics relies on studies of nuclei with proton or neutron excess. The corresponding area of research in hypernuclear physics is also of particular interest. Weakly bound hypernuclei near the nucleon drip lines may allow to test hypernuclear interactions at low nuclear densities, such as those manifesting in halo systems.

Furthermore, the role of 3-body ΛNN force or density-dependent ΛN force, as well as charge symmetry breaking can also be further investigated in exotic hypernuclei [1,2]. Another interesting effect, and one we study in detail in this work, is the changes in binding of the system in response to addition of the Λ-hyperon to it. Due to their glue-like role, Λ-hyperons are able to stabilize loosely unbound non-strange nuclei, leading to formation of bound hypernuclei and thus shifting the nucleon drip lines on the hypernuclear chart as compared to the nuclear one.

Previously, we studied the light Λ-hypernuclei with an excess of protons [3,4]. The focus of this article is neutron-rich helium and lithium hypernuclei. The location of the neutron drip line is dictated by the change in the sign of the separation energy of one or two neutrons. For isotopes ^{7}He, ^{9}He and ^{10}Li, decay with the emission of one neutron is critical, whereas the two-neutron decay mode should be considered in ^{10}He. The experimental values of one/two neutron separation energies for these isotopes are negative. Since Λ-hyperons additionally bind nuclei, the goal was to test whether hypernuclei ${}^{8}_{\Lambda}$He, ${}^{10}_{\Lambda}$He, ${}^{11}_{\Lambda}$He and ${}^{11}_{\Lambda}$Li decay via neutron emission.

In this work, all calculations were performed using the Skyrme-Hartree-Fock method. This method is effective in realistic description of ordinary nuclei and can also be utilized to describe Λ-hypernuclei. We employed various parametrizations of nucleon-nucleon (NN) and hyperon-nucleon (ΛN) interactions for description of the basic characteristics of light exotic nuclei and hypernuclei.

To examine the boundness of isotopes ${}^{8}_{\Lambda}$He, ${}^{10}_{\Lambda}$He, ${}^{11}_{\Lambda}$He and ${}^{11}_{\Lambda}$Li, it is necessary to estimate their one- or two-neutron separation energies:

$$S_n({}^{A+1}_{\Lambda}Z) = S_n({}^{A}Z) + \delta B^n_\Lambda({}^{A+1}_{\Lambda}Z)$$

$$S_{2n}({}^{A+1}_{\Lambda}Z) = S_{2n}({}^{A}Z) + \delta B^{2n}_\Lambda({}^{A+1}_{\Lambda}Z)$$

where

$$\delta B^n_\Lambda({}^{A+1}_{\Lambda}Z) = B_\Lambda({}^{A+1}_{\Lambda}Z) - B_\Lambda({}^{A}_{\Lambda}Z)$$
$$\delta B^{2n}_\Lambda({}^{A+1}_{\Lambda}Z) = B_\Lambda({}^{A+1}_{\Lambda}Z) - B_\Lambda({}^{A-1}_{\Lambda}Z)$$

Here B_Λ is the Λ-hyperon binding energy equal to the difference between the binding energies of the hypernucleus and the corresponding nucleus:

$$B_\Lambda({}^{A+1}_{\Lambda}Z) = B.E({}^{A+1}_{\Lambda}Z)$$

$$B_\Lambda({}^{A+1}_{\Lambda}Z) = B.E({}^{A+1}_{\Lambda}Z) - B.E({}^{A}_{\Lambda}Z).$$

In order to determine the neutron separation energy in the considered hypernuclei, we used the values of the neutron separation energies in the corresponding nuclei

$$B_\Lambda({}^{A+1}_{\Lambda}Z) = B.E({}^{A+1}_{\Lambda}Z) - B.E({}^{A}_{\Lambda}Z).$$

In order to determine the neutron separation energy in the considered hypernuclei, we used the values of the neutron separation energies in the corresponding nuclei $S_n(^7\mathrm{He})$, $S_n(^9\mathrm{He})$, $S_n(^{10}\mathrm{Li})$ and $S_{2n}(^{10}\mathrm{He})$, as well as the hyperon binding energy $B_\Lambda(^7\mathrm{He})$ also known from experiment. The Skyrme-Hartree-Fock approach was employed for calculating the remaining values. The table displays the experimental values of the neutron separation energies in the nuclei and the range of estimations for the extra binding energy, δB_Λ for the respective hypernuclei.

Isotope	S_n or S_{2n}, MeV	δB_Λ, MeV
^{7}He	$S_n = -0{,}41 \pm 0{,}008$	$0{,}97 \div 1{,}62$
^{9}He	$S_n = -1{,}25 \pm 0{,}05$	$0{,}41 \div 0{,}57$
^{10}Li	$S_n = -0{,}026 \pm 0{,}013$	$0{,}50 \div 0{,}69$
^{10}He	$S_{2n} = -1{,}44 \pm 0{,}09$	$0{,}78 \div 1{,}12$

We inferred from our calculations that hypernuclei ${}^{8}_{\Lambda}$He and ${}^{11}_{\Lambda}$Li appear to be bound as a result of the values of δB_Λ exceeding the value of the neutron separation S_n energy in the nucleon core. Adding a Λ-hyperon to ${}^{10}_{\Lambda}$He and ${}^{11}_{\Lambda}$He, on the other hand, does not result in formation of bound hypernuclei.

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CENTRALITY ASSESSMENT OF Xe+CsI@3.8AGeV COLLISIONS USING FORWARD DETECTORS AT BM@N EXPERIMENT

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An experimental study on the interaction of xenon nuclei with a cesium iodide target was conducted at the BM@N facility, employing incident beam kinetic energies of 3.8 GeV and 3.0 GeV per nucleon. The BM@N setup is equipped with forward detectors, namely the Forward Hadronic Calorimeter (FHCal) and the Forward Quartz Hodoscope (FQH), designed to determine the geometry of nuclear collisions. This report explores the feasibility of utilizing correlations between the responses of the forward detectors to determine the centrality of nucleus-nucleus collisions, as well as their application in pileup analysis.

PERFORMANCE OF THE ELECTROMAGNETIC CALORIMETER ALICE/PHOS AND NEUTRAL MESON PRODUCTION RESULTS

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The ALICE experiment at the LHC is designed to explore the properties of the quark-gluon plasma – hot and dense medium produced in ultra-relativistic heavy-ion collisions. The photon spectrometer (PHOS) of the ALICE experiment is a high-granularity $PbWO_4$ crystal calorimeter which is intended to measure neutral meson spectra and direct photons in different colliding systems.

In this talk we report an overview of the PHOS performance during Run 2 and Run 3 and present recent results from ALICE on the neutral meson measurements in pp, p-Pb, and Pb-Pb collisions.

OPTICAL-MODEL ANALYSIS OF THE DEUTERON ELASTIC SCATTERING ON ^{12}C NUCLEUS WITH RESONANT PART CONTRIBUTION

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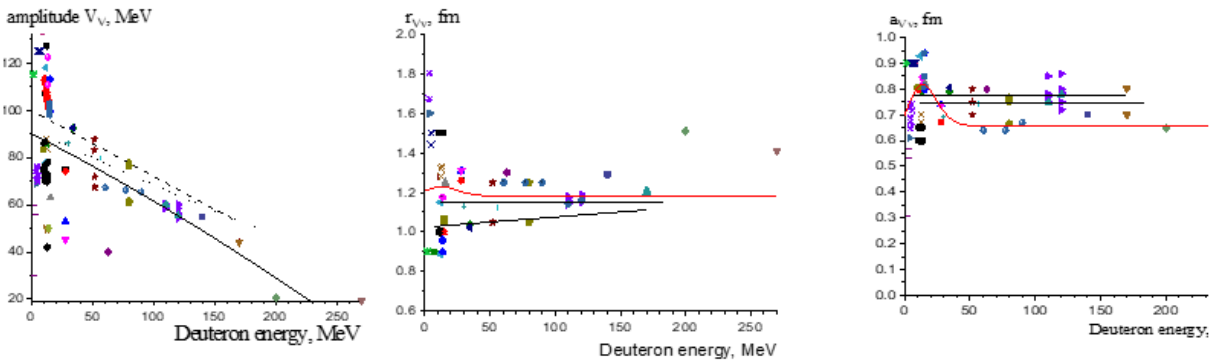
The fitting of all available experimental data of deuteron elastic scattering on ^{12}C nucleus (differential cross sections at deuteron energies from 0.45 to 270 MeV and total ^{12}C+d reaction cross sections from 0.43 to 171 MeV) with the use of the resonant optical-model code OptModel [1,2] was performed. Violation of scattering matrix unitarity (optical-model + resonance) at several energies did not exceed 15% what corresponds to the mean errors of the data analyzed. Energy dependences of amplitude VV, radius rVv and diffuseness aVv of the real volume potential obtained at the present work (solid bold line) and values presented from literature (other symbols) were shown in fig.1 a-c, respectively.



a *b* *c*

Fig. 1

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NUCLEAR SCANNING MICROPROBE IN THE STUDY OF 12X21H10T STEEL AFTER DYNAMIC LOADING

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The results of complex investigation of the steel after dynamic loading with the use of atomic-force microscope (AFM) and Nuclear scanning microprobe (NSMP) are presented. The comparison of AFM-images with the results of NSPM mapping in order to phase composition identification is carried out. The sizes of the grain and carbide inclusions are determined, structure characteristics of the main and deformation micro and nanostructures are shown. The dramatic difference in structure and chemical heterogeneity in the center of damage and far away from it is shown. The results will be useful in the studies of spall fracture damage and deformation processes in the physical mesomechanics context.

PROPERTIES OF CHARGED MESONS ($\pi\pm$) AND PROTONS IN CENTRAL pC-, -dC-, αC-, AND CC- COLLISIONS AT A 4.2 A GeV/c FIRST IMPULSE

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The peculiarities of nucleus-nucleus interactions can be seen in the study of the mechanism of these interactions depending on the degree of centrality of the events under consideration. The interaction of high-energy nuclei with the target nucleus allows for multinucleon collisions [1]. In this paper, to determine the degree of centrality of the collisions, we take the "net"charge Q: for pC interactions Q = n+- n– prp, where n+ and n- are the number of single-charged positive and negative particles in the case of npevp, the number of evaporating protons; for other collisions Q = n+- n– nps- nts, where nps and nts are the number of stripping protons from the projectile nucleus and the target nucleus, respectively. As nps- we take as nps- particles with P>3 GeV/c and departure angle $\theta < 4°$. Protons with momentum P<0.3 GeV/c were considered to be proton spectators of the target nucleus [2].

Experimental material obtained with a two-metre-long propane bubble chamber of the JINR LWE placed in a magnetic field of 1.5 Tesla and irradiated at JINR with a beam of protons, deuteron nuclei, helium and carbon with a momentum of 4.2 A GeV/sec. The experimental data are compared with the predictions of the FRITIOF model [3,4], adapted to energies below 10 GeV. As the aiming parameter decreases, the number of secondary particles and the number of cascade interactions in the remaining nuclei increase. Therefore, one can expect preferential birth of nucleons in the fragmentation regions of the nuclei. In central collisions, because of the large number of primary interactions, the nucleon yield in the fragmentation regions should be minimal.

The correlation between the mean momenta of π-mesons and their mean departure angle leads to a weak dependence on Q of the mean transverse momenta of π-mesons for all AC interactions studied by us. For <pt> $\pi+$ -mesons, a weak (10%) increase with increasing Q is observed. The vast majority of π-mesons have transverse momentum up to 0.5 GeV/s, nevertheless, in the interactions under consideration there are hard collisions leading to the formation of π-mesons with large pt (0.5-1 GeV/s). Dependence of the mean velocities of π-mesons on the collision parameter of the studied AC collisions. It can be seen that in peripheral pC-, dC-, and αC-collisions (Q<2) π-mesons are formed predominantly in the central stability region (y=1-1,1). As the collision parameter increases, there is a shift of <y> to lower values, apparently due to π-mesons produced in secondary nucleon-nucleon collisions (this is clearly seen in pC collisions). In CC collisions, both $<y\pi^{-}>$ and $<y\pi^{+}>$ are practically independent of Q.

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МОДЕЛИРОВАНИЕ ТЕРАПЕВТИЧЕСКОГО КАНАЛА ЦИКЛОТРОНА У-120 ДЛЯ ЛУЧЕВОЙ ТЕРАПИИ БЫСТРЫМИ НЕЙТРОНАМИ

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Лучевая терапия быстрыми нейтронами считается эффективным методом лечения радиорезистентных форм рака, рецидивов опухолей после фотонного лечения, метастазов и других видов рака. Такие преимущества терапии быстрыми нейтронами перед стандартным облучением как более высокое значение линейной передачи энергии; меньшая зависимость от кислородного эффекта; снижение влияния сепаративных способностей клеток позволяет применять данный тип терапии для лечения некоторых видов раковых заболеваний различной локализации. В связи с этим возникает необходимость наиболее точного определения дозиметрических и геометрических параметров нейтронного пучка.

Целью данной работы являлось моделирование формирования гамма-нейтронного поля терапевтического пучка. В рамках задач исследования проводилась оценка дозиметрических и геометрических характеристик распространения в воздушной и водной средах. Предполагается, что создание модели выводного канала позволит повысить качество терапевтических процедур путём более точного предсказания взаимодействия терапевтического пучка с различными материалами и тканями.

В качестве источника пучка быстрых нейтронов в Томском политехническом университете применяется циклотрон У-120. Поток быстрых нейтронов формируется в результате реакции ^{9}Be(d, n)^{10}B, что приводит к формированию гамма-нейтронного поля излучения. Вывод ускоренных частиц из циклотрона осуществляется в специальном оборудованном канале для терапевтических целей. Бетонная стена, в которой расположен коллиматор является разделителем между залом циклотрона и процедурным кабинетом. Геометрия терапевтического канала была воспроизведена при помощи программного кода Particle and heavy ion transport code system (PHITS v 3.31). Устройство нейтронного канала представляет собой усеченный конус, заключенный в защиту из 5%-борированного полиэтилена, окруженного стальными дисками. Наружный слой канала состоит из стальной трубы. Расчет параметров дозы нейтронного и фотонного излучений проводились в водном фантоме, который был смоделирован на выходе из терапевтического канала на расстоянии 110 см от мишени.

Анализ выходных данных позволяет оценить вклад каждого вида излучения в суммарную дозу. Отношение гамма-компоненты к нейтронной компоненте поглощенной дозы зависит от глубины и среды, в котором происходит моделирования. В воздушной среде на выходе из канала до взаимодействия с моделью водного фантома данное отношение является слабо меняется и составляет около 14%. На поверхности водного фантома отношение составляет 3,3% и экспоненциально возрастает до величины 14% на глубине 20 см. Мощность дозы напрямую зависит от тока пучка в мкА. Расчет мощности дозы в фантоме показывает сходимость результатов моделирования и базовых параметров мощности дозы, применяемых для планирования нейтронной лучевой терапии в пределах 3%.

Создание модели терапевтического канала позволит более точно изучить процесс взаимодействия нейтронного пучка с различными средами, а следовательно повысить качество терапевтических процедур.

DEFORMED SHELLS IN MASS AND ENERGY DISTRIBUTIONS OF FISSION FRAGMENTS OF ^{237}Pu COMPOUND NUCLEI FORMED IN ^{233}U(α, f) REACTION AT 29 MeV ALPHA PARTICLE ENERGY

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Mass and energy distributions of fission fragments are formed under the influence of various effects in the fissile nucleus starting from classical charged liquid droplet effects, adding effects of spherical nuclear shells and finishing with deformed nuclear shells. The latter have come more into focus of research in recent years. We present short history of research of deformed nuclear shells and show how they can be used to decompose mass and energy distributions of fission fragments of ^{237}Pu compound nuclei formed in ^{233}U(α,f) reaction at 29 MeV alpha particle energy into yields from charged liquid droplet effects, effects of spherical and deformed nuclear shells. The experiment was carried out at U-150M cyclotron at Institute of Nuclear Physics, Almaty, Kazakhstan. Fission fragments were identified using 2E method.

STUDY OF CONTINUOUS ENERGY SPECTRA FROM THE REACTIONS ^{60}Ni(p,xp) AND (p,xα) AT A PROTON ENERGY OF 22 MeV

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Experimental and theoretical studies of continuous energy spectra of secondary light particles formed as a result of the interaction of nuclei with nuclei in a wide range of energies make it possible to trace the dynamics of the formation and evolution of an excited system to a state of equilibrium, which remains an urgent problem in the theory of nuclear reactions [1]. It should be noted that such experimental data are in demand in many applied fields of science, in particular, for correct modeling of processes occurring in the structural materials of designed nuclear power plants. An example of such a facility is a hybrid electronuclear facility (Accelerator Driven System, ADS), consisting of a high-energy proton accelerator and a subcritical reactor [2, 3]. Such a system makes it possible to obtain sufficiently high neutron fluxes, which can be used to generate energy, transmutate radiotoxic isotopes, or produce tritium for thermonuclear sources.

Experimental data were obtained using the extracted proton beam from the U-150M isochronous cyclotron of the Institute of Nuclear Physics [2]. Charged ions of the required type are produced in a source located in the central part of the cyclotron chamber. Their acceleration occurs in the interpolar space of a 1.5-meter magnet at the moment the particles fly between the dees. The ion beam, accelerated in the cyclotron chamber, is then transported along the ion guide path to the reaction chamber. The energy of the incident protons was 22 MeV. A self-supporting isotope foil made of enriched ^{60}Ni isotope was used as a target. To select the desired type of particles, the dE-E method was used, where two parameters of the detected particle are recorded: specific ionization and total energy.

Cross sections for nuclear reactions were obtained in the angular range of 300 – 1350. Known states of final nuclei. Systematic errors in the measured cross sections are caused mainly by errors in determining the target thickness (no more than 5%), calibration of the current integrator (no more than 1%), and the solid angle of the spectrometer (no more than 1.3%). The energy of the accelerated particle beam was measured with an accuracy of 1%. The total error of the measured cross sections did not exceed 15%.

The theoretical analysis of the experimental results obtained was carried out within the framework of the TALYS calculation code, which is based on a modified version of the excitonic model of pre-equilibrium nuclear decay [4]. Modern versions of this model, based on separate consideration of neutron and proton degrees of freedom, describe the entire process of relaxation of an excited nuclear system, starting from the simplest quasiparticle configurations and ending with the establishment of statistical equilibrium. From a comparison of experimental and theoretically calculated integral ones, the contribution of various nuclear reaction mechanisms to the formation of continuous spectra was determined.

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NEUTRON DETECTION EFFICIENCY OF SCINTILLATION DETECTORS

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The results of measurements of neutron detection efficiency $\varepsilon(En)$, $En \approx 0.1-6$ MeV for detectors of MULTI setup [1, 2] are presented. The measurements of $\varepsilon(En)$ for scintillation detectors (CeBr3, NaI(Tl), CsI(Tl), stilbene) were carried out by tagged neutron method using

^{239}Pu/^{9}Be and ^{238}Pu/^{13}C n-γ sources and Trigger-detector (see 2 in Fig.1). Trigger-detector was used for registering γ-quanta with $E_\gamma = 4.43$ MeV and 6.13 MeV from sources ^{239}Pu/^{9}Be and ^{238}Pu/^{13}C respectively. Neutron energy values was taken from the time of flight TOF. Time scale of TOF was calibrated by γ-γ coincidence measuring (Single escape and Double escape peaks in Trigger detector and annihilation γ-peak in tested detectors).

The measurements have shown that CeBr3, NaI(Tl), and CsI(Tl) detectors have a relatively high neutron detection efficiency which is weakly dependent on the energy at $En \approx 0.5-6$ MeV and can be used for neutron detection by TOF. For example, efficiency is $\varepsilon(En) \approx 36\%$ at $En = 0.5-6$ MeV for CeBr3 $5 \times 5 \times 5$ cm^3 detector.

Stilbene detectors have good n-γ pulse shape separation, but sharp energy dependence of the efficiency $\varepsilon(En)$ at energy range $En \approx 0.5-6$ MeV ($\varepsilon \approx 50\%$ and 10% for $En = 0.5$ MeV and 6.0 MeV, respectively).

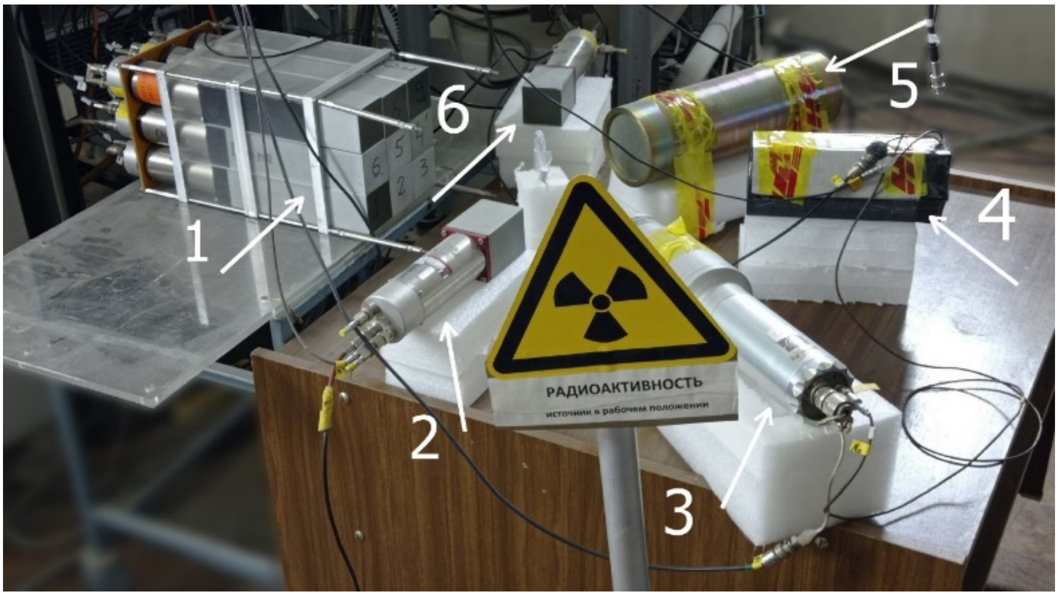

Fig.1 Scheme of measurement 1-$CeBr_3$-NaI(Tl) phosvich, 2-$CeBr_3$№1(Trig.), 3-NaI(Tl), 4-CsI, 5-$C_{14}H_{12}$ (stilbene), 6-$CeBr_3$№2

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МОДЕЛИРОВАНИЕ ЭФФЕКТИВНОСТИ РЕГИСТРАЦИИ МГНОВЕННЫХ НЕЙТРОНОВ ДЕЛЕНИЯ НА УСТАНОВКЕ ДЛЯ ИССЛЕДОВАНИЯ СВОЙСТВ МГНОВЕННЫХ НЕЙТРОНОВ ДЕЛЕНИЯ ЭНГРИН

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В ЛНФ ОИЯИ создана установка ЭНГРИН для исследования свойств мгновенных нейтронов деления (МНД), испущенных в процессе вынужденного или спонтанного деления трансурановых ядер. Установка состоит из двойной ионизационной камеры с сетками Фриша и мульти модульного детектора МНД. Детектор МНД включает в себя 32 модуля детектирования МНД, заполненных сцинтилляционной жидкостью BC-501, используемой для регистрации МНД. Установка позволяет измерять кинетические энергии, массы и направления движения осколков деления. Детектор МНД обладает свойством разделения нейтронов и гамма-квантов путем анализа формы импульсов. В данной работе приведены результаты моделирования эффективности детектирования МНД на данной установке.

CHARGE PION FORM FACTOR IN THE BETHE-SALPETER APPROACH WITH SEPARABLE KERNEL

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The charge pion form factor is calculated using the solution of the integral equation of Bethe-Salpeter for a quark-antiquark system. The phenomenological interaction potential in a separable form (rank I) is used to solve the equation. When calculating the charge pion form factor, the contributions of a one-particle current (relativistic impulse approximation) and a two-particle interaction current are taken into account. The resulting expressions are four-dimensional integrals with poles of the first and second order. Integrals are calculated numerically by two different methods: the Feynman parameterization method and the Cauchy theorem method. The charge form factors calculated by two methods coincide within the statistical accuracy. The physical constants of the pion decay are also calculated. The dependence of the charge form factor on the model parameters and the type of vertex function is investigated. In addition, comparisons of the obtained results with experimental data are given.

РАДИАЛЬНАЯ ЗАВИСИМОСТЬ ЭФФЕКТИВНОЙ МАССЫ НУКЛОНОВ И СВОЙСТВА ОСНОВНОГО СОСТОЯНИЯ

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Теоретическое и экспериментальное исследование нейтронно-избыточных ядер является одним из самых интересных и богатых источников новых сведений о структуре атомного ядра. Сложность изучаемого объекта определяет многообразие и неожиданность его свойств и предъявляет повышенные требования к теории, призванной описывать эти экзотические свойства [1]. Одним из наиболее успешных методов изучения структуры атомного ядра является подход, базирующий на самосогласованном среднем поле [2]. В таком подходе эффективное взаимодействие между нуклонами представляют в виде функционала плотности энергии (ФПЭ). Это позволяет достичь качественного описания свойств основного состояния атомного ядра вплоть до границ ядерной стабильности. Однако в рамках самосогласованного подхода наблюдается заметное отклонение теоретических расчетов от экспериментальных значений при описании одночастичного спектра. Как было показано в работе [3], учет радиальной зависимости эффективной массы нуклонов в ФПЭ Скирма приводит к увеличению плотности одночастичных состояний около поверхности Ферми. Однако учет данной зависимости требует незначительной модификации ФПЭ Скирма. В данной работе изучено влияние радиальной зависимости эффективной массы нуклонов на свойства основного состояния магических ядер ^{40,48}Ca, ^{56,78}Ni, ^{100,132}Sn и ^{208}Pb. Показано, что ФПЭ типа Скирма, учитывающий радиальную зависимость эффективной массы нуклонов, улучшает описание экспериментальных данных, а именно, плотность одночастичных состояний около поверхности Ферми [4].

Исследование было поддержано в рамках научной программы Национального центра физики и математики, направление No.6 «Ядерная и радиационная физика» (этап 20232025).

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LATEST RESULTS FROM DOUBLE CHOOZ

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Double Chooz (DC) is a reactor neutrino experiment aimed to precise measurements of the neutrino oscillation parameter θ_{13}. The latest measured DC value for the θ_{13} is $sin^2(2\theta_{13}) = 0.102 \pm 0.011(syst.) \pm 0.04(stat.)$[1]. The experiment has completed data-taking. During the decommissioning of the detectors the mass measurements has been taken again for one of the detectors volume, the Gamma-Catcher. The final analysis is in progress and it is expected that the total uncertainty $\sigma_{sin^2(2\theta_{13})}$ will reduce from 0.012 to 0.0105 [1]. The overall status and the final detection systematics is presented including the new proton number.

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CHARACTERISTICS OF ALPHA-DECAY OF ACTINIDES

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В работе изучается зависимость тонкой структуры альфа-распада четно-четных ядер актинидов. В рамках подхода, основанного на модели двойной ядерной системы, спектроскопические факторы альфа-распада определялись диагонализацией коллективного гамильтониана по координате массовой асимметрии. Для расчета зависимости спектроскопического фактора от углового момента учитывалось относительное движение альфа-частицы и дочернего ядра [1]. Показано, что эта зависимость существенным образом определяется параметрами деформации тяжелого ядра.

Для отличного от нуля спектроскопического фактора для переходов в состояния с нечетным угловым моментом необходимо ввести октупольную деформацию дочернего ядра. Для расчета туннелирования через барьер по координате относительного расстояния использовался двухпотенциальный подход [2,3]. Учитывалась возможность изменения углового момента из-за нарушения сферической симметрии потенциала по координате относительного расстояния, связанного с деформацией дочернего ядра. Разработанная модель была применена для анализа тонкой структуры цепочек изотопов Ra, Th, U и Pu.

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$\Delta 0$-ISOBAR FORMATION IN CENTRAL $p^{12}C$- AND $d^{12}C$-COLLISIONS AT 4.2 A GeV/c

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In the present work, we present new experimental data on the different characteristics of $\Delta 0$-isobars formed in central $p^{12}C$- and $d^{12}C$- collisions at 4.2 A GeV/c.

Since the average number of protons in both collisions was found to be close to 1 (see Table), those $p^{12}C$- and $d^{12}C$- collisions in which the number of participating protons is ≥ 3 were considered to be central collisions. Figs. 1 show the mass spectra of $\Delta 0$-isobars in the considered collisions.

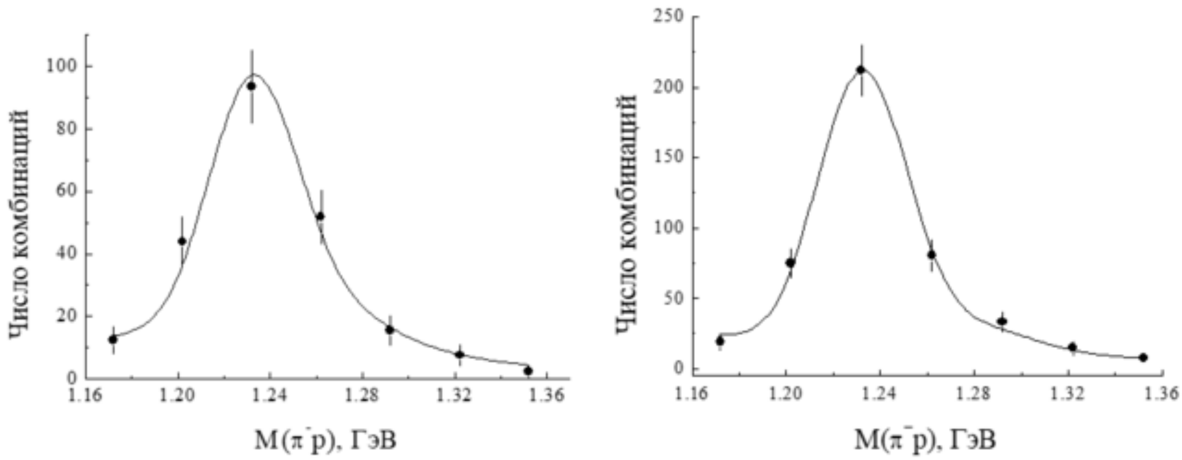

Fig.1. Effective mass distribution of π-p -pairs in the central collisions of $p^{12}C$ interactions at 4.2 GeV/c; Effective mass distribution of π-p -pairs in the central collisions of $d^{12}C$ interactions at 4.2 GeV/c

The curves in the figures are the result of approximation of the experimental spectra of the effective masses of proton and π-pairs M(π-p) by the relativistic Breit-Wigner formula [1]. Width of the mass spectrum of $\Delta 0$-isobars, in both types of collisions close to each other.

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ОПРЕДЕЛЕНИЕ ЭНЕРГИИ α-РАСПАДА НА ОСНОВЕ МАССОВЫХ СООТНОШЕНИЙ

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С момента открытия α-распада, одного из основных каналов распада нестабильных атомных ядер, не прекращается его интенсивное изучение. Особо актуальны данные исследования в области сверхтяжелых элементов, поскольку в процессе синтеза новых изотопов ключевым моментом в их идентификации является наблюдение соответствующей цепочки α-распадов [1].

Методики с использованием массовых соотношений, связывающих соседние ядра, давно и успешно применяются для предсказания масс неизвестных ядер. Ранее эффективность метода, основанного на соотношении для остаточного np-взаимодействия, была показана на примере характеристик α-распада для изотопов $Z \leq 106$ [2]. В докладе представлены результаты для ядер вплоть до $Z = 118$, полученные как с использованием локальных массовых соотношений для энергий связи, так и на основе экспериментальных значений Q_α. Также на основе современных экспериментальных данных проведен отбор соотношений и получены новые параметризации для аппроксимаций периодов полураспада по альфа-каналу.

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SPONTANEOUS AND INDUCED TERNARY FISSION WITH DIFFERENT THIRD PARTICLE EMISSION

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Using the virtual approach [1,2] to describe the ternary fission as a two-stage process in which, after the light particle emission, the virtual state of the intermediate nucleus is formed, the main characteristics of the third light particle are investigated. Calculations carried out in early works within the framework of this approach [3] demonstrated good agreement with experimental data on ternary fission with the prescission α-particles emission [4].

Using experimental data for the induced by thermal neutrons [5-7] and spontaneous [8-9] ternary fission ^{235}U, ^{239}Pu and ^{252}Cf, respectively, on the basis of Gamow's alpha decay theory, formation probabilities for the prescission light nuclei ^{6}He, ^{8}He, Li, Be in the parent nuclei were obtained.

It is shown that the energy of a thermal neutron introduced into a compound fissile nucleus during induced ternary fission does not affect the energy of the prescission third particles formed during ternary fission, which fly out, like an alpha particle, from the neck of a compound fissile nucleus. This energy is stored in the energy of the collective deformation states of the compound fissile nucleus in the prescission region where the nucleus is divided into two fission fragments. It is also demonstrated that the values of energies, yields and formation probabilities calculated for prescission light particles are close in spontaneous and induced ternary fission of nuclei.

Using the results of [10], it is shown that the concept of virtuality of spontaneous and induced ternary fission with the emission of third light nuclei successfully describes the most important characteristics of this process (yields, angular and energy distributions of third particles), which allows a deeper understanding of the theory of atomic fission.

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METHODS FOR CENTRALITY DETERMINATION AT THE BM@N EXPERIMENT

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In heavy-ion collisions the produced strongly interacting matter whose evolution depends on the collision initial geometry, defined by centrality. Experimentally collisions can be characterized by the measured multiplicities or energy of produced particles and spectator fragments. The relation between collision geometry and experimental measured multiplicity is evaluated using the Monte-Carlo Glauber approach.

We will present the procedure for centrality determination using multiplicities of the produced particles in Xe+Cs(I) collisions at the BM@N experiment.

РАДИАЦИОННЫЕ ПОВРЕЖДЕНИЯ SiC- И Si-ДЕТЕКТОРОВ ПОСЛЕ ОБЛУЧЕНИЯ АЛЬФА-ЧАСТИЦАМИ

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Представлены результаты исследования детекторов из карбида кремния (SiC) [1, 2] и кремния (Si). Облучение проводилось с помощью 4-х образцовых спектрометрических α-источников (ОСАИ) с энергиями E = 4,8 $\div$ 7,7 МэВ. Толщина эпитаксиального слоя n-типа SiC-детекторов составляла 25 и 50 мкм. Контакты Шоттки диаметром 3,0 мм были изготовлены путем вакуумного испарения двойного слоя Ni и Au. Исходное энергетическое разрешение детекторов составляло $<$ 25 кэВ. Si-детекторы изготовлены по планарная технология на кремнии n-типа. Контакты — имплантация B и P (+Al). Рабочая площадь 2.6×2.6 мм^2, толщина 300 мкм.

Радиационная стойкость SiC- и Si-детекторов исследовалась до и после облучения альфа-частицами с интегральными потоками до $1.1{\times}10^{11}$ α/см^2. Показано, что после облучения α-частицами наблюдалась значительная деградация: пики от α-частиц сместились в сторону меньших каналов и стали шире. Установлено, что с увеличением дозы облучения энергетическое разрешение ухудшается в 2.8-11.5 раз для SiC 50 мкм, в 1.5-3.4 раза для SiC 25 мкм и в 1.5-1.8 раза для Si. При этом эффективность сбора заряда (CCE) снизилась со 100% до 86% (рабочее напряжение 200-300 В) для SiC 50 мкм, со 100% до 94% (рабочее напряжение 200 В) для SiC 25 мкм и со 100% до 98% (рабочее напряжение 100 В) для Si при дозе α-излучения $\sim 1.1 \times 10^{11}$ α/см^2 соответственно.

Работа поддержана грантом ОИЯИ для молодых специалистов № 23-202-03.

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SEARCH FOR MUON CATALYZED d^{3}He FUSION

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This report presents the results of an experiment aimed at observation of the muon catalyzed d^{3}He fusion reaction which might occur after a negative muon stop in the D2+^{3}He(5%) gas mixture. The basic element of the experimental setup is a Time Projection Chamber (TPC) which can detect the incoming muons and the products of the fusion reaction. The TPC operated with the D2+^{3}He(5%) gas mixture at 31 K temperature. The results of experimental data will be present and compared with the previously published data.

ПРОГРАММНЫЙ КОМПЛЕКС ДЛЯ СБОРА И ОБРАБОТКИ ДАННЫХ С ПРИМЕНЕНИЕМ ПЛАТ CAEN

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Представлены результаты разработки DAQ (data acquisition) системы для сбора и обработки данных с блоков Flash ADC и TDC (time to digital converter) фирмы Caen. Проведен сравнительный анализ скоростных характеристик передачи данных по шине Optical link и VMEBus плат разных версий с различными изначальными конфигурациями внутренних буферов памяти, а также по типу подключения к персональному компьютеру.

Показан вариант организации сбора данных, как в режиме одиночного блока, так и в режиме множественного подключения через контроллер Caen v2718-v3718 с использованием механизма прерываний.

Описан подход клиент-серверного взаимодействия между основной DAQ системой и удаленным пользовательским интерфейсом. Кратко приведен обзор промежуточного кеширования данных, способы и виды их записи на основной носитель информации.

Дан краткий обзор реализованного функционала обработки накопленных спектров, в том числе инструменты калибровки, автоматического детектирования пиков в заданной области и точечного исследования спектра.

INVESTIGATION OF ANGULAR CORRELATION IN REACTIONS OF INELASTIC SCATTERING OF NEUTRONS WITH ENERGY 14.1 MeV ON ^{12}C

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The knowledge about (n,γ) and (n,n'γ) correlations is very useful for understanding the process of inelastic neutron scattering and for estimation of the influence of the direct and compound nucleus (CN) mechanisms on the nuclear reaction. A detailed review of the CN approach is presented in [1], the direct mechanism is described in [2]. The formalism reported in [1] works quite well for low-energy particle scattering, but it fails to describe 14 MeV neutron scattering [3]. There are not too many experiments measuring (n,n'γ) correlation with 14 MeV neutrons, and the largest part of them was carried out more than 40 years ago with rather poor accuracy [4,5]. In recent years (n,n'γ)-correlation in the reaction of inelastic neutron scattering on ^{12}C was measured in work [6], but their results don't generally agree with previous experiments. Thus, it is interesting to obtain data on (n,n'γ)-correlation with small errors and higher angular resolution.

In Dubna, at the TANGRA setup, an experiment is being carried out to measure angular correlations (n, n'γ) in the inelastic scattering of neutrons with an energy of 14.1 MeV on ^{12}C using the tagged neutron method. We use 12 long (1 meter) plastic scintillation detectors with two PMTs. Ten of them are placed around the target in the plane of reaction and two detectors are placed perpendicular to the plane of reaction. These detectors have time resolution about 3ns and space resolution about 20cm that helps us to obtain better angular resolution and separate gamma-rays from neutrons by the time-of-flight.

In this report a theoretical approach will be proposed to describe the differential probability of gamma ray emission in the reaction of inelastic neutron scattering depending on the directions of the initial neutron, scattered neutron and gamma quanta for both direct and CN reaction mechanisms. This approach is based on invariant spherical functions of several vectors - see, for example, [7]. Our formula for angular correlations includes elements of the S-matrix, which can be obtained from the TALYS program, which calculates cross sections for nuclear reactions.

In this work we compare our theoretical approach with experimental data. Parameters of the model in TALYS were adjusted to fit data on neutron inelastic scattering and gamma-quanta angular distribution.

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FORMATION OF PROTONS AND DEUTRONS FROM THE INTERACTION OF DEUTRONS WITH AN ENERGY OF 14.5 MeV WITH COBALT

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Programs to develop a new generation of nuclear power systems with a high level of safety (Accelerator Driven System), consisting of a proton accelerator, a neutron-producing target and a subcritical reactor, have been deployed in many countries. When creating such devices, for correct modeling of the neutron flux, data on the spectral composition and angular distributions of secondary protons and light charged particles produced by the primary proton beam is required [1]. Experimental data on reactions in which light complex particles (deuterons, tritons, ^{3}He and α particles) are in the input and/or output channels are very limited. It is worth noting that the presence of such experimental data directly affects the quality of existing theoretical models and increasing their predictive power [2].

New experimental data on reactions (d,xd) and (d,xp) on the ^{59}Co nucleus at $E_d = 14.5$ MeV were obtained at the U-150M isochronous accelerator of the Russian State University of Nuclear Physics. A self-supporting 3.5 μm thick natural cobalt foil was used as a target. The thickness and uniformity of the target used was determined by measuring the energy loss of alpha particles (^{226}Ra preparation). The reaction products were recorded with an ΔE–E telescope. Double-differential and integral cross sections of emitted deuterons were measured in the angle range $30° - 135°$ in the laboratory mass system. Energy calibration was carried out using peaks corresponding to the known states of the final nuclei. The total error of the measured sections usually did not exceed 10% for all angles.

The experimental data were analyzed within the framework of the phenomenological exciton model of pre-equilibrium decay within the framework of the Talys calculation code. The developed fast methods for solving kinetic equations have opened up the possibility of studying multiparticle particle emission. The exciton model simultaneously describes the energy spectra of not only nucleons, but also complex particles. In addition to calculations within the framework of the exciton model, calculations were carried out within the framework of other mechanisms of nuclear reactions: direct processes (transfer - nucleon knockout, inelastic scattering) and equilibrium radiation using the Hauser-Feshbach compound nucleus decay formalism. It has been determined that the cross section under study is predominantly formed by pre-equilibrium decay mechanisms. The contribution of single-stage direct processes is negligible.

The experimental results obtained supplement the nuclear database on reaction cross sections and can be used in the design of safe and waste-free hybrid nuclear power plants.

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РАЗРАБОТКА МЕТОДОВ ОБРАБОТКИ ОЦИФРОВАННЫХ СИГНАЛОВ ДЛЯ ЭКСПЕРИМЕНТАЛЬНЫХ УСТАНОВОК ПРОЕКТА TANGRA

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Для γ-спектрометрии высокого разрешения в проекте TANGRA [1] используются два полупроводниковых детектора из особо чистого германия (HPGe) с зарядочувствительными предусилителями. При большой загрузке детекторов возникает эффект наложений сигналов [2], для учета которого требуется применение специализированной методики обработки сигналов.

В экспериментах проекта используются разработанные в ОИЯИ оцифровщики «ЦРС», работающие под управлением разработанного в рамках проекта TANGRA программного обеспечения «Romana». Снизить эффект наложения сигналов при большой загрузке детектора можно уменьшив длину обработки оцифрованного сигнала. Однако как следствие энергетическое разрешение (FWHM) существенно ухудшается. Поэтому были разработаны несколько методов цифровой обработки сигналов и найдены оптимальные параметры для улучшения энергетического разрешения при высокой загрузке детекторов.

В докладе будут представлены исследования по оптимизации параметров нескольких методов обработки оцифрованных сигналов от HPGe-детекторов.

OPTIMIZATION OF THE MULTILAYER DETECTOR SND (SCATTERING NEUTRINO DETECTOR) FOR NEUTRINO PHYSICS AND PHYSICS BEYOND THE STANDARD MODEL

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The **SHiP** (Search for Hidden Particles) experiment at the SPS at CERN is aimed at searching for particles beyond the Standard Model. **SHiP** is a fixed target experiment with a 400 GeV proton beam energy.

For neutrino physics tasks and the search for light dark matter particles in **SHiP**, it is planned to use the neutrino detector **SND** (Scattering and Neutrino Detector), consisting of a sequence of layers of magnetized iron (1.7 T) as an absorber, a **SciFi** tracker in the form of scintillating fibers with a diameter of 250 μm, and layers of scintillator (**Sci**) with a thickness of 1.5 cm and granularity of 1 cm $\times$ 1 cm, which will register energy deposition.

To reconstruct the interaction pattern in the neutrino detector of all flavors or hidden particles, it is necessary to determine the momentum and energies of all particles produced in deep inelastic neutrino scattering and in the decay of short-lived particles—tau leptons or charm mesons, and the interaction vertex in the detector material.

Simulation of neutrino interaction with iron was carried out based on the **GENIE** v3 neutrino event generator. The response in the tracker and scintillators was modeled using the **GEANT4** software package. It is assumed that the momentum of the particle will be determined by the curvature parameter of its trajectory in the magnetic field. The average momentum determination error for muons was about 12%, while the accuracy of neutrino interaction vertex reconstruction based on tracker data was $\sim$1.5 cm. For the considered detector configuration, the energy resolution was $\sim 50\%/\sqrt{E}$ for pions with energies from 1 to 100 GeV. Signal image parameters in the scintillation matrix were used to determine interaction properties.

STATUS OF SOME PARTS OF THE TPC FOR THE MPD/NICA EXPERIMENT

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As part of the creation of a new accelerator complex NICA, a Multi-Purpose Detector (MPD) is being developed, the central part of which is a Time Projection Chamber (TPC).

The TPC being a large but conceptually simple detector must be constructed with very high precision to reduce nonlinear systematic effects. Together with the time of flight and inner tracker detectors, the TPC detector provides tracking, pattern recognition, vertex reconstruction and charged particle identification. High stability of the mechanical structure and uniformity of the drift field, the temperature, the drift gas purity and the gas gain have to be provided to get precise track reconstruction and energy-loss measurements. The TPC has a cylindrical body with a diameter of 2.8 m and length of 3.4 m and is placed in the magnet with solenoidal field of 0.5 T. The sensitive volume contains around 17.6 m^3 of argon-methane mixture. The detector will register charged products of heavy ion collisions and provide registering events with a trigger rate up to 7 kHz.

The structure of the TPC, the basic design parameters of the TPC and the basic TPC configuration are provided. Status of some parts of the TPC are presented.

EFFECTIVE AND EQUIVALENT NUCLEON MASS IN BOUND THREE-NUCLEON SYSTEM

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The three-nucleon systems ^{3}H and ^{3}He can be considered assuming the neutron and proton as indistinguishable particles (AAA model) or taking into account the real masses of neutrons and protons (AAB model). We have focused on the AAA model, which is widely used for 3N calculations. The Faddeev configuration space calculations were perfumed to show a manifestation of the equivalence of mass m and energy E in a bound state of a three-nucleon system. We found that the dependence of the three-body energy on the nucleon mass, can be expressed by the formula dE/dm = const. Varying the averaged nucleon mass, we show the mass-energy compensation effect for the three-body Hamiltonian. Based on this findings we have determined the effective nucleon mass required to compensate for the perturbative effect of a three-body potential [1]. Additionally, we define "AAA equivalent nucleon mass"to take into account the difference of energies calculated within the AAA and AAB models related to the nucleons mass difference [2]. The equivalent nucleon mass corrects the AAA model to reproduce the experimental binding energy of the ^{3}H nucleus which is naturally AAB system.

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NEUTRINO QUANTUM DECOHERENCE DUE TO THE INTERACTION WITH MATTER

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The phenomenon of neutrino oscillations arises due to the coherent superposition of neutrino mass states.

The interaction between neutrinos and the external environment can disrupt this coherent superposition. This disruption is called neutrino quantum decoherence, and it leads to the suppression of flavor and spin-flavor oscillations. Previously, in [1–2] we presented a novel theoretical framework based on quantum field theory of open systems applied to neutrinos that allowed to describe the neutrino evolution taking in to account the neutrino decay. In this talk we present our studies on the process of neutrino quantum decoherence due to the neutrino scattering on external electron environment.

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STUDY OF PROTON INDUCED REACTIONS ON SCANDIUM AT THE ENERGY 100, 160 AND 200 MeV

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The study of nuclear reactions on scandium is of some interest for fundamental nuclear physics, since the number of protons in this nucleus is one more than the magic number "20". In addition, natural scandium is a monoisotope. Therefore, when it is irradiated with accelerated protons, it is easy to identify the channels of different reactions.

We have irradiated scandium targets with accelerated protons at energies of 100, 160 and 200 MeV. The irradiation was performed at the Prometheus proton therapy complex of the Physical-Technical Centre, Lebedev Physical Institute of the Russian Academy of Sciences. The irradiated targets were measured using Ortec and Canberra semiconductor spectrometers with ultrapure germanium detectors having an energy resolution of 1.8-2.0 keV for 1333 keV ^{60}Co gamma radiation. The detection efficiency of the spectrometers was determined using standard calibration sources ^{152}Eu, ^{226}Ra, ^{137}Cs.

Gamma transitions accompanying the decay of ^{45}Ti, ^{44}Sc, ^{43}Sc, ^{43}K, ^{42}K, ^{41}Ar, ^{39}Cl, ^{38}Cl, ^{38}S were reliably identified in the gamma spectra of the measured targets.

The table shows the cross sections of the studied reactions at a proton energy of 160 MeV. The experimental values were compared with theoretical values calculated in the framework of the constant temperature Fermi gas model [1] using the software code Talys 1.96 [3]. The results are discussed.

Table. Cross sections of the studied reactions at a proton energy of 160 MeV

Reaction	σ_{exp}, mb	σ_{Talys}, mb
^{45}Sc(p,n)^{45}Ti	0.80	0.970
^{45}Sc(p,pn)^{44}Sc	68,00	75.400
^{45}Sc(p,p2n)^{43}Sc	17.60	37,000
^{45}Sc(p,3p)^{43}K	1.63	0.420
^{45}Sc(p,3pn)^{42}K	8.80	2.350
^{45}Sc(p,4pn)^{41}Ar	0.76	0.244
^{45}Sc(p,5p2n)^{39}Cl	0.34	0.095
^{45}Sc(p,5p3n)^{38}Cl	2.20	0.080
^{45}Sc(p,6p2n)^{38}S	6.3×10^{-3}	4.8×10^{4}

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ТАБЛИЦА

CALCULATION OF DOSES TO PEDIATRIC PATIENTS FROM COMPUTED TOMOGRAPHY EXAMINATIONS

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Doses from CT examinations to reference 10- and 15-year-old patients were calculated using Monte-Carlo simulation in voxel phantoms. The exposure of patients of all age groups was simulated by consecutive calculation of exposures with 1 cm collimation each. The resulting table contained 139×H values of doses. 139 corresponds to the organs and tissues segmented in the phantom. H is the height of the patient in cm. The doses were stored in Microsoft Excel file. Further calculations resulted in reducing 139 lines of the file to 28 lines which correspond to the organs and tissues to calculate effective dose. The results show that there is a discrepancy in calculations depending on whether the deck is included in the model. The effect of relative position of phantom and rotation axis was studied. Normalized effective dose at 100 kV (Medium M bowtie filter for Toshiba Aquilion ONE CT scanner) falls from 1.73 mSv/(100 mAs) for 5 year old to 0.699 mSv/(100 mAs) which corresponds to fall by 60%. However, the absolute doses are multiplied by actual time-current product which increases with the thickness of the patient. The following suggestions were made during the calculations. 1) The number of organs and tissues which are used in the phantom could be reduced from 138 at least to 72 by calculating pair organs and extensive organs as single organs. The calculation of effective dose could be performed directly in Monte Carlo software by constructing the appropriate linear combination of organ and tissue doses with tissue weighting coefficients. 2) For the purpose of saving computer time calculation by region could be performed instead of slice-by-slice calculation. Five standard regions should be considered: head, neck, chest, abdomen and pelvis. 3) The accuracy of calculations should be preserved with the highest possible degree.

RECONSTRUCTION OF IMPACT PARAMETER DISTRIBUTION USING HADRON CALORIMETER

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Centrality determination is an important task because it allows one to estimate the collision system size in relativistic heavy-ion collisions.

With the help of centrality, it is also possible to compare the results of BM@N at NICA with data from other experiments and calculations of the oretical models. In this work is proposed a new approach for

centrality determination with the two-dimensional distribution the energy of spectator fragments and the multiplicity of charged particles and based on the inverse Bayes theorem.Centrality determination procedure was tested on NA61/SHINE data for Pb+Pb collisions at p_{lab} = 13A GeV/c.

EFFECTS OF LOW ENERGY X-RAY DOSES ON THE RIPENING OF LABA BANANA IN LAM DONG, VIETNAM

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This study investigates the impact of low-energy X-ray irradiation on the ripening process of Laba bananas in Lam Dong, Vietnam. This presented results on the delayed repining of bananas when irradiated at doses ranging from 0 to 800 Gy. In addition, the effect of filtering as well as irradiating one side and two sides of the banana was also carried out. The results show that the optimal irradiation dose for each banana side is 250 Gy, and using a 1mm thick aluminum filter, with this parameter, the ripening time is the longest and most cost-effective, while not reducing quality banana due to too high radiation dose.

MONTE CARLO SIMULATION FOR COINCIDENT PLASTIC SCINTILLATOR DETECTORS MONITORING RADON-NEUTRON INTERACTION IN SOIL FOR EARTHQUAKE EARLY WARNING SYSTEMS

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This study utilizes Monte Carlo simulation technique to model the detection apparatus employing plastic scintillators for recording photons produced by the interaction between radon and neutrons. Furthermore, the interactions of neutrons from cosmic, with the near surface atmosphere, along with radon present in the soil are investigated. The object/purpose is to establish correlations between abnormal radon levels and imminent seismic events, in suggestion of providing a prospective early warning mechanism for earthquakes.

FORMATION OF CORRELATED CHARGED PARTICLES AT ABSORPTION OF π^--MESON IN "LIVE" TARGET

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The results of measuring the energy spectra correlated at an angle of 180° of pairs of single-charged particles emitted by the nuclei of a "live" target at the absorption of stopped π^--mesons are presented. The Si detector (an analogue of the ^{28}Si target) was installed as a "live" target.

The use of a "live" target in the experiment makes it possible, simultaneously with the registration of the formed secondary particles (p, d, t), to measure the energy release in it itself. The energy release in the sensitive volume of the "living" target consists of energy losses of the incoming pion and the resulting particles, including the recoil core.

The energy spectra measured on a "live" target are interesting from the point of view of testing hypotheses about the mechanisms of formation of complex particles [2]. The large energy releases in the target are due to the high multiplicity of particles in the final state and indicate the significant role of incoherent processes in these reactions. At the same time, for reaction channels in which secondary processes are suppressed, the energy release in the target is near zero [3].

Analysis of the dependences of the average particle energies in pd, pt and dt pairs on the excitation energy of the nucleus showed that the deuteron in the pd pair is formed as a result of neutrons picking up protons on the surface of the nucleus. In turn, pt and dt pairs arise through the absorption of the π^--meson on the α-cluster, when the triton is a "direct" particle, and the other charged particles are secondary products of the intracellular interaction.

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HOLOGRAPHIC MODEL FOR NEUTRON STAR WITH COLOR SUPERCONDUCTIVITY IN THE INNER CORE

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In this holographic model, we use the 6d AdS black hole in Einstein-Gauss-Bonnet gravity for the dual to the color superconductivity in the inner core of the heavy neutron star and the baryonic matter dual to instanton gas. By holography, we find the equation of state of color superconductivity in the inner core of neutron star.