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FUNDAMENTAL PROBLEMS OF NUCLEAR PHYSICS, ATOMIC POWER ENGINEERING AND NUCLEAR TECHNOLOGIES

BOOK OF ABSTRACTS
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LXIV INTERNATIONAL CONFERENCE «NUCLEUS 2014». FUNDAMENTAL PROBLEMS OF NUCLEAR PHYSICS, ATOMIC POWER ENGINEERING AND NUCLEAR TECHNOLOGIES (LXIV MEETING ON NUCLEAR SPECTROSCOPY AND NUCLEAR STRUCTURE).
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The scientific program of the conference covers almost all problems in nuclear physics and its applications such as: neutron-rich nuclei, nuclei far from stability valley, giant resonances, many-phonon and many-quasiparticle states in nuclei, high-spin and super-deformed states in nuclei, synthesis of super-heavy elements, reactions with radioactive nuclear beams, heavy ions, nucleons and elementary particles, fusion and fission of nuclei, many-body problem in nuclear physics, microscopic description of collective and single-particle states in nuclei, theory of few-particles systems, non-linear nuclear dynamics, meson and quark degrees of freedom in nuclei, mesoatoms, hypernuclei and other nuclear exotic systems, double beta-decay and neutrino mass problem, interaction of nucleus with electrons of atomic shell, verification of theories of elementary particles interaction and conservation laws, physics of nucleus and particles in application to astrophysical objects, theory of direct and statistical nuclear reactions, theory of multiple scattering, theory of reactions with clusters and heavy ions, theory of relativistic nuclear collisions, theory of polarization phenomenon in nuclear reactions, theories of proton, two-protons and cluster radioactivity and fission of nuclei, instruments and methods of nuclear-physical experiment, analysis of measurements, accelerators, radio-ecology, application of nuclear-physical experimental methods to astrophysics, medicine and other fields of research, fundamental problems of nuclear power and nuclear technologies.

ISBN

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CONTENTS

CONFERENCE PROGRAM

July 1, Tuesday, 10:00

Plenary Session I

July 1, Tuesday, 15:30

Section I

Experimental Investigations of Atomic Nucleus Properties

July 1, Tuesday, 15:30
Section III
Theory of Atomic Nucleus and Fundamental Interactions

July 2, Wednesday, 9:00
Section II
Experimental Investigations of Nuclear Reactions Mechanisms

Sakuta S.B.
The channel coupling and triton cluster exchange effects in ^{3}He scattering on ^{6}Li nuclei. - 15 *min.* 86

Chuvilskaya T.V.
Investigation of fusion reactions ^{194}Pt(α,n)^{197mg}Hg and ^{195}Pt(^{3}He,n)^{197mg}Hg at near-barrier energies. - 15 *min.* 87

Joint talk:
Isomeric yields ratios of ^{238}U photofission fragments at end-point energy of bremmsstrahlung photons about 18 MeV. 88
Investigation of $^{178m2,\ 179m2}$Hf isomers creation in reactions with alpha-particles. 89
Reporter *Savrasov A.N.* - 15 *min.*

Joint talk:
The measurements of diffraction of the angular distributions of alpha particles with energies 29 MeV on nuclei ^{59}Co, ^{197}Au, ^{209}Bi. 90
The phenomenon of diffraction rise of cross sections in the forward hemisphere of angles as the effect of nuclear and cluster interference. 91
Reporter *Dyachkov V.V.* - 15 *min.*

Krutenkova A.P.
Fragmentation of carbon ions at 0.3—2.0 GeV/n: comparison with the models of ion-ion interactions. - 15 *min.* 92

Erdemchimeg B.
Study of projectile fragmentation of ^{40}Ar on ^{9}Be target at 40·*A* MeV. - 15 *min.* 93

Kotov D.O.
Light hadron production in Cu+Au collisions at 200 GeV. - 15 *min.* 94

Pritula R.V.
Mechanisms of hydrogen isotope formation during preequilibrium stage of stopped pion absorption reaction. - 15 *min.* 95

July 2, Wednesday, 9:00
Section III
Theory of Atomic Nucleus and Fundamental Interactions

Okhunov A.A.
Properties of rotational bands of isotopes Yb. - 15 *min.* 139

July 2, Wednesday, 9:00

Section V

Equipment, Methods and Automation of Nuclear Experiments, Interaction of Nuclear Radiation with the Matter and Applications of Methods of Nuclear Physics

Rozov S.V.
New phase of the EDELWEISS dark matter search experiment. – 20 *min.* 190

Yakushev E.
Development of setup for neutrino-nucleus coherent scattering observation. - 20 *min.* 191

Lyashuk V.I.
Neutrino factory on the base of intense neutron sources. - 15 *min.* 192

Tikhomirov V.V.
To the new sources for photo-nuclear reaction study. - 15 *min.* 193

Karamian S.A.
Prospects for the methods of radionuclide production. - 15 *min.* 194

Fomichev A.S.
EXPERT setup to study exotic radioactivity. - 15 *min.* 195

Kuchinskiy N.A.
Straw-detector with cathode read-out. - 15 *min.* 196

Rumiantcev M.M.
Time of flight system of the MPD. - 15 *min.* 197

July 2, Wednesday, 15:30

Section II

Experimental Investigations of Nuclear Reactions Mechanisms

Fedotov G.V.
Recent results on $\pi^+\pi^-$ electroproduction off protons. - 15 *min.* 96

Chesnokov V.V.
Estimates of exclusive channel cross-sections from the CLAS meson electroproduction data. - 15 *min.* 97

Isupov E.L.
New results of nucleon resonances studies in photo and electroproduction of charged pions in CLAS. - 15 *min.* 98

Skorodumina Iu.A.
$\pi^+\pi^-p$ electroproduction off the bound proton in resonance region with CLAS. - 15 *min.* 99

July 2, Wednesday, 15:30
Section IV
Nuclear Reactions Theory

Rouba A.A.
Birefringence of deuterons in an unpolarized target: theory and experiment. - 15 *min.* 166

Zelenskaya N.S.
The analysis of (t, p) reactions on ^{16}O nucleus. - 15 *min.* 167

Solovyev A.S.
The resonating group model description of the radiative capture reaction $^{3}He(\alpha,\gamma)^{7}Be$. - 15 *min.* 168

Platonova M.N.
Theoretical description of scattering in 3*N* system with account of dibaryon channels and 3*N* forces. - 15 *min.* 169

July 2, Wednesday, 15:30
Section V
Equipment, Methods and Automation of Nuclear Experiments, Interaction of Nuclear Radiation with the Matter and Applications of Methods of Nuclear Physics

Samedov V.V.
Fluctuations in the process of charge induction in semiconductor detectors with cylindrical geometry. - 15 *min.* 198

Shvetsova N.Yu.
Gas gain and aging rate of the gas discharge detectors. - 15 *min.* 199

Sytov A.I.
To the influence of single scattering on nuclei on the efficiency of the future LHC crystal-based collimation system. - 15 *min.* 200

Kuzhir P.
Heat resistant carbon nanotubes based in organic unfired ceramics for nuclear application. - 15 *min.* 201

Generalov L.N., Karpov I.A.
Application of $^{27}Al(p,\gamma_2)^{28}Si^*$ (4.618 MeV) resonance reaction excited at proton energy of 2.489 MeV in calibration experiments. – 15 *min.* 202

<u>Joint talk:</u>
Application of variations calculus methods for optimization of time-of-flight neutron spectrometer characteristics. 203
Improvement of dynamical characteristics of rhodium-based self-powered neutron detector. 204
Reporter *Kuten S.A.* - 15 *min.*

Abalonski D.
The results of numerical simulation of the detection device and measurement geometry for deep radiation monitoring. - 15 *min.* 205

Belousov A.V.
GEANT4 Monte Carlo calculated dosimetry parameters for ^{169}Yb. - 15 *min.* 206

Kadmenskii A.G.
High energy nuclei channeling. - 15 *min.* 207

Chuvilskaya T.V.
Copper fragmentation in nuclear reactions under impact of high energy cosmic protons. - 15 *min.* 208

July 3, Thursday, 9:00
Semiplenary Session I

Lukyanov V.K.
Theoretical analysis of inelastic pion-nucleus scattering within the microscopic optical potential. - 20 *min.* 32

Kadmensky S.G.
The properties of true quaternary nuclear fission with the taking into account it's multisteps and sequential character. - 20 *min.* 33

Tsekhanovich I.A.
A multi-parameter nuclear-fission experiment: why and how to measure all at once? - 20 *min.* 34

Barabanov M.
Search for charmonium and exotics with hidden charm and strangeness in antiproton-proton annihilation. - 20 *min.* 35

Artemenkov D.A.
Clustering features of light neutron-deficient nuclei in relativistic dissociation. - 20 *min.* 37

Barbui M.
Exploring the alpha cluster structure of nuclei using the thick target inverse kinematics technique for multiple alpha decays. - 20 *min.* 38

Skobelev N.K.
The population of isomeric states in fusion and transfer reactions with beams of weakly bound nuclei near the Coulomb barrier. - 20 *min.* 39

July 3, Thursday, 9:00
Semiplenary Session II

Kezerashvili R.Ya.
Lightest kaonic nuclei. - 20 *min.* 40

Severyukhin A.P.
Complex configuration effects on β-decay rates. - 20 *min.* 41

Rukhadze N.I.
New search for double electron capture of ^{106}Cd with the TGV-2 spectrometer. - 20 *min.* 42

Joint talk:
Dependence of branching coefficients for multidecay nuclei from *K*-shell population of their atoms in strongly heated medium. 43
Effect of atomic ionization on p-nucleus synthesis rate in extremely heated substance of massive star. 44
Effect upon characteristics of nuclear isomeric states by synchrotron radiation. 45
Reporter *Kopytin I.V.* - 20 *min.*

Gurevich G.M.
"Complete experiment" in meson photoproduction. - 20 *min.* 46

Joint talk:
Partial and total photoneutron reaction cross sections new data for ^{91,94}Zr isotopes. 47
Photodisintegration of ^{186,188,189,190,192}Os isotopes: likenesses and differences. 48
Reporter *Varlamov V.V.* - 20 *min.*

Joint talk:
Production of isotopes and isomers with irradiation of $Z = 47$ — 50 targets by 23 MeV bremsstrahlung. 49
Microstructure manifestations in nuclear reactions.
Reporter *Karamian S.A.* - 20 *min.* 50

July 3, Thursday, 15:30
Poster Session
Section I
Experimental Investigations of Atomic Nucleus Properties

Chechev V.P.
New evaluation of decay and radiation characteristics of ^{198}Au. 70

Section II
Experimental Investigations of Nuclear Reactions Mechanisms

Section III
Theory of Atomic Nucleus and Fundamental Interactions

Section IV
Nuclear Reactions Theory

Section V

Equipment, Methods and Automation of Nuclear Experiments, Interaction of Nuclear Radiation with the Matter and Applications of Methods of Nuclear Physics

Section VI
Fundamental Problems of Nuclear Power Engineering

Section VII
Experience and problems of high-quality training in nuclear physics, atomic power engineering and nuclear technologies

July 4, Friday, 9:00
Section IV
Nuclear Reactions Theory

Samarin V.V.
The quantum description of the coupling with neutron rearrangement channels in fusion reactions in the vicinity of Coulomb barrier. - 15 *min.* 176

Ivankov Yu.V.
The description of characteristics of two-protons decay of Fe-45 in the theory of two-steps two-proton decay. - 15 *min.* 177

Lubashevsky D.E.
The role of wriggling–vibrations of fissile nuclei for the formation of angular and spin distributions of neutrons and gamma-quanta evaporated by fission fragments. - 15 *min.* 178

Unzhakova A.V.
Clustering mechanism in fission and CCT channel formation. – 15 *min.* 179

July 4, Friday, 9:00

Section V

Equipment, Methods and Automation of Nuclear Experiments, Interaction of Nuclear Radiation with the Matter and Applications of Methods of Nuclear Physics

Verenich K.A.
Secondary neutrons generated by medical linear electron accelerator. - 15 *min.* 209

Mustafaeva S.N.
Aurum-doped $CdIn_2S_4$ single crystals for Roentgen detection. – 15 *min.* 210

Joint talk:
Radiation effects of near-field in gamma activated nanoparticles ZrO_2-catalystes in methanol conversion. 211
Element analysis of biological samples of children with different chronic diseases by accelerator base techniques. 212
Reporter *Dikiy N.P.* - 15 *min.*

Mamatkulov K.Z.
Implantation of ions ^{8}He, Kr and Xe in nuclear track emulsion. - 15 *min.* 213

Prokopev E.P.
Study of electronic properties of transition metals and alloys by positron annihilation spectroscopy. - 15 *min.* 214

Filosofov D.V.
^{44}Ti(^{44}Sc) - PAC study in TiO_2 and Sc_2O_3. - 15 *min.* 215

Lukashevich R.
Comparator units for metrological certification of weak *X*-ray and gamma radiation fields by dose rate. - 15 *min.* 216

Savderova N.V.
MuSun experiment: the control of impurities in ultraclean deuterium gas. - 15 *min.* 217

Ivshin K.A.
Cryogenic time–projection chamber for measurement of muon capture rate on the deuteron. - 15 *min.* 218

Nichyparchuk A.
"In situ" monitoring of soil contamination by multifunctional AT6101DR portable gamma spectrometer taking into account radionuclide depth. - 15 *min.* 219

Krassovitskiy P.M.
Resonant diffusion of beryllium molecule. - 15 *min.* 220

July 4, Friday, 9:00
Section VI
Fundamental Problems of Nuclear Power Engineering
Section VII
Experience and problems of high-quality training in nuclear physics, atomic power engineering and nuclear technologies

Bahdanovich R.B.
Method for calculation capturing energy reactions contribution to total energy release in nuclear reactors. - 15 *min.* 254

Kiyavitskaya H.
The challenges of creating subcritical research installations driven by external neutron sources. - 15 *min.* 255

Korbut T.
Birth-death model adaptation for description of time evolution of the neutron + subcritical multiplying medium system. - 15 *min.* 256

Kish Yu.V.
Measurement of the reaction rates in ^{232}Th samples irradiated by 4 GeV deuterons and secondary neutrons. - 15 *min.* 257

Zavorka L.
Investigation of the effective neutron energy at the massive spallation uranium target QUINTA. - 15 *min.* 258

Joint talk:
Structure of material of reactor vessel for nuclear power plants: neutron small-angle scattering data. 259
Study of interaction of deuterium plasma with the first wall in Globus-M tokamak by nuclear microanalysis techniques. 260
Reporter *Lebedev V.M.* - 15 *min.*

Zamani M.
Release assessment of tritium in liquid effluents of Bushehr nuclear power plant (BNPP) in 2013. - 15 *min.* 261

Sovestnov A.E.
Research of evolution of an atomic order and valence state of rare-earth atoms and uranium in a new metalcarbon composite pyrolyzate of bis-phthalocyanine $C_{64}H_{32}N_{16}Me$ (Me = Y, La, Ce, Eu and U). - 15 *min.* 263

Varonik N.I.
Polymeric compositions for “dry” decontamination of NPP equipment and premises. - 15 *min.* 264

Sytova S.N.
Classification and systematization of structure of Belarusian educational and research portal of nuclear knowledge. - 15 *min.* 268

July 4, Friday, 15:30
Plenary Session II

Urin M.H.
The particle-hole dispersive optical model and its application to the description of the simplest photonuclear reactions. - 30 *min.* 51

Shlomo Sh.
Sensitivities of energies of giant resonances to properties of the energy density functional. - 30 *min.* 52

Korjik M. M.
International nuclear physics research platforms and their impact on the science progress. - 30 *min.* 53

Abramovich S.N.
Threshold phenomena in nuclear reactions. - 30 *min.* 54

Tchuvil'sky Yu.M.
T-Odd correlations in (n,γγ)-, (n,αγ)- and (n,*f*γ)-reactions. - 30 *min.* 55

Conference closing.

HIGH-ENERGY NUCLEAR OPTICS OF POLARIZED PARTICLES

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The phenomena of interference, diffraction and refraction of light are well known, and their applications are described in school and university manuals.

Further analysis showed that the effects due to optical activity of matter, which we consider in optics, are a particular case of coherent phenomena emerging when polarized particles pass through matter with unpolarized and polarized electrons and nuclei [1].

The effects of optical anisotropy are very important for the interpretation of the experiments to search for electric dipole moments (EDMs) of deuterons.

The study of the deuteron birefringence effect in experiments for the EDM search is essential to distinguish the contributions from the deuteron birefringence effect and the deuteron EDM to spin rotation.

According to [1], in both EDM experiments and studies of deuteron spin rotation in storage rings, one should take into account deuteron electric and magnetic polarizabilities.

The advent of the Facility for Low-Energy Antiproton and Ion Research (FLAIR) has spurred the rapid development of low–energy antiproton physics

For low–energy neutrons, the phenomenon of ”optical” spin rotation (nuclear precession of the neutron spin in a nuclear pseudomagnetic field of a polarized target) is studied with slow neutrons passing through targets with polarized nuclei.

In contrast to neutrons, a charged particle moving in matter undergoes Coulomb interaction with the atoms of matter, which causes multiple scattering and rapid deceleration of the charged particle due to ionization energy losses.

When the energy of a positively charged particle diminishes, the Coulomb repulsion eliminates nuclear interaction between the incident particle and the target nucleus, thus suppressing the phenomenon of spin rotation due to nuclear interaction. Conversely, a negatively charged particle (antiproton, hyperon) is attracted to the nucleus and, as a result, participates in nuclear interaction even at low energies. As a consequence of this, spin rotation of a negatively charged particle in polarized matter does not disappear at low energies either and becomes observable.

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PROPERTIES OF NUCLEI IN THE NEIGHBORHOOD OF NEUTRON AND PROTON DRIP LINES

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We investigated the ground state properties of even-even nuclei in wide range of mass number A including nuclei with neutron and proton excess in the neighborhood of neutron and proton drip lines. Special attention was focused on nuclei beyond the theoretically known neutron drip line which form the peninsulas of nuclei which are stable against one and sometimes two neutrons emission for $N = 32, 58, 82, 126, 184, 258$. These calculations are based on the Hartree–Fock (HF) method with Skyrme forces (SkM*, SkI2, SLy4, Ska, SkP) and are the continuation of our investigations of nuclei with extreme neutron excess [1, 2]. Our calculations take into account axial deformation and the BCS pairing approximation. For neutron rich nuclei ^{248}Gd, ^{250}Dy and ^{266}Pb with magic neutron number $N = 184$ we have analyzed the potential energy curve as the function of the mass quadrupole parameter deformation $E(\beta_m)$ using the constrained HF. The analysis of the robustness of numerical solutions of HF equations for nuclei belonging to peninsulas of stability has been also made. We have also investigated the deformations, separation energies of one and two neutrons for the long isotope chains for $56 \le Z \le 72$ up to the neutron drip line. It is shown that for some superheavy nuclei with $Z \ge 120$ the oblate superdeformed shapes of neutron and proton density distributions can correspond to ground state.

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RECENTLY DEVELOPED APPROACHES TO CALCULATE NUCLEAR STRUCTURE NEED TESTS BY NOVEL EXPERIMENTAL METHODS

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At present, *ab initio* calculations cover a broad range of light nuclei. Recently they were developed to include descriptions of new phenomena, such as elastic and inelastic nucleon scattering (see[1] and references therein)

Therefore the various experimental data can be compared with the direct calculations which based on the bare nucleon interaction. However, calculations of nuclear structure need knowledge of parameters of the *N–N* interaction which cannot be properly fixed from the *N–N* scattering (for example, having a large orbital momentum between nucleons). Therefore the *ab initio* calculations of nuclear structure give possibility to fix the needed parameters of the *N-N* interaction and understand the importance of three-(four) body forces in nuclei. A test of these new theoretical approaches will be made by using resonance reactions induced by rare beams. I will consider several examples of such tests [2-7]

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SYNTHESIS OF HEAVY AND SUPERHEAVY NUCLEI IN INTENSIVE NEUTRON FLUXES OF EXPLOSIVE PROCESSES

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The model of heavy elements production under condition of pulse explosive nucleosynthesis was developed in 1985 [1] – 1990 [2] years. Later on this model was extended by including effects connected with adiabatic expansion of matter and adopted for pulse conditions of very short in time nuclear explosion [3]. The model was also extended for binary starting target-isotopes compositions [4] - adiabatic binary model (ABM). Also this modified method with new data base was used for the description of superheavy elements (SHE) production in astrophysical processes [5]. And now we have two models connected by the similar algorithm for the heavy and superheavy elements production in intensive neutron fluxes of the rapid – r-process nucleosynthesis.

When process is shot in time ($t \leq 10$ s for astrophysical events and $t < 10^{-6}$ s for nuclear explosion) so we may speak about the explosive processes. In this case the possibility of SHE production in astrophysical explosive processes is strongly depends on the parameters of processes, because it may be not enough time to rich the island of stability for SHE. In the prompt process of nuclear explosion we have another problem connected with the nuclear data in the region of very neutron-rich heavy and superheavy nuclei and their stability to the beta-delayed and spontaneous fission processes. All these problems are analyses in this work and the probabilities of heavy and superheavy nuclei production in intensive neutron fluxes of explosive processes are discussed for the Supernova and thermonuclear explosions.

The work is supported by the Russian Foundation for Basic Research Grants no. 12-02-00955 and 13-02-12106 ofi-m.

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DYNAMICAL EFFECTS' ROLE IN THE FORMATION OF *T*-ODD ANGULAR ASYMMETRIES OF THE PRODUCTS OF TERNARY FISSION CAUSED BY POLARIZED NEUTRONS

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In the framework of the quantum theory of nuclear fission [1-3] the following dynamic effects that determine the character of the formation of *T*-odd *P*-even asymmetries in the angular distributions of prescission and evaporation third particles for low-energy ternary fission caused by cold polarized neutrons have been highlighted:

1) the conservation of axial symmetry for the transition fission states of the fissioning system both before and after the appearing of fission products;

2) the coldness of the fissioning system in the vicinity of the scission point, which provides the smallness of Coriolis interaction and leads to the conservation of its spin projection onto the symmetry axis;

3) the main role of wriggling vibrations of fissile compound nucleus [2] in the vicinity of its scission point for the focusing of the flight direction for binary fission fragments along or against the symmetry axis;

4) the necessity to take into account the interference of fission amplitudes [3] of different *s*- neutron resonances of compound fissile nucleus with the same and different values of its spins for the formation of the angular distributions of fission products;

5) the main role of the knock out mechanisms of appearance for prescission third particles caused by strong nonadiabaticity of compound fissile nucleus collective deformation motion near its scission point;

6) the influence of the collective rotation of the polarized fissioning system on the amplitude of the angular distributions of emitted fission fragments and prescission third particles caused by Coriolis interaction of orbital momenta of fission fragments and prescission third particles with total spin of the fissioning system;

7) the appearence of *T*-odd TRI- and RO*T*- asymmetries in the angular distributions of the prescission third particles due to the contribution of only even or only odd orbital momenta of the third particles correspondently caused by interference of fission amplitudes of different neutron resonances [3].

It is concluded about necessity to continue experimental studies of *T*-odd *P*-even asymmetries for ternary fission of new target-nuclei by cold polarized neutrons in order to verify validity of the above named representations.

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COMPREHENSIVE *AB INITIO* STUDY OF LIGHT NUCLEI WITH JISP16 *NN* INTERACTION

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We perform a detailed *ab initio* study of all known states in *s*- and *p*-shell nuclei with a width not exceeding 300 keV using a realistic JISP16 *NN* interaction [1]. This interaction was obtained in the *J*-matrix inverse scattering approach [2] and fitted by phase-equivalent transformations to reproduce properties of light nuclei without three-nucleon forces. The effect of three-nucleon interaction is mimicked by off-shell properties of JISP16.

The calculations of nuclear observables are performed in the No-core Shell Model [3] using modern supercomputers and largest attainable basis spaces. The results for energies of ground and excited states are extrapolated to the infinite basis space (the so-called No-core Full Configuration (NCFC) approach [3]) using various extrapolation techniques. The NCFC approach makes it possible to estimate the uncertainty of theoretical predictions for energies.

It is shown that the JISP16 *NN* interaction provides an accurate description of binding energies and spectra of nuclei with $A \leq 12$. The NCFC extrapolation technique and new generation of supercomputers which make it possible to increase basis spaces in NCSM calculations, reveals a drawback of JISP16 interaction: it overbinds nuclei at the end of *p* shell.

I discuss a recent progress in fully microscopic description of light nuclei and further development of *NN* interaction of JISP type.

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THEORETICAL ANALYSIS OF INELASTIC PION-NUCLEUS SCATTERING WITHIN THE MICROSCOPIC OPTICAL POTENTIAL

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The microscopic model of optical potential (OP) [1] was adapted in [2, 3] for calculations of the pion-nucleus elastic and inelastic scattering cross sections. At present we apply this OP (its direct and transition parts) for further calculations of the $\pi^{\pm} + {}^{28}$Si, ^{58}Ni, ^{40}Ca, ^{208}Pb inelastic cross sections at energies 160, 180, 230, 290 MeV with excitations of the 2^{+} and 3^{-} collective states of nuclei. In so doing we use the known nuclear density distributions and the parameters of the πN-scattering amplitudes obtained in [4] by fitting the calculated pion-nucleus elastic cross sections to the data. Thus for inelastic scattering, the only adjusted parameters were the quadrupole β_2 and octupole β_3 deformations inherent in transitions to the 2^{+} and 3^{-} excited states of nuclei. The cross sections were obtained by solving the relativistic wave equation transformed to the non-relativistic form when one obeys the high-energy condition $T \gg U_{opt}$. Then the equation was computed with a help of the DWUCK4 program [5], and thus the relativistic and distortion effects in initial and final channels of the process were accounted for automatically. The calculated cross sections were found to be in a fairly well agreement with the corresponding experimental data.

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THE PROPERTIES OF TRUE QUATERNARY NUCLEAR FISSION WITH THE TAKING INTO ACCOUNT IT'S MULTISTEPS AND SEQUENTIAL CHARACTER

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It is demonstrated that the true ternary (quaternary) fission has two-(three-) steps character, when due to the influence of strong nonadiabatic deformation motion of the compound fissile nucleus at first the prescission light particles (neutrons, gamma-quanta, light nuclei) are emitted with forming of intermediate nuclei, which are then divided into two fission fragments. It is noted that the non-simultaneous character of the fission fragments and light particles flights is in good agreement with the condition of *T*-invariance of the experimentally observed *T*-odd asymmetries in the angular distributions of the true ternary fission products [2].

Using the results of the theory of two-proton two-steps decay of nuclei [3] it is shown that due to the large positive values of the fission energies the true ternary and quaternary fission of heavy nuclei have sequential two-steps and three-steps character when after the light particles flight the processes of the formation the lying on the mass surface of the fissioning system real states of intermediate nuclei dominate and the contribution of virtual states of these nuclei can be neglected. Using the constructed in [3] formulae for the widths of nuclear sequential basic decays the calculations of flight pobabilities angular and energy distributions for the second and first emitted prescisission third and fourth particles are carried out.

The analysis of the differences between flight probabilities, angular and energy distributions for the second and first emitted prescission third and fourth particles has been carried out using the experimental data on quaternary spontaneous and induced (by thermal neutrons) fission and it has been demonstrated that the reasons of the mentioned differences are the changes of the geometrical structure of the fissile nucleus and of the shell structure of its neck after the emission of the first prescission particle by the fissile nucleus.

It is demonstrated that the interaction between the two light particles can be significant if the particles are emitted from the fissioning nucleus in the form of long-lived quasistationary state, which then decays with the emission of mentioned particles. This fact is illustrated by the example of nuclear fission with the flight of the two α-particles with the approximately equal probabilities, as by an independent way, so as through the state of the nucleus Be-8.

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A MULTI-PARAMETER NUCLEAR-FISSION EXPERIMENT: WHY AND HOW TO MEASURE ALL AT ONCE?

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Since the time of the discovery of nuclear fission, much of experimental and theoretical efforts have been aimed at studying different aspects of this complicated phenomenon. Despite the very strong motivation given by the military and civil applications of the reaction, our comprehension of the fission process is still quite far to be complete. Putting aside the complexity of the nuclear force, this fact is also due to a certain lack of multi-parameter experimental data. An example here is the correlation between fractional independent yields of fission products and neutron and gamma-ray multiplicities. Fragment-gamma-neutron measurements, especially if correlated with fission-fragment kinetic energies, give the complete set of observables issue of the fission reaction and are therefore potentially of great interest from the point of view of modeling and understanding of the fission process.

Several years ago, a two-arm spectrometer of fission products (STEFF) has been built at the Manchester University. It uses double energy / double velocity measurement to identify masses of complementary fission products and is capable of delivering information on nuclear charge of lighter fission products, which is achieved from the analysis of the fragments pulse shapes and ranges in gaseous detectors. The spectrometer also comprises an array of efficient photon detectors and may house a further array of neutron detectors thus allowing correlation measurement of a large number of observables. The performances achieved during the test and $^{235}U(n_{th}, f)$ experiments will be demonstrated and discussed, along with the technical challenges linked to an efficient use of such a device. The future experimental program of the spectrometer will be shortly presented and the range of physical questions which can be addressed with STEFF will be outlined.

SEARCH FOR CHARMONIUM AND EXOTICS WITH HIDDEN CHARM AND STRANGENESS IN ANTIPROTON-PROTON ANNIHILATION

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The study of strong interactions and hadron matter in the process of antiproton-proton annihilation seems to be a challenge nowadays. One of the main goals of contemporary physics is to search for new exotic forms of matter, which must manifest in the existence of charmed hybrids $c\bar{c}g$ and multiquark states such as meson molecules and tetraquarks [1, 2]. The researches of spectrum of charmed hybrids and tetraquarks with hidden charm and strangeness ($cq\bar{c}\bar{q}'$, q and $q' = u, d, s$) together with the charmonioum spectrum are promising to understand the dynamics of quark interactions at small distances. It is a good testing tool for the theories of strong interactions: QCD in both perturbative and non-perturbative regimes, QCD inspired potential models, phenomenological models, non-relativistic QCD and LQCD.

Two generic types of multiquark states have been described in the literature [2 - 4]. The first, a molecular state, is comprised of two charmed mesons bound together to form a molecule. These states are by nature loosely bound. Molecular states bind through two mechanisms: quark/colour exchange interactions at short distances and pion exchange at large distance (although pion exchange is expected to dominate). Since the mesons inside the molecule are weakly bound, they tend to decay as if they are free. The second type is a tightly bound four-quark state, so called tetraquark that is predicted to have properties that are distinct from those of a molecular state. In the model of Maiani [2], for example, the tetraquark is described as a diquark-diantiquark structure in which the quarks group into colour-triplet scalar and vector clusters and the interactions are dominated by a simple spin-spin interaction. A prediction that distinguishes tetraquark states containing a $c\bar{c}$ pair from conventional charmonia is possible existence of multiplets which include members with non-zero charge $cu\bar{c}\bar{d}$, strangeness $cd\bar{c}\bar{s}$, or both $cu\bar{c}\bar{s}$.

The detailed analysis of the spectrum of charmed hybrids with exotic ($J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, 3^{-+}$) and non-exotic ($J^{PC} = 0^{-+}, 1^{+-}, 2^{-+}, 1^{++}, 1^{--}, 2^{--}, 2^{++}, 3^{+-}$) quantum numbers and tetraquarks with hidden charm and strangeness was carried out, and attempts to interpret a great quantity of experimental data above the $D\bar{D}$ threshold were considered. The analysis of charmonium spectrum was carried out earlier [5, 6]. New higher lying states of charmonium, charmed hybrids and tetraquarks are expected to exist in the mass region above the $D\bar{D}$ threshold. But much more data on different decay modes are needed for deeper analysis. These data can be derived directly from the experiments with high quality antiproton beam.

A special attention is given to the new *XYZ* states with hidden charm discovered recently [3, 4, 7, 8]. Their interpretation is far from being obvious nowadays [2 -4]. The experimental data from different collaborations like BES, Belle, BaBar, LHCb, CLEO were carefully studied. Some of these states can be interpreted as charmonium [5, 6] and tetraquarks [9, 10] in the framework of the combined approach proposed earlier [11, 12]. It has been shown that charge/neutral tetraquarks must have neutral/charge partners with mass values which differ by few tens of MeV. This treatment coincides with hypothesis proposed by Maiani and Polosa [13, 14]. It seems to be a promising approach and needs to be carefully verified in experiments using high quality antiproton beam with momentum ranging up to 15 GeV/c.

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CLUSTERING FEATURES OF LIGHT NEUTRON-DEFICIENT NUCLEI IN RELATIVISTIC DISSOCIATION

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The nuclear track emulsion (NTE) has still retained its exceptional position as a means for studying the structure of fragmentation of relativistic nuclei owing to the completeness of observation of fragment ensembles and owing to its record spatial resolution. Separation of products of fragmentation and charge-exchange reactions of accelerated stable nuclei make it possible to create beams of radioactive nuclei. A unification of the above possibilities extends the investigation of the clustering phenomena in light radioactive proton-rich nuclei. Conclusions concerning clustering features are based on the probabilities for observing of dissociation channels and on measurements of angular distributions of relativistic fragments.

At the JINR Nuclotron exposures of NTE stacks are performed in the beams of relativistic isotopes of beryllium, boron, carbon and nitrogen, including radioactive ones. To date, an analysis of the peripheral interactions of relativistic isotopes of beryllium, boron, carbon and nitrogen, including radioactive ones, with nuclei of the emulsion composition has been performed, which allows the clustering pattern to be presented for a whole family of light nuclei [1].

In general, the results confirm the hypothesis that the known features of light nuclei define the pattern of their relativistic dissociation. The probability distributions of the final configuration of fragments allow their contributions to the structure of the investigated nuclei to be evaluated. These distributions have an individual character for each of the presented nuclei appearing as their original "autograph". The nuclei themselves are presented as various superpositions of light nuclei-cores, the lightest nuclei-clusters and nucleons. Recent data on dissociation of the nuclei ^{7}Be, ^{10}C [2], ^{11}C and ^{12}N [3] will be discussed in this context.

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EXPLORING THE ALPHA CLUSTER STRUCTURE OF NUCLEI USING THE THICK TARGET INVERSE KINEMATICS TECHNIQUE FOR MULTIPLE ALPHA DECAYS

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The alpha cluster structure of nuclei with an equal number of protons and neutrons (alpha conjugate nuclei) was proposed in the 1968 by Ikeda *et al.* [1] to explain some excited states not reproduced by the shell model. Since then many studies have been performed and now the alpha clustering in light nuclei is well established [2]. However further investigation is required to fully understand the clusterization in medium light and heavy nuclei. In particular states analogous to the Hoyle state, in which the nucleus is described by a cluster of n alpha particles, have not yet been unambiguously identified in nuclei larger than ^{12}C.

We investigated the reaction $^{20}Ne+\alpha$ using the Thick Target Inverse Kinematics (TTIK) technique [3]. This technique is particularly suited for this study because it allows exploration of a large range of incident energies in the same experiment. Moreover, in the inverse kinematics, the reaction products are focused at forward angles and can be detected with detectors covering a relatively small portion of the solid angle in the forward direction.

A ^{20}Ne beam of energy 11 MeV/nucleon was delivered by the K150 cyclotron at Texas A&M University. The reaction chamber was filled with ^{4}He gas at a pressure sufficient to stop the beam few centimeters before the detectors. In this way we could detect particles emitted at zero degrees. The energy of the light reaction products was measured by three silicon detector telescopes placed at a radial distance of 48 cm from the entrance window. Each telescope consisted of two 5x5 cm^2 Micron Semiconductors DC quadrant detectors (Design G). The time of flight of the detected particles was also measured relative to the cyclotron radiofrequency. A monitor detector was used to measure the intensity of the incident beam.

For the first time the TTIK method was used to study multiple α-particle decays and single α-particle emission. According to the Ikeda picture ^{24}Mg can be described as $^{20}Ne + \alpha$, $^{16}O + 2\alpha$, $^{12}C + 3\alpha$ or a cluster of 6 α particles. Each configuration is expected to be observable at excitation energies around the corresponding threshold values. New results from the analysis of the events with α-multiplicity one, two and three will be shown. Particular attention will be given to the three α-particle emission data.

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THE POPULATION OF ISOMERIC STATES IN FUSION AND TRANSFER REACTIONS WITH BEAMS OF WEAKLY BOUND NUCLEI NEAR THE COULOMB BARRIER

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Fusion reactions with stable nuclei at sub-barrier energies are now well studied. In particular, much effort has been devoted to studying nuclear isomers and isomeric cross section ratios (σ_m/σ_g) clarifying the main factors affecting isomeric state feeding [1]. However, studies of isomerism in reactions involving weakly bound nuclei are not sufficient; neither are experimental results for reactions induced by weakly bound nuclei consistent with theoretical descriptions.

The compound nuclei formation is a great theoretical and experimental challenge in case with weakly bound and halo nuclei [2]. Loosely bound nucleons or entire clusters can be captured by the target nuclei in the sub-barrier energy region, like in reactions involving deuterons and the ^{6}Li nuclei [3].

The work aims at further investigation of fusion and transfer reactions of weakly bound nuclei d and ^{3}He and cluster nuclei ^{6}Li and ^{6}He with light and heavy target nuclei, leading to population of high-spin isomeric and ground states in evaporation residues, neutron and cluster transfer to both the target and projectile nuclei.

The conclusions drawn both from the present investigation and the previous studies are as follows. The behavior of excitation functions and isomeric ratios for the products of fusion reactions with neutron evaporation can be explained within the compound nucleus models of nuclear reactions (usually characterized by energy dependence of the isomer ratios). A comparison of experimental cross sections and σ_m/σ_g obtained in various reactions through charged-particle emission shows a great difference in the behavior of excitation functions and isomeric ratios for fusion and direct reactions. Isomeric ratio is usually low in direct transfer reactions. Reactions involving nucleon transfer on incident particles are also for the most part characterized by low isomeric ratios essentially independent of energy. This behavior is mainly related to low-lying excited particle-hole states in the target nucleus.

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LIGHTEST KAONIC NUCLEI

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Nowadays, the study of kaonic nuclear states is an important topic in hadron physics, because their existence is related to kaon condensation and to the physics of the core of neutron stars that by todays understanding are built up from exotic matter: pion and kaon condensates and quark matter. We address the hottest topic in nuclear physics – lightest kaonic nuclei that consist from kaons and a few proton and neutrons. The current status of the experimental and theoretical studies of the lightest kaonic nuclei is presented. Particularly a quantitative and qualitative understanding of an antikaon-two-nucleon and antikaon-three-nucleon quasibound states are considered. The review of studies of three- and four-body kaonic nuclei within well-known model-independent methods of Faddeev equations and the hyperspherical function method, as well as variational method are presented. The theoretical discrepancies in the binding energies and widths for kaonic nuclei related to the different K*N* and KK interactions are discussed.

We present our study of kaonic three-body K^-NN, K^-K^-N and $K^-K^+K^+$ and four-body K^-NNN, K^-K^-NN and $K^-K^-K^-N$ nuclei within the method of hyperspherical functions in momentum representation, using realistic local and separable potential models for the nucleon-nucleon and kaon-nucleon interactions, as well as for the kaon-kaon interaction. We solve nonrelativistic three- and four-body Schrodinger equation in momentum representation in the framework of the method of hyperspherical harmonics to find a ground state binding energy and corresponding wave function. We calculate the deeply bound state and width of three- and four-body kaonic nuclei. The following ground-state binding energies were obtained: 48.3 MeV (K^-pp), 28.2 MeV (K^-K^-p), 67.2 MeV (K^-ppn), and 89.3 MeV (K^-K^-pp), which are in good agreement with previous results obtained for the same potentials using Faddeev equations and variational method.

COMPLEX CONFIGURATION EFFECTS ON β-DECAY RATES

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One of the successful tools for nuclear structure studies is the quasiparticle random phase approximation (QRPA) with the self-consistent mean-field derived by making use of the Skyrme interaction. Many charge-exchange versions of it were developed during the last decade. Their common feature is that they allow to relate the properties of the ground states and excited states through the same energy density functional. On the other hand, it would be desirable to extend the description beyond the QRPA scheme in order to include damping effects observed experimentally. Making use of separable residual interaction one can perform the spin-isospin excitation calculations in large configuration spaces since there is an opportunity to avoid matrices whose dimensions grow with the size of configuration space. For the same reasons, we develop the finite rank separable approximation for the Skyrme interactions [1,2] that enables one to perform the charge-exchange calculations in the large configuration space [3,4].

In this talk we briefly describe our method for the charge-exchange excitations and present our studies of the coupling between one- and two-phonon terms in the wave functions and the tensor force effects on properties of Gamow-Teller (GT) states. We observe a redistribution of the GT strengths due to the tensor correlation influence on the $2p$-$2h$ fragmentation of GT states. The β^--decay half-lives is decreased by these effects [5]. As an application we present the evolution of the β-decay scheme of the neutron-rich N=50 isotones, in comparison to the doubly-magic nucleus ^{78}Ni that is also an important waiting point in the r-process.

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NEW SEARCH FOR DOUBLE ELECTRON CAPTURE OF ^{106}Cd WITH THE TGV-2 SPECTROMETER

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The new search for double electron capture decay of ^{106}Cd was performed at the Modane underground laboratory (LSM, France, depth 4800 m w.e.) using the multi-detector spectrometer TGV-2 (Telescope Germanium Vertical) [1]. The detector part of the spectrometer is composed of 32 HPGe planar type detectors with the sensitive volume of 2040 mm^2 ×6 mm each mounted one over another together with double beta emitters placed between them in a common cryostat tower. Previous experimental runs performed with TGV-2 spectrometer to search for EC/EC, β^+EC, and $\beta^+\beta^+$ decays of ^{106}Cd used ~10 g of ^{106}Cd [2] and ~13.6 g of ^{106}Cd [3] with enrichment of 75%. As a result, the new experimental limit on 2νEC/EC decay of ^{106}Cd – $T_{1/2}$>4.2×10^{20}y (90%CL) [3] were obtained improving existing limits by more than two orders of magnitude and reaching the range of theoretical predictions for this decay [4]. The analysis of *KX*-*KX* coincidences obtained in the last run [3] showed a small increase in the number of measured events in the region of ~21 keV (*KX*Pd), which might be the 2νEC/EC decay of ^{106}Cd. But the statistics was not enough to make any significant claim about the presence of the process searched. A larger statistics should be accumulated with a higher mass of enriched ^{10i6}Cd in the new experimental run. The new measurement was started in December 2013 with the TGV-2 spectrometer and 16 foils of ^{106}Cd with enrichment of 99.57%. Investigated foils have a thickness of 70(10) μm and a total mass of ~23.2 g. The foils of enriched ^{106}Cd were preliminary measured during 17 days at LSM with a high-efficiency low-background HPGe spectrometer [5] to obtain their contaminations. The limits on 0νEC/EC resonant decay to the excited states of ^{106}Pd were obtained in this measurement to be – $T_{1/2}$(*KL*, 2741 keV) > 0.9×10^{20} y (90% CL) and $T_{1/2}$(*KK*, 2718 keV) > 1.4×10^{20} y (90%CL).

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DEPENDENCE OF BRANCHING COEFFICIENTS FOR MULTIDECAY NUCLEI FROM *K*-SHELL POPULATION OF THEIR ATOMS IN STRONGLY HEATED MEDIUM

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In [1] we have calculated the δ branching coefficients for a number of multidecay odd-odd nuclei in an extremely heated medium. The δ coefficient determines the fraction of the electron beta-decay in the total decay rate for multidecay nucleus. The range of nuclear temperatures from 0.2 to 0.3 MeV which corresponds to the stage of the oxygen layer burning in massive star was considered. In the extremely heated medium the atomic ionization multiplicity, including the *K* shell, is high and the capture of atomic electrons by the nucleus is hindered. This effect for multi-decay nuclei with anomalously small values of the branching coefficients can significantly increase the contribution of their electronic beta-decay.

The aim of the research is to investigate how the ionization of an atomic *K* shell in a high-temperature field varies the δ coefficients for the multidecay nuclei. In the mass-number range between 74 and 196 there are 33 of such nuclei. The results obtained by calculating the δ coefficients for some multidecay nuclei are given in the table.

The calculated branching coefficients for multidecay nuclei. Here, δ_0 is the branching coefficient received in the terrestrial conditions [2]; column 1 is the calculations accounting K-capture [1], column 2 is the calculations without it; columns 1 and 2 contain the results for $T = 3\times10^9$ K

Nucleus	δ_0	δ, theory		Nucleus	δ_0	δ, theory	
		1	*2*			*1*	*2*
$^{92}_{41}$Nb	$<5.0\times10^{-4}$	0.082	0.441	$^{144}_{61}$Pm	0	4.4×10^{-4}	0.908
$^{96}_{43}$Tc	0	6.1×10^{-5}	5.7×10^{-3}	$^{156}_{65}$Tb	0	6.7×10^{-4}	0.180
$^{102}_{45}$Rh	0.2	0.112	0.841	$^{162}_{67}$Ho	0	4.2×10^{-3}	0.537
$^{120}_{51}$Sb	0	0.169	0.773	$^{180}_{73}$Ta	0.14	0.532	1.0
$^{124}_{53}$I	0	7.6×10^{-4}	0.025	$^{184}_{75}$Re	0	6.3×10^{-6}	0.124
$^{132}_{55}$Cs	0.019	0.201	0.998	$^{190}_{77}$Ir	0	1.0×10^{-4}	0.770
$^{136}_{57}$La	0	2.4×10^{-3}	0.964	$^{196}_{79}$Au	0.075	1.3×10^{-3}	1.0

The action of the high-temperature field on beta processes and the suppression of the electron *K* capture change substantially the δ coefficients in the relation to their δ_0 values. The δ values presented in the table may be of interest not only as it is but also for the models intended for describing the synthesis of *p*-nuclei at various stages of massive-star evolution.

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EFFECT OF ATOMIC IONIZATION ON *P*-NUCLEUS SYNTHESIS RATE IN EXTREMELY HEATED SUBSTANCE OF MASSIVE STAR

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We performed the calculations of *p*-nucleus abundances on the base of the synthesis process model. This model considers the quasi-equilibrium stages of massive-star evolution. We investigated the high temperature stages of oxygen burning in massive stars when the temperature of the substance reaches the "nuclear" values of 0.2–0.3 MeV in energy units. In these calculations it is significant to take into account all the modes of thermal nuclear beta-transitions (electron capture, electron and positron transitions) and nuclear photobeta-decay. The chain of the beta-decays, $(A; Z) \rightleftarrows (A; Z{+}1) \rightarrow (A; Z{+}2)$, is considered. Here under terrestrial conditions the progenitor nucleus, $(A; Z)$, and the *p*-nucleus, $(A; Z{+}2)$, are stable but the intermediate odd-odd nucleus, $(A; Z{+}1)$, is multibeta-decay. The *p*-nucleus abundances are found from the set of kinetic equations written for the above chain of the beta-decays. For the $N(\tau)$ final abundance of the *p*-nucleus, $(A; Z{+}2)$, the analytical solution to the set has the form,

$$N(\tau)/N_0 = 1 - \frac{1}{2}[\exp(-\delta_+\tau/2) + \exp(-\delta_-\tau/2)] - \frac{\lambda_{123}}{\delta}\sinh(\delta\tau/2)\exp(-\lambda_{123}\tau/2). \quad (1)$$

Here, τ is the stage duration; N_0 is the initial abundance of the progenitor $(A;Z)$ nuclei,

$$\delta = (\lambda_{123}^2 - 4\lambda_1\lambda_3)^{1/2}; \delta_\pm = \lambda_{123} \pm \delta; \lambda_{123} = \lambda_1 + \lambda_2 + \lambda_3.$$

λ_1 is the total rate of electron beta-transition, $(A; Z) \rightarrow (A; Z{+}1)$, λ_2 is the total rate of reverse beta-transition, $(A; Z{+}1) \rightarrow (A; Z)$ (it includes the positron beta transition and the electron *K* capture) and λ_3 is the total rate of the electron beta transition, $(A; Z{+}1) \rightarrow (A; Z{+}2)$. All these rates depend on medium temperature.

We estimated the effect of almost complete ionization of atoms in the extremely heated substance of a massive star on the magnitudes of *p*-nucleus abundances. In this case *K* capture is strongly suppressed. Therefore the *p*-nucleus abundances were calculated by using Eq. (1) but now the electron *K* capture rate in the λ_2 total rate was not taken into account. As expected, the suppression of *K* electron capture in extremely heated medium increases the total yield of *p*-nuclei. In some cases, when the electron beta-transition, $(A; Z{+}1) \rightarrow (A; Z{+}2)$, was strongly suppressed in the background of the electron capture the increase of abundances is especially noticeable. It is obtained for the following *p*-nuclei, ^{136}Ce, ^{144}Sm, ^{156}Dy, ^{162}Er, ^{184}Os, ^{190}Pt and ^{196}Hg. As a result, the "solar" abundances of the latter and 20 more isotopes can be received at the stage of the oxygen burning in massive stars.

EFFECT UPON CHARACTERISTICS OF NUCLEAR ISOMERIC STATES BY SYNCHROTRON RADIATION

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The excitation and decay of nuclear isomeric states in the synchrotron radiation field are theoretically investigated. In the calculations of the probability of these processes a radiation from the synchrotron of the third generation (Spring-8, Japan) is used. This synchrotron produces electromagnetic waves with the photon energies up to 300 MeV. Such radiant energy range assumes a research of the direct action of a radiation on the nuclear state characteristics. In addition the synchrotrons of the third generation produce high-power radiation of the frequency continuous spectrum (from the wiggler) or even more high-power radiation of the frequency line spectrum (from magnetic undulators). These properties of the synchrotron radiation make much more effective its influence on nuclear characteristics than the laser emission action.

We investigated the excitation and decay of isomeric states in nuclei having two lower excited states. One of them is the isomeric state having the E^* energy and J^* total spin. The other one is the excited state which has the E energy in less than 250 MeV. Besides the J total spin of this state is such one that the electromagnetic transitions of the low multipolarity in the ground state and isomeric state are probable. These nuclei with the reliable values of the experimental characteristics are: ^{58}Co (the total spin of the ground state is J_0=2$^+$; E^*=24.95 keV, J^*=5$^+$; E=53.15 keV, J=4$^+$), ^{94}Nb (J_0=6$^+$; E^*=40.89 keV, J^*=3$^+$; E=58.71 keV, J=(4)$^+$); ^{96}Tc (J_0=7$^+$; E^*=34.23 keV, J^*=4$^+$; E=45.28 keV, J=5$^+$); ^{144}Pr (J_0=0$^-$; E^*=59.03 keV, J^*=3$^-$; E=99.95 keV, J=2$^-$); ^{171}Lu (J_0=7/2$^+$; E^*=71.13 keV, J^*=1/2$^-$; E=73.01 keV, J=5/2$^-$); ^{189}Os (J_0=3/2$^-$; E^*=30.81 keV, J^*=9/2$^-$; E=69.54 keV, J=5/2$^-$); ^{191}Os (J_0=9/2$^-$; E^*=74.38 keV, J^*=3/2$^-$; E=131.94 keV, J=5/2$^-$); ^{235}U (J_0=7/2$^-$; E^*=0.0765 keV, J^*=1/2$^+$; E=51.71 keV, J=5/2$^+$). The rates of the excitation processes of the nuclear isomeric states are calculated by using the Breit-Wigner formula and well-known forms of the electromagnetic spectra of the Spring-8 synchrotron [1]. Single-particle estimations of the radiation widths of the transitions are used. It is obtained that the quantities of these rates are in the (10^{-11}–10^{-9}) c^{-1} range. Only the ^{171}Lu isotope with a very small energy of the $5/2^- \rightarrow 1/2^-$ transition is an exclusion. In this case the rate of the isomeric state excitation is the 2.3×10^{-19} c^{-1}. Sometimes the experimental widths of the radiation transitions were known. The rates of the excitation processes of the isomeric states calculated by using these widths were differed from the average by one order of the magnitude from the rates received by using single–particle widths.

1. http://www.spring8.or.jp

“COMPLETE EXPERIMENT” IN MESON PHOTOPRODUCTION

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The new generation of meson photoproduction experiments is now being realized at three international laboratories - Jlab (USA), ELSA (Bonn), MAMI (A2 collaboration in Mainz). This extensive program is aimed at the comprehensive description of various individual meson photoproduction channels and requires the measurement of at least 8 thoroughly chosen observables for each channel over a wide energy range.

A review is given of the latest results obtained in the framework of this “complete experiment” program. The world’s first measurements are discussed of the polarization observables T, F, E, G in the photoproduction of π^0 and η mesons as well as $\pi^0\pi^0$ and $\pi^0\eta$ pairs on the protons and deuterons performed by A2 collaboration with the use of circularly and linearly polarized photon beams with maximum energy 1.5 GeV from the MAMI C accelerator and the target with transverse and longitudinal polarization of protons and deuterons. These data form a base for the study of photoproduction dynamics through the amplitude and multipole analyses of individual meson photoproduction channels.

PARTIAL AND TOTAL PHOTONEUTRON REACTION CROSS SECTIONS NEW DATA FOR ^{91,94}Zr ISOTOPES

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Systematic investigations of experimental partial photoneutron cross sections for many medium and heavy nuclei [1] show that many of them do not satisfy specially introduced criteria of data reliability [2]. That was found out that in various energy ranges of initial photons the ratios $F_1 = \sigma(\gamma,1n)/\sigma(\gamma,xn) = \sigma(\gamma,1n)/\sigma[(\gamma,1n) + 2(\gamma,2n) + 3(\gamma,3n) + \ldots]$ have physically forbidden negative values and at the same time corresponding ratios $F_2 = \sigma(\gamma,2n)/\sigma(\gamma,xn)$ have physically unreliable values larger 0.50. That means that experimental neutron multiplicity sorting has been done erroneously because of large systematic uncertainties.

New data free of such kind uncertainties were evaluated for ^{91,94}Zr [3] using new experimentally-theoretical method [4]. The only experimental reaction cross section $\sigma^{exp}(\gamma,xn)$ [5] used was shared into partial parts using the equations $F^{theor}{}_i = \sigma^{theor}(\gamma,1n)/\sigma^{theor}(\gamma,xn)$ of combined pre–equilibrium exciton model of photonuclear reactions [6, 7]. The way of new cross sections evaluation - $\sigma^{eval}(\gamma,in) = F^{theor}{}_i \cdot \sigma^{exp}(\gamma,xn)$ – means that competition between partial reactions is in accordance with model free from neutron multiplicity sorting problems and their sum $\sigma^{eval}(\gamma,xn)$ is equal to $\sigma^{exp}(\gamma,xn)$ also free from problems mentioned.

New cross sections were evaluated for (γ,n) and (γ,2n) reactions in the case of ^{91}Zr and for (γ,n), (γ,2n) and (γ,3n) in the case of ^{94}Zr. Using evaluated partial reactions cross sections for both isotopes new data were obtained for total photoneutron reaction $\sigma[(\gamma,1n) + (\gamma,2n) + (\gamma,3n) + \ldots] \approx \sigma(\gamma,abs)$.

Large deviations of evaluated cross sections from experimental ones are discussed in details.

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PHOTODISINTEGRATION OF ^{186,188,189,190,192}Os ISOTOPES: LIKENESSES AND DIFFERENCES

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In continuation to evaluation of partial and total photoneutron reaction cross sections for ^{188,189}Os isotopes carried out [1] in the frame of experimentally-theoretical approach [2, 3, 4] using special criteria of data reliability [5] new evaluated data were obtained [6] for isotopes ^{186,190,192}Os on the base of experimental data [7] for photoneutron yield reaction cross section $\sigma^{exp}(\gamma,xn) = \sigma^{exp}[(\gamma,n) + 2\sigma(\gamma,2n) + 3\sigma(\gamma,3n) + \ldots]$. New data evaluated by the way $\sigma^{eval}(\gamma,in) = F^{theor}{}_i \cdot \sigma^{exp}(\gamma,xn)$ are reliable being obtained in conditions free from shortcomings of experimental measurement of outgoing neutron multiplicity sorting.

Energy dependencies of new reliable evaluated σ(γ,n), σ(γ,2n) and σ(γ,3n) cross section data for ^{186,188,189,190,192}Os were compared to each other and to correspondent energy dependencies of neutron multiplicity functions $F_i = \sigma(\gamma,in)/\sigma(\gamma,xn) = \sigma(\gamma,in)/\sigma[(\gamma,1n) + 2(\gamma,2n) + 3(\gamma,3n) + \ldots]$. It was shown that deviations of $F^{exp}{}_i$ from $F^{thor}{}_i$ are individual for separate isotopes and are clear dependent on the shape of outgoing neutrons spectra. The differences in various reactions energy thresholds play definite role certainly. That confirms the supposition proposed before that the complex connection of neutron multiplicity and its kinetic energy is one of important sources of systematic uncertainties of neutron multiplicity sorting.

New evaluated cross sections were obtained for ^{186,188,189,190,192}Os partial (γ,n), (γ,2n), (γ,3n), and total photoneutron reaction $\sigma[(\gamma,1n) + (\gamma,2n) + (\gamma,3n) + \ldots] \approx \sigma(\gamma,abs)$ reactions cross sections.

Data for ^{186}Os(γ,2n)^{184}Os reaction are discussed from the point of view of astrophysical problems of formation of *p*–isotope ^{184}Os can not be produced in traditional s– and r–processes.

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PRODUCTION OF ISOTOPES AND ISOMERS WITH IRRADIATION OF *Z* = 47 – 50 TARGETS BY 23 MeV BREMSSTRAHLUNG

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Irradiations of the Ag to Sn targets by bremsstrahlung were performed at 23 MeV electron beams of the M*T*-25 microtron. Gamma spectra of induced activities have been measured and the yields of all detected radio-nuclides and isomers were carefully measured and analyzed. A regular dependence of yields versus changed reaction threshold is confirmed. Many isomers were detected and the suppression of production probability is observed when the product spin is increased. Special peculiarities for the isomer-to-ground state ratios were deduced for the ^{106m}Ag, ^{108m}Ag, ^{113m}In, ^{115m}In, and ^{123m}Sn isomers. The accumulations of ^{108m}Ag, ^{115m}In, ^{117g}In, and ^{113m}Cd nuclides are of interest for applications, especially when economic production method is available, as in the case of microtron. The In species are promising for therapy of patients. The ^{108m}Ag and ^{113m}Cd long-lived isomers are considered for energy storage because definite schemes are visible for energy release by demand with depletion of these excited isomeric states. As a first step for the isomer depletion experiment, their accumulation in μg to mg amounts is required. The presently measured yields supply a basis for estimates of the production rates. Photon-induced reactions at low/moderate energy, ≤ 30 MeV, offer the most productive and economic options for the listed above applications. At higher energies many reaction channels are open in competition and many background activities are produced with suppression of the yield for the specially selected one. The theoretical analyses of yields are complicated in addition. After processing of our data taken at low energy, we succeeded to establish the following peculiarities in the reaction yields: a) the inversion of the spin values for the ground and isomeric states of the In nuclides makes an effect in anomalous isomer-to-ground state ratios *m*/*g*; b) the decay chains of the ^{115}Cd, ^{117}Cd *m* and *g* species allow the production of ^{115m}In and ^{117g}In radio-nuclides for medical application in an advantageous mode of the “generator” scheme similar to the one widely-used at the case of ^{99m}Tc; c) accumulation of the long-lived ^{108m}Ag and ^{113m}Cd isomers through the (γ, n) reaction is quantitatively characterized being of interest in a view of potential “triggering” experiments for the isomeric energy release; d) the reduced *m*/*g* ratio observed for ^{108m}Ag may supply an evidence for the microscopic-structure influence onto the isomeric yield despite the reaction is typically attributed to the statistical mechanism. Some other cases of such an influence were recently discussed in [1].

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MICROSTRUCTURE MANIFESTATIONS IN NUCLEAR REACTIONS

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Many nuclear reactions are described in macroscopic approach that involves only potential and excitation energies, statistical equations and macroscopic parameters such as radius, level density, rotational energy, and so on. At the case of direct reactions, the initial and final states are known as definite quantum states, and the theory must account the matrix element of this quantum transition. That is hardly applicable when the continuum of microstates is populated on the stages of intermediate compound-nucleus, or even of the final product formation. However, this does not mean that the nucleon orbits filled in the target nucleus and the final-product quantum numbers must be completely neglected. The problem is formulated, how to find the manifestation of microstructure peculiarities in the experimental data on cross sections and yields of studied reactions. Inelastic neutron acceleration (INNA) process has been recently approved [1, 2] to have much higher cross section compared to the standard-theory predictions for the ^{177m}Lu and ^{178m2}Hf isomeric targets. This special reaction with thermal/cold neutrons involves the transition from isomeric to lower-lying level with energy release to the neutron kinetic energy (acceleration). Such a transition is normally accompanied with the transfer of a great orbital momentum to the accelerated neutron. Thus, the process probability is restricted due to low transmission coefficients $T_l << 1$ for $l \geq 3$. Experimental INNA cross sections exceed the predicted ones by an order of magnitude. The only explanation could be drawn that the intrinsic orbital-momentum distribution influences the neutron emission. The single-particle shell model predicts that in medium and heavy nuclei only about 30% of all neutrons sit at the orbits with the lowest moments $l = 0, 1, 2$. Their emission is regulated by normal T_l values but only for 30% of neutrons in the nucleus. Therefore, the integral emission rate is suppressed by a factor of about 0.3. The statistical neutron-emission width Γ_n must be respectively reduced. This must be manifested in experimentally-tested time scale of the compound-nucleus decay. Emission of neutrons from the orbits with $l = 3 - 5$ and greater is hindered by the centrifugal barrier, but could happen after the orbital moments exchange with the re-arrangement of orbits – the dynamical process inside the nucleus. A minor addition into the total emission rate is yet expected. Moreover, both direct neutron emission and past re-arrangement could not provide a great orbital momentum release being useless for explanation of the enhanced INNA probability. The new mechanism must be introduced for virtual penetration of a neutron pair through the centrifugal barrier. The pair possesses zero angular momentum in sum and could virtually penetrate to the external space. Remind that the energy conservation hinders a real penetration of the pair. But in virtual process, the pair could split: one of neutrons is ejected with a great orbital momentum and the second one returns back to its initial bound orbit. The INNA probability arises strongly while total emission rate is changed only slightly.

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THE PARTICLE-HOLE DISPERSIVE OPTICAL MODEL AND ITS APPLICATION TO THE DESCRIPTION OF THE SIMPLEST PHOTONUCLEAR REACTIONS

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The particle-hole dispersive optical model (PHDOM) was developed recently to describe in a semimicroscopic way main properties of high-energy (*p-h*)-type excitations (including giant resonances) in "stiff" spherical nuclei of medium-heavy mass [1, 2]. Within the model the *p-h* strength distribution (Landau damping) and coupling of (*p-h*)-type states to the single-particle continuum are described microscopically (using Landau-Migdal *p-h* interaction and a phenomenological mean field partially consistent with this interaction), while coupling to many-quasiparticle configurations (the spreading effect) is treated phenomenologically (and in average over the energy) in terms of the imaginary part of the effective optical-model potential. The imaginary part determines also the respective real part via a proper dispersive relationship [1-3].

We present some results of description within the PHDOM of photo-absorption, direct + semi-direct (DSD) photoneutron and inverse reactions accompanied by excitation of the isovector giant dipole and quadrupole resonances (IVGDR and IVGQR, respectively) in a few neutron-closed-shell nuclei. In this description we use additionally isovector velocity-dependent separable forces. The presented approach is an extension of our previous study [4], where a simplified semimicroscopic model was exploited. In description of the partial (γ, n) and inverse DSD reactions accompanied by IVGDR excitations the specific adjustable parameters are not used. Within the model we describe also asymmetry of the above-mentioned DSD-reaction differential cross sections in the IVGQR region. Being determined by the interference of *E*1- and *E*2-reaction amplitudes, the asymmetry is a proper subject for studying IVGQR in photonuclear reactions. The calculations results are found to be in satisfactory agreement with the corresponding experimental data.

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SENSITIVITIES OF ENERGIES OF GIANT RESONANCES TO PROPERTIES OF THE ENERGY DENSITY FUNCTIONAL

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We will first describe a method for determining a modern energy density functional (EDF), based on the effective nucleon-nucleon Skyrme type interaction, with an enhanced predictive power for properties of nuclei and the equation of state (EOS) of nuclear matter (NM), the needed ingredient in the study of nuclei and the structure and evolution of compact astrophysical objects. The parameters and some properties of the new and improved EDF (named KDE0 and KDE0v1) will be presented.

Next the results of HF-based RPA calculations of properties of neutron-rich nuclei and of multipole isoscalar and isovector giant resonances (strength distribution and centroid energies) will be presented and their sensitivity to NM properties, such as the incompressibility coefficient, the symmetry energy density and the effective mass, that are needed to determine the next generation EDF, will be discussed.

INTERNATIONAL NUCLEAR PHYSICS RESEARCH PLATFORMS AND THEIR IMPACT ON THE SCIENCE PROGRESS

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International nuclear physics research platforms are forge highly qualified scientists , able to lead and conduct research at the forefront of science. The report provides an overview of research work carried out at CERN and planned to run on FAIR, ILC and new technologies that have emerged as a result of training and the creation of the collider experiments. The prospects for joint participation of Russian and Belarusian scientists in the preparation and conduct scientific experiments at colliders.

THRESHOLD PHENOMENA IN NUCLEAR REACTIONS

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For more than half a century threshold phenomena in nuclear reactions have been drawing attention of researchers by its unique capability for a detailed study of nuclei structure near the energy threshold of opening of any reaction channel, since here occurs an abrupt change of energy dependence of physical quantities characterizing a compound system, caused by its radical internal reconstruction. A flow of probability conservation causes a unitarity of collision matrix, what together with a requirement for reaction amplitude analyticity, conditioned by a causality principle, is a basis for the formal apparatus of threshold phenomena theory (TPT). Specific features of behavior of differential and total cross-sections of reaction channels and elastic scattering near a threshold of one of the channels were predicted by E.Wigner in the year 1948 [1]. In a decade (in the year 1957) G. Breit [2] and A. Baz [3] there was built a consistent TPT theory, which was generalized on the basis of Feshbach microscopic theory [4] by L.M. Lasarev [5] in case of multi-particle reactions and resonances in the compound nucleus near the threshold.

The report represents a review of experimental data on threshold anomalies in a few nucleon systems. As an illustration of wealth of spectroscopy information, obtained when studying threshold anomalies, the system ^{7}Li+t near the threshold ^{7}Li(t,n)^{9}Be*(E_x=14.4 MeV, T=$^{3}/_{2}$) is considered. Analysis of excitation functions of ^{7}Li+t reaction channels has allowed obtaining of energy of the lowest levels with isospin T=2 of nuclei ^{10}Be, determination of their spins and parities, as well as quantum characteristics of nucleon-unstable nucleus ^{10}Li, its mass and energy of the first excited level [6].

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T-ODD CORRELATIONS IN (n,γγ)-, (n,αγ)- AND (n,*f*γ)-REACTIONS

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The results of the measurements of exotic three- and five-vector pseudo-T-noninvariant correlations of fission products – so-called TRI and ROT effects – look intriguing. It is generally recognized that the effects are not consequences of the actual T-invariance break up. More or less consistent approaches in the frame of classical mechanics are built to explain the data related to simultaneous three-body decay processes such as the ternary fission (n,*f*α) process.

Due to the smallness of γ-radiation width the (n,*f*γ)-process may be cited as typical sequential cascade as well as (n,αγ)-and (n,αγ)-reactions. As it was shown in Ref. [1], the TRI effect is negligibly small in sequential cascades so the attention should be focused on the ROT effect. A general approach to the description of the T-odd correlations in these three processes is discussed in the present work. The theory of angular correlations is used. Selection rules, impact of properties of the nuclear spectra on the values of the correlations are studied.

T-odd effects in (n, αγ)-reactions on light nuclei were investigated in [2]. In that case the basic origin of the ROT effect is the interference of α-emission amplitudes with different angular momenta.

Both this and another mechanism originating the T-odd correlations are studied in the present work. It is shown that for reactions induced by neutron absorption by heavy nuclei three discussed T-odd correlations all are the result of one and the same effect – the interference of amplitudes related to neutron resonances with different spins in the reaction entrance channel.

The T-odd (n,*f*γ)-correlations measured by now are explained in this way. A broad assortment of target nuclei promising for search for (n,γγ)-correlation exist. Due to that the measurements of the ROT effect may be involved in considerable use as a method of investigation of the properties of neutron resonances in various nuclei. An unique example is ^{149}Sm target. By use of it not only (n,γγ)- but also (n,αγ)-correlation may be measured; in so doing one can expect a large effect for the latter process.

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EXPERIMENTAL INVESTIGATIONS OF ATOMIC NUCLEUS PROPERTIES

HIGH EXCITED STATES OF ^{6}He

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High excited states of heavy helium isotope ^{6}He were studied in stopped pion absorption on ^{9}Be and ^{10,11}B nuclei. The measurements were carried out at low energy pion channel of LANL with two-arm multilayer semiconductor spectrometer [1].

Several levels of ^{6}He were originally observed. In two reaction channels ^{10}B(π^{-}, pt)X and ^{11}B(π^{-}, dt)X state with $E_x \approx 9.3(2)$ MeV and $\Gamma \approx 1.0(4)$ MeV was produced. Beyond the threshold of ^{6}He decay on two tritons ($E_x \geq 12.3$ MeV) two states of ^{6}He with $E_x = 22(1)$ MeV, $\Gamma = 2.7(1.4)$ MeV and $E_x = 27.0(8)$ MeV, $\Gamma = 2.5(1.1)$ MeV were observed in the ^{10}B(π^{-}, pt)X channel.

In measurements of ^{9}Be(π^{-}, tt)t reaction we separated ^{6}He excited states decaying on t + t. For the first time three levels with $E_x = 15.8(6)$ MeV, $\Gamma = 1.1(6)$ MeV, $E_x = 20.9(3)$ MeV, $\Gamma = 3.2(1.5)$ MeV and $E_x = 31.1(1)$ MeV, $\Gamma = 6.9(2.3)$ MeV were observed.

Our results were compared with theoretical and experimental results obtained up to now.

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DETECTION OF LIGHT NEUTRON NUCLEI IN ALPHA-PARTICLE-INDUCED FISSION OF ^{238}U BY ACTIVATION METHOD WITH ^{27}AL

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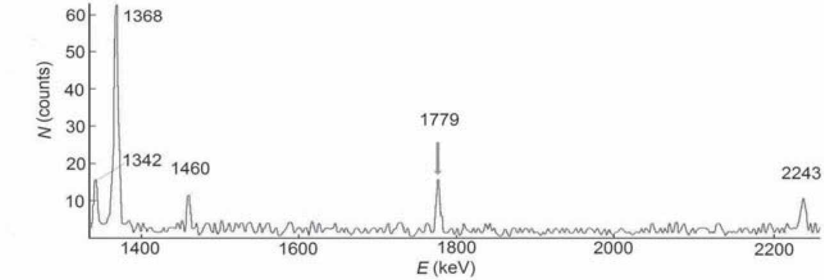
Nuclear-stable multineutrons among products of the ternary fission of ^{238}U nuclei that is induced by 62-MeV alpha particles have been sought by activation method. The beta-active isotope chain $^{28}Mg \rightarrow ^{28}Al \rightarrow ^{28}Si$ was used as an indicator of neutron nuclei. The ^{28}Mg with a half-life of 20.915 h could be formed in this chain in the $^{27}Al + {}^{x}n \rightarrow {}^{28}Mg + (x\!-\!2)np$ process induced by multineutrons in the secondary ^{27}Al target. The gamma lines 1342 and 1779-keV (as it is shown in the Figure) accompanying the beta decay of the ^{28}Mg and ^{28}Al



nuclei, respectively, have been observed in the spectra of the irradiated ^{27}Al sample (after its the preliminary diffusion cleaning from sodium) [1]. The decay time of the indicated lines is in agreement within the measurement accuracy with the known half-life of ^{28}Mg. Thus, the reported measurements confirm the results of our previous work [2], where the possible emission of multineutrons from the ternary fission of ^{238}U was established by characteristic 1384-keV gamma rays from the $^{88}Sr + {}^{x}n \rightarrow (x\!-\!4)n + {}^{92}Sr \rightarrow {}^{92}Y$ process in the activated strontium sample. Comparison showed that the yield of ^{28}Mg in the case of the interaction of multineutrons with ^{27}Al is an order of magnitude higher than the yield of ^{92}Sr.

The results of two independent experiments indicate that nuclear-stable multineutrons (most likely, ^{6}n) are emitted from the alpha-particle-induced ternary fission of ^{238}U. In the future, we are going to improve the statistics of the measurements by increasing the intensity of the beam and irradiation time of samples.

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SEARCH FOR ALPHA CLUSTER STATES IN ^{11}B

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There are predictions [1,2] based on the model of antisymmetrized molecular dynamics (AMD) and alpha-condensate models that two states in ^{11}B: ½$^-$, E^* = 8.56 MeV and ½$^+$ (possibly E^*=12.56 MeV), have mean-square radii RMS, which are much larger than the radius of the ground state.

For verification of this prediction two experiments on ^{11}B+α scattering were performed at E_α=65MeV and 40MeV (last data were partly published in [3]). Goal of these experiments was to determine radius values of exciting states in ^{11}B using Modified Diffraction Model (MDM). Preliminary value of 8.56 MeV state radius was determined: $\langle R \rangle$ = 2.68 ± 0.15 fm, which is 0.4 fm larger than radius of the ground state. This value is in agreement with previous data [5] and AMD calculations [1].

For the 12.56 MeV (½$^+$) state [6] of ^{11}B there exists contradictory information concerning its isospin. The model [2] suggest that T = ½. In the case of T = 3/2, this state cannot be excited in the inelastic alpha particle scattering.

In our experiment we observed state with excitation energy 12.6 MeV. As it is excited in alpha scattering, so it's with T = ½. Also this state was detected in the resonance reaction ^{7}Li + α [6].

We got preliminary results for differential cross-section of inelastic scattering with excitation of this state. We estimated RMS radius for 12.6 MeV state using MDM. Its value is rather smaller than predicted in [2]. Thus, we can conclude that the predictions [2] were not confirmed.

We got preliminary results for the differential cross-section of the inelastic scattering leading to 10.34 and 13.1 MeV states. These states are considered [7] to be the second and the fourth members of the rotational band based on the 8.56 MeV state.

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RESONANCES IN THE $\alpha+^{13}C$ INTERACTION

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The data on $\alpha+^{13}C$ interaction are important for nuclear astrophysics as one of the main source of neutrons for the *s*-process [1]. The data on the alpha cluster resonances are needed to understand clusterization in *N≠Z* nuclei [2]. Therefore, the $\alpha+^{13}C$ interactions were topic of several recent experimental and theoretical investigations [3].We performed an experiment to study the resonance reaction $^{13}C(\alpha,\alpha)^{13}C$ using Thick Target Inverse Kinematics method [4] at DC-60 cyclotron in Astana, Kazakhstan. As a result of the experiment, we obtained new data at low energies, which are important in astrophysics. Fig. 1 shows the excitation function for the $\alpha+^{13}C$ elastic scattering reaction at 180° angle in center of mass (c.m.) frame. The data on the elastic scattering and $^{13}C(\alpha,n)^{16}O$ reaction will be analyzed by multi-level multi-channel *R*-matrix approach. The influence of new data on the understanding the *s*-process in stars and considerations on alpha clusterization in *N≠Z* nuclei will be reported.

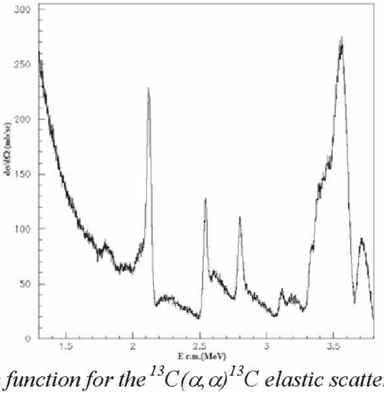

Fig.1.Exicitation function for the $^{13}C(\alpha,\alpha)^{13}C$ elastic scattering reaction.

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ON THE POSSIBILITY OF STUDYING CLUSTER STRUCTURE OF LIGHT NUCLEI BY PROTON QUASIFREE SCATTERING AT LOW ENERGIES

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Availability of radioactive nuclear beams led to the discovery of unusual structure at the periphery of the nucleus – a neutron or a proton halo. However, even for the most studied ^{6}He halo nucleus the structure of its halo (dineutron or cigar-like configuration) is not completely determined.

In this work, we consider a possibility to study the structure of halo nuclei (^{6}He, ^{8}He) using the reaction of quasifree scattering (QFS) of proton by the clusters composing these nuclei. As clusters of ^{6}He and ^{8}He we considered ^{6}He, ^{4}He, n and ^{2}n. To determine the kinematical regions allowed for proton kinematical calculations were performed for reactions ^{6,8}He + p→ p + C + S, where C and S are clusters constituting the halo nucleus: cluster C is involved in proton QFS, and cluster S is a spectator. By definition, the spectator does not undergo scattering and continues moving with the same total momentum as that which it had in the incident halo nucleus.

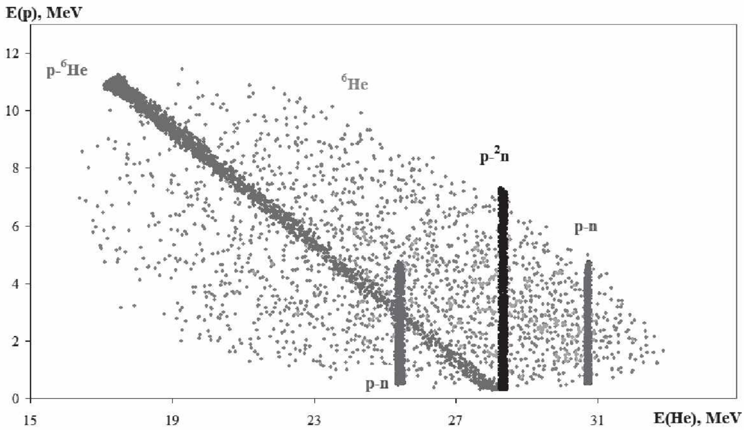

Fig. 1. Two-dimensional plot E_{He}–E_p for proton QFS by clusters of ^{8}He (kor ^{6}He). E_{8He}=40 MeV. Grey dots represent calculation for ^{8}He+p→^{6}He+p+n+n breakup reaction.

The simulation results for proton QFS by ^{6}He, n and ^{2}n clusters of ^{8}He are presented in Fig. 1 as a two-dimensional plot $E_{\rm He}$–$E_{\rm p}$. One can see that events of quasifree proton scattering by different clusters occupy different regions in the two-dimensional Dalitz plot. Thus we can hope that experimental study of proton quasifree scattering by constituents of halo nuclei allows one to determine their cluster structure.

DATA EVALUATION AND STRUCTURE OF NUCLEI WITH A = 146

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The data evaluation on the structure and decays of nuclei with mass number of A = 146 in the standard ENSDF [1] is completed. We present results of this work [2], which takes into account data up to the beginning of 2014. Based on them an overview of the properties and the characteristics of the structure of the nuclei in the isobaric chain is provided.

Systematics of the binding energies of one S_p and two S_{2p} protons, of the energies of the first excited 0^+, 2^+ and 3^- ($E(3^-) < E(2^+)$) levels point out to a closed proton shell with Z = 64 at N = 82 and to the magic properties of the nucleus ^{146}Gd as a whole. Results of single-particle transfer reactions and probabilities of electromagnetic transitions are indicative a large single-particle component of the ground and low-lying excited states of the neighboring odd-A nuclei.

The shell-correction method with the standard mean-field potential gives the single-particle orbitals in the vicinity of Z = 64, N = 82 qualitatively consistent with the experimental data, which enables one interpret the configuration of the ground and low-lying excited states of odd-odd nuclei, in particular ^{146}La and ^{146}Pr.

The peculiarities of the level scheme and characteristics of the low-lying levels and transitions in ^{146}Pm were given earlier [3].

Unlike classical doubly magic nuclei region, "magicity" in A = 146 region is sufficiently narrow as to the number of nucleons and excitation energy. Two-quasiparticle excitations and residual neutron-proton interaction give rise to the states with static deformation, which shows itself in the existence of rotational bands in neutron-rich nuclei, including the ^{146}Gd (superdeformed bands excited in heavy-ion reactions). All the rotational bands are described by two models: polynomial parameterization of Bohr-Mottelson and the variable moment-of-inertia model.

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INVESTIGATION OF ^{166}Er IN (n, $n'\gamma$) REACTION

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The results of measurements of γ-spectra, γ-quantum angular distributions with respect to the neutron beam axis and linear polarizations of γ-transitions following ^{166}Er(n, n' γ) reaction are presented. Experiments were performed by using fast neutron beam facilities on the IR-8 reactor installed at the NRC "Kurchatov Institute". A lot of earlier unknown γ-transitions belonging to ^{166}Er were found and for more 50 γ-transitions the multipole mixig ratios were determined. The level and γ-transition scheme of this nucleus was constructed. Using the obtained experimental data and features of (n, n' γ) reaction all levels with angular momentum J = 0÷4 up to 1.9 MeV excitation energy was established and the problems with $K^\pi = 0^+_2$ and $K^\pi = 2^+_2$ rotational bands (the lack of $J^\pi K = 2^+0_2$, 4^+0_2 and 3^+2_2 band levels at expected energies) [1] were confirmed.

The levels for the $K^\pi = 1^+_1$ rotational band (2^+1_1, 3^+1_1 and 4^+1_1 levels) were ascertained. It is necessary since one from reasons of the observed peculiarities connects with Coriolis interaction of the levels with $K^\pi = 0^+_2$, 2^+_2 and 1^+_1 (the level energies of these ground bands: 1713.41 keV, 1703.10 keV and 1812.76 keV).

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ON ROTATIONAL BANDS WITH $K^{\pi} = 0^+_2$, 2^+_2 AND 1^+_1 IN ^{160}Gd, ^{164}Dy AND ^{166}Er

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In our investigations of γ-rays in the (n,n'γ) reaction on ^{160}Gd [1], ^{164}Dy [2] and ^{166}Er [3] we established the completeness of level schemes with $J^{\pi} = 0^+ \div 4^+$ in these nuclei up to 1.9 MeV excitation energy. Obtained in these works results allowed to define that problems arising at construction of rotational bands with $K^{\pi} = 0^+_2$ and 2^+_2 exist in all of these nuclei (for ^{166}Er see also [4]). In particular, the levels with $J^{\pi}K = 2^+0_2$, 4^+0_2, 3^+2_2, 4^+2_2 were not found at the expected excitation energies. The energies of head levels for bands with $K^{\pi} = 0^+_2$, 2^+_2 and $K^{\pi} = 1^+_1$ are given in the table in keV units.

K^{π}	^{160}Gd	^{164}Dy	^{166}Er
0^+_2	1558.37	1779.14	1713.41
2^+_2	1586.69	1706.66	1703.10
1^+_1	1568.69	1840.67	1812.76

The one of possible explanation is that Coriolis interaction leads to the confluence of states with $J^{\pi}K = 2^+0_2$ and 2^+1_1, 3^+2_2 and 3^+1_1, 4^+0_2 and 4^+1_1 since the presence of $K^{\pi} = 1^+_1$ band levels plays important role in this interaction [5].

Another reason of discussed phenomenon may be connected with distribution of Nilsson two-quasiparticle states among bands. There are two groups of Nilsson states expected in this excitation energy region: a) the ν[521]↓, ν[521]↑, ν[523] ↓, π[411]↓, π[411]↑ and π[413]↓ states with small orbital momenta and b) the neutron $1i_{13/2}$ subshell states (ν[651]↑, ν[642]↑, ν[633]↑) and the proton $1h_{11/2}$ subshell ones (π[532]↑, π[523]↑) with large orbital momenta [5,6] (the latter set states determine the nonspherity of nuclei). The neighbour states of the second group cannot participate in creating the $K^{\pi} = 2^+_2$ band (in contrast to the 1^+_1 band). Pairs with $J^{\pi} = 0^+$ give small contributions into $K^{\pi} = 0^+_2$ band in ^{160}Gd and ^{166}Er but put essential contribution into in ^{164}Dy (νν[633]↑ state) [6]. It is possible in ^{164}Dy the essential Coriolis interaction of levels for $K^{\pi} = 1^+_1$ and $K^{\pi} = 0^+_2$ bands is expected. The factors mentioned above should have an influence on the $K^{\pi} = 0^+_2$ and 2^+_2 band structure in ^{160}Gd, ^{164}Dy and ^{166}Er.

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INFLUENCE OF ATOM ENVIRONMENTS ON ENERGIES OF THE *KLL* AUGER TRANSITIONS IN ^{85}Rb FROM THE EC DECAY OF ^{85}Sr

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In the frame of the development of a new technique for the preparation of super stable calibration ^{83}Rb/^{83m}Kr electron sources [1,2] for the KATRIN neutrino mass experiment [3], the rubidium *KLL* Auger spectrum was investigated in detail with the use of a combined electrostatic electron spectrometer [4] and two ^{85}Sr($T_{1/2}$=64.9 d) sources prepared by vacuum evaporation on a C backing and by implantation of 30 keV ^{85}Sr ions into a Pt matrix. Preliminary values (in eV) of the absolute energies of the dominant $KL_2L_3(^1D_2)$ transition related to the Fermi level and relative positions of the others *KLL* transitions for the both sources measured are given in the table. As can be seen from the table, the relative energies agree with each other within the standard deviations quoted

Transition	^{85}Sr source	
	Evaporated	Implanted
$KL_1L_1(^1S_0)$	– 451.7(7)	– 452.1(7)
$KL_1L_2(^1P_1)$	– 254.8(4)	– 255.1(4)
$KL_1L_2(^3P_0)$	– 227.6(17)	– 227.9(9)
$KL_1L_3(^3P_1)$	– 190.7(6)	– 190.2(5)
$KL_1L_3(^3P_2)$	– 167.1(8)	– 166.4(7)
$KL_2L_2(^1S_0)$	– 65.2(9)	– 66.1(8)
$KL_2L_3(^1\mathrm{D}_2)$	11443.3(28)	11440.1(25)
$KL_3L_3(^3P_0)$	+ 47.5(9)	+ 48.4(8)
$KL_3L_3(^3P_2)$	+ 69.4(4)	+ 69.4(4)

and the same is found for the $KL_2L_3(^1D_2)$ absolute transition energies. However, a value of +(2.4±0.6) eV determined from electron retarding voltages applied [4] for the $KL_2L_3(^1D_2)$ position difference between the evaporated and implanted ^{85}Sr sources clearly demonstrates an environmental effect on the rubidium $KL_2L_3(^1D_2)$ absolute energy. To our knowledge it is the first time the influence of atom environment on the *KLL* Auger transitions involving the inner atomic shells was undoubtedly proved.

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SEARCHING FOR THE LIFETIME BROADENING OF THE RUBIDIUM *KLL* AUGER LINES

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It is known that if the peripheral electron configuration of an atom is changed (by multiple ionization or by chemical bonding), atomic level energies changed and Coster-Kronig decay channels may either open or close. This results also in changing of the *KLL* Auger line widths. Thus, e.g., in the case of 3*d* transition metal series the KL_2L_3 Auger lines are broader in the metal than in free atoms due to this lifetime effect. Having to our disposal two ^{85}Sr ($T_{1/2}$=64.9 d) sources prepared by vacuum evaporation on a C backing and by implantation of 30 keV ^{85}Sr ions into a Pt matrix we decided to search for the about effect also in the case of ^{85}Rb situated in quite different matrices. The *KLL* Auger spectra were measured with a combined electrostatic electron spectrometer [2]. Obtained natural widths (in eV) for individual *KLL* Auger lines are presented in the table together with the estimated values. As can be seen, the values measured for the evaporated and implanted sources agree with each other within one standard deviation with the exception of the KL_3L_3 line. Nevertheless some indication of broadening can be identified for the well resolved KL_1L_2, KL_2L_3, and KL_3L_3 lines. Evidently much higher spectrum statistics is required for searching for the lifetime effect. Estimated natural widths values do not fit well the weighted means of the measured ones for the KL_1L_1 and KL_2L_3 lines.

Auger line	^{85}Sr source			Estimated
	Evaporated	Implanted	W.M.[a)]	W.M.[b)]
KL_1L_1	9.3(1.3)	8.2(1.0)	8.6(8)	10.9(3)
KL_1L_2	7.8(9)	8.1(6)	8.0(5)	8.3(3)
KL_1L_3	8.1(1.9)	7.3(8)	7.4(8)	8.2(3)
KL_2L_2	5.5(2.0)	5.3(1.3)	5.4(1.1)	5.7(2)
KL_2L_3	4.8(2)	5.1(2)	5.0(1)	5.6(2)
KL_3L_3	4.6(4)	5.6(4)	5.1(3)	5.5(2)

[a)] W.M. means "weighted mean".

[b)] Values obtained from weighted means of natural level widths [2,3,4].

The work was supported by the GACR grant P 203/12/1896.

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EXPERIMENTAL PARAMETERS OF THE ISOVECTOR *E*1 GIANT RESONANCE IN DEPENDENCE ON CORRECTNESS OF TAKING INTO ACCOUNT BREMSSTRAHLUNG SPECTRA

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In the region of the Electric Dipole Giant Resonance (*E*1GR) accurate calculations of electron bremsstrahlung in the fields of atom is a very difficult task, whose solution requires a number of approximations. Earlier spectra [1] were considered as the best solution of this task. Spectra [1] were used in the overwhelming majority of experimental photonuclear studies of *E*1GR. But now spectra [2] are accepted as the most reliable ones [3, 4]. So it is necessary to compare spectra [1] and [2] and, supposing that spectra [2] describe reality correctly, to estimate misrepresentation of *E*1GR parameters, obtained from photonuclear bremsstrahlung experiments using for data processing spectra [1].

In [5] on the base of own approximate analytical descriptions of ζ- ratios of spectra [2] to [1] in dependence on energies of bremsstrahlung photons E_γ there was pointed out reason for hypertrophied fine structure (in ~2 times for peaks with width ~100 keV) in photonuclear cross sections $\sigma\{E_\gamma\}$, obtained with processing of data spectra [1]. ζ>~2 at $E_\gamma = E_{\gamma\,\max}$ (in disagreement with [3]).

Influence of differences between spectra [1] and [2] on obtained results in data processing depends on the type of monitoring, used in experiment: monitoring of γ-beam with some ionization camera, as it used to be at cyclic electron accelerators with internal radiators, or monitoring of electrons at accelerator with external electron beams. These differences at low and middle E_γ may change values of integral cross sections (on ≤~10%). The most serious misrepresentations of cross section structure are connected with value $\zeta>1$ for $E_\gamma \sim E_{\gamma\,\max}$. $\sigma\{E_\gamma\}$ may increase due to it for narrow peaks. But in disagreement with [6]: factor of this increasing depends on a peak width; position for maximum of a peak may be shifted (in dependence on a peak width and shape); for narrow standing separately peaks senseless in physics negative $\sigma\{E_\gamma\}$ may appear. It is extremely significant that at processing of bremsstrahlung data for reactions (γ,n) on ^{52}Cr and ^{51}V with spectra [1] and [2] in [7] there was for the last case much better situation with negative values of obtained $\sigma\{E_\gamma\}$.

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WIDTH OF THE GIANT DIPOLE RESONANCE IN HEAVY NUCLEI

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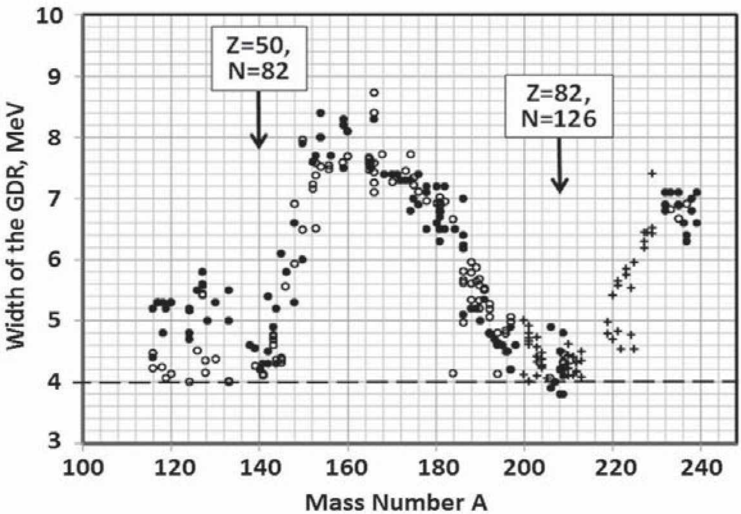
Based on the analysis of available experimental data on the widths of the giant dipole resonance (GDR) and the parameters of the quadrupole deformation of nuclei with $Z \geq 50$ is demonstrated a high degree of correlation between these values. The conclusion is that the quadrupole deformation is the only significant factor broadening (splitting) of GDR for heavy non-spherical nuclei. The database of the Web-site of the Centre for Photonuclear Experiments data SINP MSU was used. 116 Cross sections for 73 isotopes received by the most reliable experimental techniques were selected. As the data of experiments on registration of photoneutron and experiments on nuclear photoabsorption were used. Parameter of the quadrupole deformation δ is determined in accordance with the monograph Aage Bohr and Ben R. Mottelson "Nuclear Structure". The results of the analysis are presented in figure, where for the same isotopes experimental widths of the GDR (dark spots) are compared with the values $|\delta|$ (bright dots) calculated with the formula $\Gamma = \Gamma_0 + \Delta\Gamma$, in which $\Gamma_0 = 4$ MeV - GDR width for heavy spherical nuclei (dotted line), and $\Delta\Gamma = 11 \cdot |\delta|$ MeV - the value of deformation splitting (broadening) of the GDR. Crosses - calculated widths of the GDR for the areas with mass number (A = 200-205 and 210-230), where the photonuclear cross sections are absent.



SYSTEMATICS
OF THE GIANT DIPOLE RESONANCE WIDTHS
OF NUCLEI WITH THE NUMBER OF NUCLEONS ≥ 40

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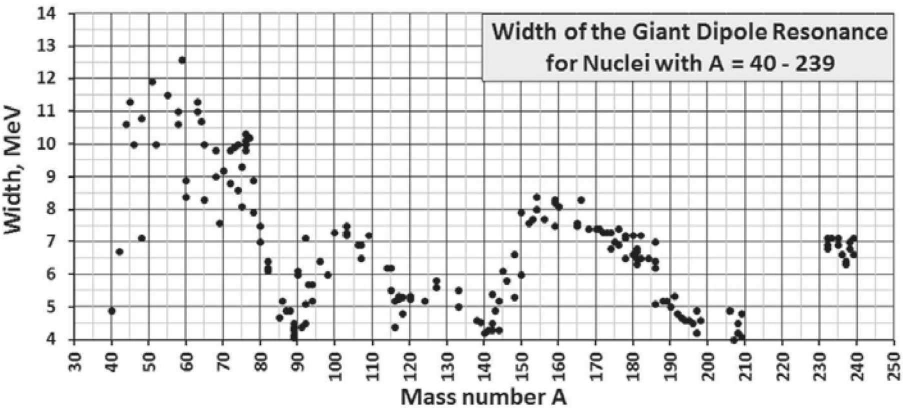
Analyzed all the available experimental data on photonuclear cross sections in mass numbers $A \geq 40$. Systematics of the Giant Dipole Resonance (GDR) widths of medium and heavy nuclei is created (see figure) вased on the 192 total photonucleon and photoabsorption cross sections for the 121 nuclei. Width was considered as the energy interval within which cross section exceeded half its maximum value. The width of the GDR reaches its minimum (4 to 5 MeV) in spherical nuclei with a magic number of protons and/or neutrons. In heavy nuclei ($A > 120$) the main reason of increasing width of the GDR in comparison with magic value (4 to 5 MeV) is the deviation form the nucleus from the spherical (effect of Danos-Okamoto) and this increase is proportional to the modulus of quadrupole deformation of the nucleus in the ground state (see the appropriate I.M. Kapitonov′s thesis to this conference).

Further analysis showed that the main factor of increasing the width of the GDR for nuclei with A = 46-115 compared to magic ones is the dipole-quadrupole friction - decay of doorway dipole states to states of more complex nature, arising due to connection of dipole oscillations with quadrupole vibrations of the nuclear surface.



NUCLEAR DECAY STUDY USING TOTAL ABSORPTION γ-RAY SPECTROSCOPY

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The total absorption γ-ray spectroscopy (TAGS) is based on summation of cascade gamma quantum energies in the 4π geometry [1,2]. The TAGS may be applied for β-decay strength function $S_\beta(E)$ measurement, for total β-decay energy Q_β determination and for decay scheme completeness testing. The total absorption spectrometers (TAS) are used in many laboratories [1,2]. Applications of the total absorption γ-ray spectroscopy (TAGS) and it's combination with high resolution nuclear spectroscopy methods for $S_\beta(E)$ fine structure measurement, for total β-decay energy Q_β determination and for decay scheme completeness testing are presented.

By comparison of the TAGS spectra with the existing decay schemes data one may estimate the degree of the decay scheme completeness. It is shown that more than 30%-50% of the beta decay strength to the nuclear levels with more than 2 MeV-3 MeV excitation energy in the medium and heavy nuclei may not been identified in decay schemes [1,2]. The principles of the more complete decay schemes construction by using the combination of the TAGS spectroscopy with high resolution gamma spectroscopy are presented both for neutron-deficit (β^+/EC-decay) and neutron-rich nuclei (β^--decay). The possibilities of TAGS applications for fission products decay schemes completeness testing and more complete data using for decay heat [2,3] calculations are discussed.

The experimental measurement data on the fine structure of $S_\beta(E)$ in spherical and deformed nuclei are analyzed. Modern nuclear spectroscopy methods allowed the split of the peaks caused by nuclear deformation to be revealed in $S_\beta(E)$ for transitions of the Gamow–Teller (GT) type [2]. The resonance nature of $S_\beta(E)$ for first-forbidden (FF) transitions in both spherical and deformed nuclei is experimentally proved. It is shown that at some nuclear excitation energies FF transitions can be comparable in intensity with GT transitions.

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NEW EVALUATION OF DECAY AND RADIATION CHARACTERISTICS OF ^{198}Au

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The isotope ^{198}Au is widely used in radiotherapy, medical diagnostics and activation analysis. Therefore high-quality evaluated decay data are merited for this radionuclide.

This ^{198}Au decay data evaluation has been carried out within the Decay Data Evaluation Project (DDEP) [1]. The previous DDEP evaluation for ^{198}Au was done by E. Schönfeld and R. Dersch in 1998 with minor update in 2004 [2]. The current evaluation takes into account experimental data and other information (compilations, analyses, corrections) published up to May 2014.

The ^{198}Au half-life of 2.6943(3) days was evaluated in this work taking into account the new measurements and corrections of 2005–2014. The recommended value of the half-life was obtained as the weighted average of 26 experimental values published since 1953.

The energies of β^- transitions of ^{198}Au were obtained using the $Q(\beta^-)$ value of 1372.8 (5) keV from the new mass tables [3] and the ^{198}Hg level energies adopted from [4]. The probabilities of β^--transitions $P_{\beta-}$ were deduced from the gamma ray transition probabilities ($P(\gamma$+ce)) balance at each level of ^{198}Hg.

Gamma ray transition probabilities were obtained from their γ ray emission probabilities and the total internal conversion coefficients interpolated with the BrIcc computer program [5] from the tables of Band *et al.* [6].

The recommended γ ray emission probabilities ($P\gamma$) in decay of ^{198}Au given below were deduced using averaged measured relative γ ray intensities. The normalization factor (0.9562(6)%) to convert the adopted relative gamma ray intensities to absolute emission probabilities was obtained from the gamma ray transition intensity balance at the ground state of ^{198}Hg.

Energy, keV	$P\gamma$, %
411.80205(17)	95.62(6)
675.8836(7)	0.804(5)
1087.6842(7)	0.1591(21)

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POSSIBILITY OF THE USE OF FISSION REACTION AS AN INDICATOR OF NEUTRON CLUSTERS

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The problem of the existence of neutron-only nuclei is closely connected with the cluster structure of nucleus. The typical approaches are to try to find these multineutrons in multinucleon transfer reactions in experiments with radioactive beams, in which charged products of reactions are registered [1,2], or in reactions of the direct capture of a free neutron cluster by a nucleus with the following activation analysis of exposed sample [3].

In the present report, another method for searching for multineutrons is discussed. This method was discovered in the course of the analysis of the technique which the author used for fission cross-sections measurements using a spallation neutron source.

In a spallation process, multineutrons can be born along with neutrons and these multineutrons will be contained in the neutron flux from such a source. You must identify the fission events (in sample placed in this flux) caused by neutrons, as opposed to those caused by multineutrons. This identification is ensured by using the method for selection of neutron by time-of-flight.

We should look for fission events in the region of low neutron energies located before the fission threshold for the nuclei placed in that neutron flux. In the region of low energies of incident neutrons, the fission events will be induced by multineutrons because they insert enough energy into fissionable nuclei. The method sensitivity depends on fission cross-section difference across the fission threshold. For Th-232, for instance, this difference is ~ 10^5. The above-presented reasoning is illustrated by Fig.1.

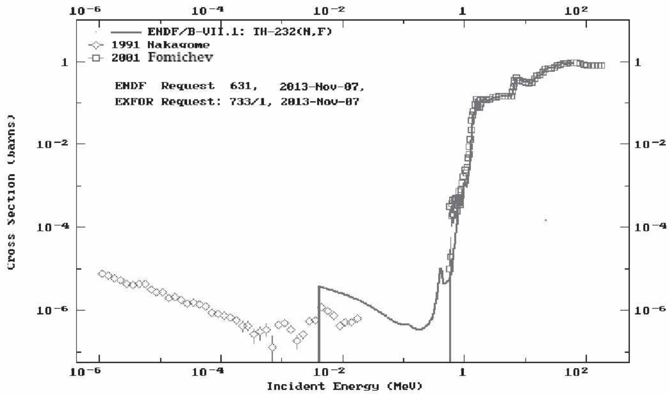

Fig. 1. Energy dependence of fission cross-section of threshold nucleus for Th-232.

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STUDY OF HIGHLY EXCITED STATES OF ^{9}Li ISOTOPE IN PION ABSORPTION REACTION

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Search for the highly excited states of ^{9}Li was provided in ^{11}B(π^{-}, dt)X reaction. The measurements were carried out at low energy pion channel of LANL with two-arm multilayer semiconductor spectrometer [1].

The analysis of two-dimensional distributions (Dalitz' diagram) allowed to identify following reaction channels:

Quasi-particle pion absorption on the intra-nuclear cluster of ^{5}Li $\pi^{-} + {}^{5}\text{Li} \rightarrow \text{d} + \text{t}$, where the residual ^{6}He system is a "spectator"; thus, indications of the existence of the rare cluster structure in ^{11}B nuclei were found: (^{6}He + ^{5}Li).

The cascade process with the formation of ^{9}Li excited states, which break up with respect to t and ^{6}He

$$\pi^{-} + {}^{11}\text{B} \rightarrow \text{d} + {}^{9}\text{Li}^{*} + \text{n} \rightarrow \text{d} + \text{t} + {}^{6}\text{He} + \text{n};$$

two-particle channels $\pi^{-} + {}^{11}\text{B} \rightarrow \text{d} + {}^{9}\text{Li}^{*}$ and the following ^{9}Li* decay.

In the Missing Mass spectrum of $\pi^{-} + {}^{11}\text{B} \rightarrow \text{d} + {}^{9}\text{Li}^{*}$ two-particle channel reaction the highly excited ^{9}Li level was found for the first time. It was shown that this state breaks up with the triton emission, his resonance parameters are $E_x \approx 11$ MeV, $\Gamma \approx 1$ MeV.

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INFLUENCE OF METAL ENVIRONMENT ON ^{212}Po α–DECAY HALF-LIFE AT ROOM TEMPERATURE

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An attempt has been made to investigate a possible change in the decay rate of ^{212}Po implanted into different metal matrix from Be to Pb (20 elements) at room temperature. The comparison experiments have been made also for activity implanted into plastic scintillator and ftoroplast. The measurements were performed with single crystal scintillation time spectrometer [1]. The sources of ^{212}Po nuclei were prepared by electrostatic collection of ionized ^{220}Rn decay products in emanatory with ~ 10 grams powder of ^{232}Th oxide. Fig. 1 presents the results of our measurements of half life ^{212}Po in different metal environment in comparison with Be matrix. Range of statistical errors don't exceed a limit from ±0.06% ÷ 0.17%. Results of the measurements are presented on Fig. 1. Correlation coefficient r = 0.037 proves that no evidence for any dependence $T_{1/2}$ from metal environment.

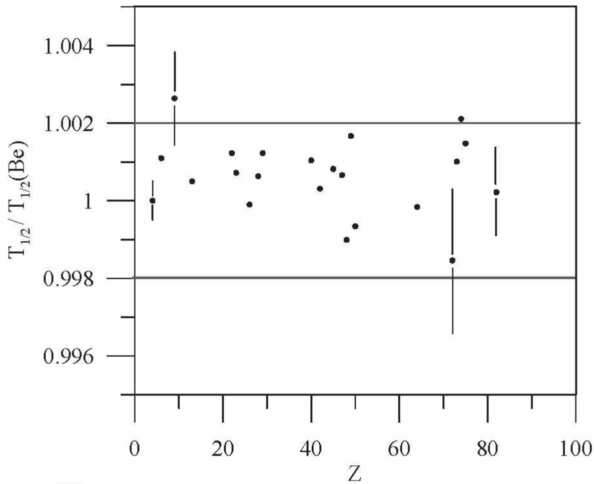

Fig.1. Half life of ^{212}Po in different metal environment in comparison with Be matrix.

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AN ESTIMATE OF ISOMERIC TRANSITION ENERGY IN THE DECAY OF ^{234M}Pa

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Isomeric $E3$-transition in the decay of ^{234m}Pa ($T_{1/2}$ = 1.17 min.) proceeds between 0^{-} and 3^{+} states with main configurations p1/2^{-} [530] n1/2^{+} [631] and p1/2^{-} [530] n7/2^{-}[743]. Authors [1] establish limit (<10 keV) of its energy, authors [2] determined its energy as E = 2.6±0.3 keV, but this value has to be confirmed.

For different values of supposed isomeric transition energy in the range 25 eV — 10 keV the values $T_{1/2}(\gamma)$ were calculated using known $T_{1/2}$, isomeric branching (0.16 ± 0.04)% and internal conversion coefficients which were determined by extrapolation of theoretical values [3]. The values $T_{1/2}(\gamma)$ are shown in the column 3 of the Table below. For the same energies theoretical $T_{1/2}(\gamma)$ values were calculated using Weiskopf formula and these are shown in the column 4. The ratio of γ-probabilities calculated by both methods defines the values of hindrance factor F shown in the last column. These factors F could be compared with value $F = 36 \pm 5$ for isomeric transition in ^{237}Pu which proceeds between the same neutron configurations as in ^{234}Pa. For lower energies (less than 10 eV) transition would be enhanced, for higher energies (more than 25 eV) it would be strongly forbidden both cases being unreasonable. So it could be concluded that the energy discussed is 10–30 eV.

E_γ, eV	Conversion coefficient, α [3]	$T_{1/2}(\gamma) = \alpha \cdot T_{1/2}/0.16\%$, sec.	$T_{1/2}(\gamma)$, sec. (theory)	$F_{hindr.} = T_{1/2}(\gamma)/T_{1/2}(\gamma)$ (theor.)
1	2	3	4	5
25	$9.1 \cdot 10^{22}$ $(P_3+P_4+P_5+Q)^*$	$4.0 \cdot 10^{27}$	$6.0 \cdot 10^{25}$	67
50	$4.1 \cdot 10^{21}(P_\Sigma+Q)$	$1.8 \cdot 10^{26}$	$4.7 \cdot 10^{23}$	380
120	$1.6 \cdot 10^{19}(O+P+Q)$	$6.6 \cdot 10^{23}$	$1.0 \cdot 10^{21}$	660
1400	$4.6 \cdot 10^{12}(N+O+P+Q)$	$2.0 \cdot 10^{17}$	$3.6 \cdot 10^{13}$	$5.6 \cdot 10^{3}$
2600	$3.3 \cdot 10^{11}(N+O+P+Q)$	$1.4 \cdot 10^{16}$	$4.6 \cdot 10^{12}$	$3.0 \cdot 10^{4}$

*The binding energies of electrons in Pa atom are as follows (in eV): 43 (P_1), 27(P_2), 17(P_3), 4.6(P_4) and 5.6 (P_5) [4].

For testing of the method described the hindrance factor of isomeric transition in ^{235}U was estimated. This transition proceeds between the same neutron configurations n1/2^{+} [631] and n7/2^{-}[743] as in ^{237}Pu and in ^{234}Pa. At the value $\alpha = 2.5 \cdot 10^{20}$ $F_{hindr.}$ = 20 and is not far from ^{237}Pu case. Still for ^{234}Pa one should have in mind that F-factors in odd-odd and in odd nuclei could be different even for the same type of transitions.

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NEUTRON DETECTOR TETRA TO REVEAL THE β-DECAY PROPERTIES OF NEUTRON RICH NUCLEI IN THE VICINITY OF NEUTRON CLOSED SHELLS N=50, N=82

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According to available schemes the nuclei in the vicinity of N=50, 82 shell undergo Gamow Taylor (allowed) decays. In contrast, for nuclei crossing the N=50, 82 shella, the first Forbidden (FF) transitions are expected to give a noticeable contribution [1, 2]. With new experimental data on β-decay properties of more neutron rich species already (or shortly) available at new facilities the relative contribution of the Gamma-Teller and FF decays can be understood more. Furthermore, for an r-process site, β-decay properties „waiting points" (nuclei on closed neutron shells) have significant effects on the r-process dynamics and the abundance distribution [3, 4].

One of the means to investigate nuclear structure is in β-decay. Since β-delayed neutron emission becomes significantly strong decaying channel for neutron-rich nuclei far from stability, usage of a proper neutron detector to reveal their properties is indispensable. To conduct the appropriate investigations, in the frame of collaboration JINR (Dubna) and IPN Orsay a new detection system consisting of 80 ^{3}He-filled counters (TETRA neutron detector [5]), 4πβ detector and a HPGe in order to measure simultaneously β, γ and neutron activities was constructed [7]. The efficiency of single neutron registration is ~60% and is almost flat up to ~1 MeV neutron energy range.

It is presented the first data on β-decay properties ($T_{1/2}$, P_n) of neutron rich nuclei $^{82, 83}$Ga, $^{123–125}$Ag produced at ISOL facility ALTO and measured with recently introduced neutron detector TETRA [7].

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CORRELATIONS OF α-PARTICLES IN SPLITTING OF ^{12}C NUCLEI BY NEUTRONS OF ENERGY OF 14.1 MeV

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Correlations of α-particles are studied on statistics of 400 events of splitting $^{12}C \to 3\alpha$ in nuclear track emulsion (NTE) exposed to 14.1 MeV neutrons [1]. Measurements of ranges and emission angles of the α-particles are performed. Distributions over energy of α-particle pairs $Q_{2\alpha}$ (Fig. 1) and triples $Q_{3\alpha}$ are obtained on a basis the SRIM model. This data indicate on superposition of the 0^+ and 2^+ states of the nucleus ^8Be in the ground state of the nucleus ^{12}C at that $^8Be_{2+}$ is dominating. In a classical pattern it can be presented as rotation in opposite directions of two α-clusters around a common center presented by a third α-cluster.

Recently, samples of boron enriched NTE exposed to thermal neutrons allow one to extend range calibration for the ^7Li nucleus on a basis of 200 measured events $n_{th} + {}^{10}B \to \alpha + {}^7Li$ (+ γ, 93%). Angular measurements will allow studying of correlations in the decaying system.

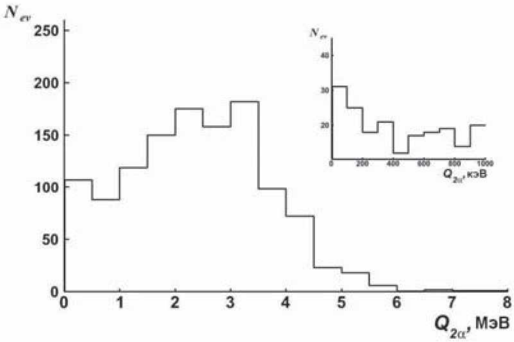

Fig. 1. Distributions over energy of α-particle pairs $Q_{2\alpha}$ produced in the splitting $n(14.1\,MeV) + {}^{12}C \to 3\alpha$.

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ANGULAR CORRELATION IN INELASTIC SCATTERING $^{24}Mg(p, p_1\gamma)^{24}Mg$ AT E_p = 7.4 MeV

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The angular correlation functions (ACF) that is the double differential cross section $W(\theta_\gamma, \varphi_\gamma; \theta_p)$ was measured for the inelastic $^{24}Mg(p, p_1\gamma)^{24}Mg$ scattering for several angles θ_p in the range from 30° to 150° (lab.) at 120-cm cyclotron of SINP MSU at E_p = 7.4 MeV. The ACF measurements were carried out on a three planes φ_γ of γ-rays registration that allowed to restore all density matrix spin-tensor even components of the final nucleus $^{24}Mg(2^+$, 1.369 MeV) for each angle θ_p [1].

Analysis of the experimental characteristics of the reaction was performed assuming the collective interaction mechanism by the coupled-channel method and mechanism of the compound nucleus formation.

The comparison of the calculated and experimental ACF shows that calculation qalitatively corresponds to the position of the extrema but the relative values ACF differs considerably for some θ_p and φ_γ (example on Fig. 1).

This suggests the need for careful choice of different scattering mechanisms contribution, including the mechanism of resonance scattering through the formation of one or more compound nucleus levels.

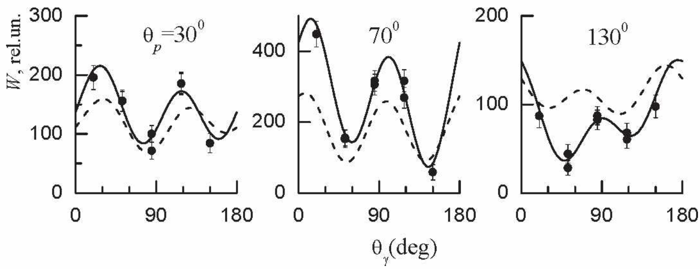

Fig. 1. Angular correlation functions in inelastic p-scattering on ^{24}Mg at some θ_p (lab.) in reaction plane. The solid curves represent a nine-parameter fit to experimental results. The dashed curves correspond to the sum of the compound nucleus *formation* and *collective interaction mechanisms.*

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NEUTRAL KAON PRODUCTION IN p+p, d+Au AND Cu+Cu COLLISIONS AT 200 GeV

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At very high energy densities, exceeding approximately 1 GeV/fm quantum chromodynamics predicts a phase transition from ordinary hadronic nuclear matter to a new state of matter where the degrees of freedom are quarks and gluons. This state of matter exhibits very strong coupling between its constituents and is thus called the strongly coupled Quark-Gluon Plasma [1]. Matter at such high energy density can be produced in laboratory conditions by colliding heavy nuclei at relativistic energies. A wealth of measurements is available from the experiments at the Relativistic Heavy Ion Collider [2].

The PHENIX experiment [3] at the Relativistic Heavy Ion Collider performed a systematic study of the K^0_s and K^{*0} meson production at mid-rapidity in p + p, d+Au and Cu+Cu collisions 200GeV. The measured production spectra are used to determine the nuclear modification factors of K^0_s and K^{*0} mesons in d+Au and Cu+Cu collisions at different centralities. In the d +Au system, the nuclear modification factor of K^0_s and K^{*0} mesons is almost constant as a function of transverse momentum and is consistent with unity showing that cold nuclear matter effects do not play a significant role in the measured kinematic range. In the Cu+Cu system, no nuclear modification is registered in peripheral collisions within the uncertainties. In central collisions, both mesons show suppression relative to the expectations from the p + p yield scaled by the number of binary collisions. In the p_T range 2–5 GeV/c, the strange mesons show an intermediate suppression between the more suppressed light quark mesons and the non-suppressed baryons. At higher transverse momentum all particles, light quark mesons, strange mesons and baryons, show a similar level of suppression.

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MEASUREMENT OF Phi MESON NUCLEAR MODIFICATION FACTORS IN p+Pb AND Pb+Pb COLLISIONS IN THE ALICE EXPERIMENT AT LHC

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Measurements of hadron spectra in proton-proton and nucleus-nucleus collisions at the Large Hadron Collider (LHC) [1] provide the means to study the mechanisms of particle production and properties of the medium formed in relativistic heavy ion collisions. The phi meson is a very rich probe since it is sensitive to several aspects of the collision such as strangeness enhancement, chiral symmetry restoration and parton energy loss. Due to its small inelastic cross section the phi meson is not strongly affected by the late hadronic rescattering and is sensitive to the initial evolution of the system. With a mass similar to that of the proton, it is interesting to see how the phi meson fits within the meson/baryon pattern of observables. Being a pure s-anti-s state, it further constrains the energy loss and recombination pictures.

The ALICE Collaboration [2] performed systematic measurement of the phi meson production in K^+K^- at mid-rapidity in p + p, p + Pb and Pb + Pb collisions at LHC energies. This poster presents recent results on phi meson invariant yields and nuclear modification factors measured in a wide range of transverse momentum up to 21 GeV/c in p + p and p + Pb, Pb + Pb collisions at different centralities.

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EXPERIMENTAL OBSERVATION OF THE CHANNELING EFFECT IN THE STUDY OF dd-REACTION IN THE ASTROPHYSICAL DEUTERON COLLISION ENERGY RANGE IN TITANIUM DEUTERIDE

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The experiment has been carried out using high-current pulsed Hall plasma accelerator (NSR TPU, Russia). The measurements were performed for an incident deuteron energy range of $7 \div 12$ keV in the lab. system. The detection of neutrons with energy of 2.5 MeV from dd-reaction was done with eight plastic scintillation spectrometers ($100 \times 100 \times 400$ mm) placed around target. To quantify the contribution of the process of channeling in the enhancement effect of nuclear reactions at ultralow energies need information about the orientation of the crystal lattice of the target relative to the direction of the incident beam of accelerated particles. The energy dependence of the neutron yield from $D(d, n)^3He$ reaction in textured titanium deuteride target with preferred orientation of the microcrystals in the direction [100] was investigated. It is shown that the energy dependence of *S*-factor for pd-reaction is not only described by the potential of screening, but also in the framework of a simple account of the effects of channeling. Channeling model does not contradict to the experimental data and may explain the relative increase of the yield of the nuclear reaction products of at ultralow energies.

STUDY OF d + d → ^{2}He + ^{2}n REACTION AT DEUTRON ENERGY OF 15 MeV

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In this work the experimental setup and preliminary results of d+d→^{2}He+^{2}n reaction study at deuteron energy of 15 MeV are presented. The goal of the experiment is a simultaneous determination of quasibound singlet states energies of two nucleons (nn and pp) being very important characteristics of *NN*-interactions. The investigation is performed using deuteron beam of U-120 cyclotron at Skobel'tsyn Institute of Nuclear Physics. In the experiment we detect the two protons and the neutron from the decay of "diproton" and "dineutron" systems, respectively. Performed simulation and preliminary measurements of the reaction show a possibility to determine the energies of pp and nn quasibound singlet states with a good accuracy.

PROTONS FROM THREE-BODY AND FOUR-BODY BREAK-UP IN THE DD-COLLISIONS

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Formation of protons in three-body and four-body break-up reactions: $D + D \rightarrow p + n + d$ and $D + D \rightarrow p + n + p + n$ were considered. Inclusive spectra of protons in the proton energy ranges of $5 \le E_p \le 40$ MeV at initial deuteron energy E_d=36.9 MeV were studied experimentally. The experiment was carried out at U-240 cyclotron of the Institute for Nuclear Research of NAS of Ukraine. Measurements were carried out on CD_2 and ^{12}C targets – for determination of background, created by carbon target in spectrum from CD_2 target. Energy and angular distributions of protons in the angle range $15° \le \theta \le 55°$ were obtained. Absolute values of the cross-sections are detected with accuracy of ~15%. Energy spectra of protons are broad, practically symmetrical maximums, and their shape is similar to energy spectra of protons and neutrons from reactions D(d,n), available in literature for energies of $10 \le E_d \le 60$ MeV.

In this paper, for analysis of inclusive spectra of protons from D(d,p)nd reactions, there is used microscopic diffraction model that allow to determine quantitatively contributions of quasi-free scattering cross-sections and distinguish the part of cross-section that is caused by other interaction processes in the output reaction channel. Analysis has shown that three-particles breakup reactions make significant contribution to cross-section of proton generation in all range of exit angles; and, for angles $\theta_p \ge 30°$, contribution of protons from D(d,p)nd reactions is a definitive one.

Among four-particle reactions, following were selected: $D(d,d^*)d^* \rightarrow p+n+p+n$ – decay of two deuterons with generation of two unbound couples neutron-proton in triplet spin state; exchange reactions with generation of dineutron and diproton couple – D(d,2p)2n. For satisfactory matching of energy and angular distributions of protons, it is necessary to take into account mainly the contribution of cross-sections for generation of np couples in singlet and triplet spin states. For proton exit angle θ_p=15°, total contribution of cross-sections for generation of *n*p couples in singlet and triplet spin states is ~40%., and for angle θ_p= 3° respective contribution decreases to 20–25%.

THE INVESTIGATION OF ^{197}Au(d, *xpyn*)X REACTIONS AT THE ENERGY OF 2.2 GeV/NUCLEON

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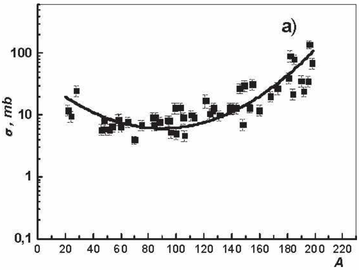
The interaction of deuterons with energy of 2.2 Gev/nucleon from the Nuclotron of the Laboratory of High Energy (LHE), Joint Institute for Nuclear Research (JINR) with a ^{197}Au target have been investigated using method of gamma spectroscopy.

The cross-sections of about 100 radioactive nuclide as well as their kinematic characteristics were obtained and were analyzed. The results including charge and mass distributions have been parameterized in term of 3-parameter equation in order to reproduces the real isobaric distribution. The kinematic characteristics of residuals were obtained using the mathematical formalism of the standard two-step vector model. The dependence of the mean excitation energy of the residual nucleus formed after cascade on product mass number were investigated.

The analysis of the mass-yield distribution (Fig.1) was allowed to suppose different channels of the interaction such as spallation, deep spallation, fission-like and multifragmentation processes.



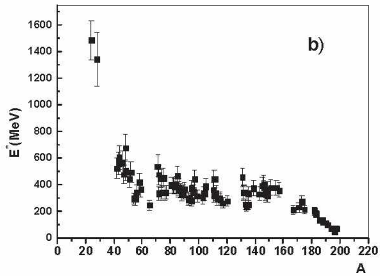


Fig. 1. The mass-yield distribution of cross-sections a) and the dependence of the mean excitation energy of the residual nucleus on product mass number b).

FORMATION OF NEUTRON-DEFICIENT HEAVY NUCLIDES IN He-3 INDUCED REACTION AT INTERMEDIATE ENERGIES

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The ^{3}He induced reactions with the actinides isotopes are promising tool for production of neutron-deficient heavy nuclides which are particularly great of interest as tracers in the environmental studies. Highly enriched 1 mg/cm^2 thick ^{235}U targets were irradiated with 20.4 – 42.0 MeV ^{3}He ions from Accelerator Laboratory of University of Jyväskylä, Finland. The irradiated targets were measured with gamma and alpha spectrometers. Then the targets were dissolved to separate chemically Pu and Np products from the fission product and target material. The chemical yields were determined by measuring the activities of ^{234}Np and ^{236}Pu before and after the chemical separation. Thus, the earlier unknown excitation functions for $^{234,235,\,236}$Pu and $^{234,235,\,236m}$Np nuclides were obtained. The experimental data were analyzed in the framework of the theoretical model with inclusion the nuclear friction in fission channel and pre-equilibrium processes [1].

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ELASTIC AND INELASTIC SCATTERING OF ^{3}He IONS ON ^{16}O NUCLEUS AT 60 MeV

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The differential cross-sections of elastic and inelastic scattering of ^{3}He ions with E=60 MeV on ^{16}O nucleus in angular range of 11–148° were measured on the U-150M Kazakh isochronous cyclotron.

The analysis of cross-sections of elastically scattered nuclides ^{3}He on studied nucleus was performed using standard optical model (by code SPI-GENOA [1]) with Woods-Saxon potential with separated form-factors of real and imaginary parts. The optimal values of inter-nuclear interaction potentials are obtained. As a criterion for matching the results of theoretical calculations with experimental data the minimization of the χ^2 values and the values of the volume integrals of the real part of the optical potential were used. The results are presented in Fig. 1 where points are experiment, solid curve are results of theoretical calculation.

Analysis of cross sections of inelastic scattered ions of helium nuclei ^{16}O was carried out using the distorted wave Born approximation (by code DWUCK4 [2]) with form-factor of a macroscopic collective excitation using optimal optical potential parameters obtained from elastic scattering. The results are presented in Fig. 2. The quadrupole deformation parameter β_2 = 0.46 of nucleus ^{16}O was defined.

The work was supported by the Program of Grant funding of scientific researches under Ministry of Education and Science of Republic of Kazakhstan - Grant 0605/GF.

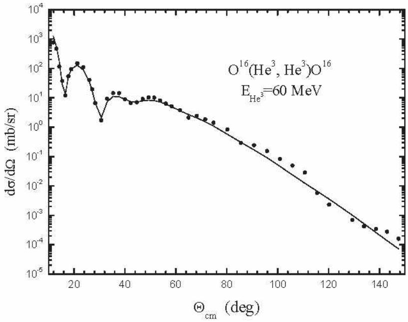

Fig. 1. Differential cross-sections of elastic scattering of ^{3}He ions on ^{16}O nucleus.

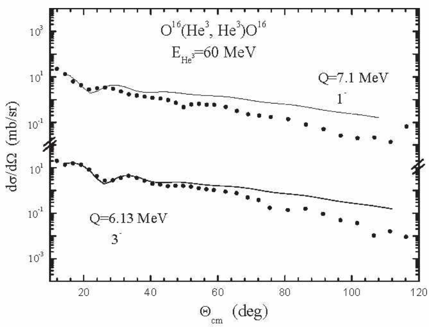

Fig. 2. Differential cross-sections of inelastic scattering of ^{3}He ions on ^{16}O nucleus at excited state 6.13 and 7.1 MeV.

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THE CHANNEL COUPLING AND TRITON CLUSTER EXCHANGE EFFECTS IN ^{3}He SCATTERING ON ^{6}Li NUCLEI

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The cluster aspects play a very important role in interaction of particles with light nuclei ($A \leq 16$). From this point of view, a typical example is the nucleus ^{6}Li, whose ground state, according to the theory, is defined by two overlapping configurations α + d and ^{3}He + t [1]. This structure affects not only the nuclear reaction cross sections, but also cross sections of the elastic scattering of deuterons, tritons, ^{3}He and α-particles due contribution the exchange mechanisms with clusters transfer.

The aim of this work is to obtain a unified description of existing data on the ^{3}He scattering on ^{6}Li nuclei with accounting the coupling channels including the mechanism of triton cluster exchange.

Experimental data on elastic and inelastic scattering of ^{3}He projectiles in the energy range from 18 to 217 MeV were analyzed within the framework of the coupled reaction channels [2]. The coupling of the elastic and inelastic scattering with the transition to the excited state of 2.186 MeV (3^{+}) and triton-exchange mechanism were taken into account in calculations. Phenomenological potentials with depths depending on the energy at fixed values of the geometric parameters were found. These potentials describe well the experimental angular distributions for both the elastic and inelastic scattering. Energy dependence of the volume integrals of the real potential for ^{3}He + ^{6}Li system is consistent with similar data for other systems p + ^{6}Li, d + ^{6}Li, α + ^{6}Li, ^{12}C + ^{12}C and also with the predictions of the microscopic theory.

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INVESTIGATION OF FUSION REACTIONS ^{194}Pt(α ,n)^{197mg}Hg AND ^{195}Pt(^{3}He,n)^{197mg}Hg AT NEAR-BARRIER ENERGIES

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Earlier the excitation functions and isomeric cross section ratios of α- [1] and deuteron-induced [2] nuclear reactions on ^{194}Pt target were measured by us. In the present work the calculations of these values for the reactions ^{194}Pt(α,n)^{197mg}Hg and ^{195}Pt(^{3}He,n)^{197mg}Hg at the energy ranges *E*=18-31 MeV – for α-particles and *E*=13-24 MeV – for ^{3}He ions were performed using codes TALYS and EMPIRE-3.1 . Such beams are produced by the cyclotron of SINP. The results of the calculations demonstrate that interesting isotopic effects similar to, in particular, the ones presented in [3], may be observed in these reactions.

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ISOMERIC YIELDS RATIOS OF ^{238}U PHOTOFISSION FRAGMENTS AT END-POINT ENERGY OF BREMMSSTRAHLUNG PHOTONS ABOUT 18 MeV

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Investigation of ^{238}U photofission fragments has been used in (γ, *f*) + (γ, n*f*) + (γ, 2n*f*) reactions at end-point energy of bremmsstrahlung photons about 18 MeV. The irradiations were done on the M-30 microtron of the Laboratory of Photonuclear Reactions at IEP, Uzhgorod. The gamma-spectra of the reaction products were measured by the semiconductor spectrometers based on HPGe-detectors. Isomeric yields ratios have been defined for isomeric pars of the heavy nuclides shown in the table.

Analysis obtained data is transacted.

Nuclide	^{238}U
^{131}Te	0.93(9)
^{132}Sb	3(1)
^{134}I	0.36(4)
^{135}Xe	0.069(7)
^{84}Br	0.40(4)
^{90}Rb	1.0(2)
^{95}Nb	0.67(7)
^{130}Sb	1.4(3)
^{133}Te	1.29(12)
^{133}Xe	1.7(5)

INVESTIGATION OF $^{178m2, 179m2}$Hf ISOMERS CREATION IN REACTIONS WITH ALPHA-PARTICLES

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The measurement of creation cross-sections of ^{178m2}Hf ($T_{1/2}$ = 31 y., $J^{\pi} = 16^{+}$) and ^{179m2}Hf ($T_{1/2}$ = 25 d., $J^{\pi} = 25/2^{-}$) at targets irradiation of natural both tantalum and lutetium by alpha-particles with energy near 100 and 27.2 MeV, properly Irradiation has been done by U-120 and U-240 accelerators of Kyiv institute for Nuclear Research of NAS of Ukraine. The measurement of induced activity has been performed by Ge-spectrometers with energy resolution 2 keV for the 1332-keV γ-line of ^{60}Co and detection efficiency of 15-40% in comparison with a 3″×3″ NaI(Tl)-detector. In gamma-spectra all γ-transitions have been observed which necessary for identification of abovementioned isomeric states.

The next cross-sections have been obtained: $\sigma = (8.0\pm1,2)\cdot10^{-30}$ sm^2 for nuclear reaction ^{181}Ta(α,α2np)^{178m2}Hf $\sigma = (7.2\pm0,7)\cdot10^{-30}$ sm^2 for reaction ^{176}Lu(α,p)^{179m2}Hf. The integral cross-sections also has been measured for nuclear reactions ^{181}Ta(α,α2n)^{179}Ta, ^{181}Ta(α,6n)^{179}Re, ^{181}Ta(α,5np)^{179}W, which is $\sigma = (33\pm7)\cdot10^{-26}$ sm^2. Experimental values of the cross-sections have been compared with the theoretical values, which calculated by using code TALYS-1.4.

The discussion is transacted about obtained data.

THE MEASUREMENTS OF DIFFRACTION OF THE ANGULAR DISTRIBUTIONS OF ALPHA PARTICLES WITH ENERGIES 29 MeV ON NUCLEI ^{59}Co, ^{197}Au, ^{209}Bi

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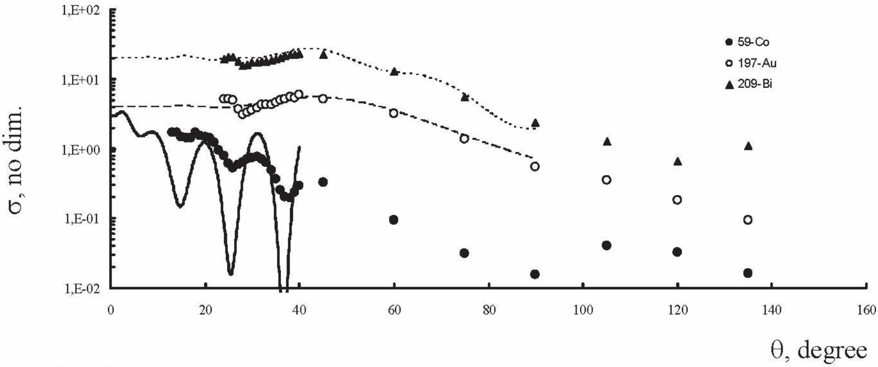
Fraunhofer and Fresnel nuclear diffraction was measured for the study of the odd shape of medium and heavy nuclei, in which, as a rule, collective states are not discovered and inelastic scattering can not be measured due to insufficient energy resolution of the spectrometer. The diffraction of angular distributions of differential cross sections of elastically scattered alpha particles with energy 29 MeV on nuclei ^{59}Co, ^{197}Au, ^{209}Bi was measured. Alpha-particle beam was extracted from the isochronous cyclotron U-150M (Republic of Kazakhstan).



The figure shows the experimental angular distributions compared with theoretical calculations in the framework of parameterized phase analysis. Fit into the angle responsible for the Fraunhofer scattering mechanism yielded average size of studied nuclei. A theoretical optimization of parameters in the range of small angles (Fresnel mechanism) yielded signs of deformation of these odd nuclei. Together with the analysis of the world's available literature data in this paper concludes their positive (^{209}Bi, ^{197}Au) and negative (^{59}Co) deformation that agrees satisfactorily with the systematization of work [1, 2].

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THE PHENOMENON OF DIFFRACTION RISE OF CROSS SECTIONS IN THE FORWARD HEMISPHERE OF ANGLES AS THE EFFECT OF NUCLEAR AND CLUSTER INTERFERENCE

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Meitner has proposed in 1921 the idea that the main structural unit of the nucleus is an alpha particle. Rutherford also adhered to the concept Meitner, assuming that the core consists of alpha particles [1].

The clustering of nuclear structure is understood in two ways in modern physics of clusters. First, the wave function of the nucleon associations can be "spread" over the entire volume of the nucleus with an increased probability of correlated motion of nucleons, regardless of their spatial localization in the nucleus. At the same time an effective amount of alpha-clusters in the nucleus is much more than $A/4$ [2]. Secondly, from the inception of the concept of clusters been attempts detections nucleon associations based on the concept of separate clusters in the volume of the nucleus. For example, the irradiation of light nuclei by high-energy protons observed dominant to fly alpha particles.

In this paper we attempt to search for the effects of separate clusters in the angular distributions of elastic scattering at the wavelength variation of the incident alpha particles is $\lambda\!\!\!^{-} \le R_\alpha < R$. There is well known phenomenon of the rise of differential cross sections in the forward hemisphere of angels in physics of the elastic scattering of light ions on light nuclei. To explain the effect of rise the cross section based on the consideration of light nuclei as much alpha-clustered structures: ^{12}C nucleus consists of three alpha clusters ^{16}O - four alpha-clusters and so on until the nucleus ^{40}Ca. Description cross section multi-cluster structure of the nucleus in the spatial differentiation of alpha-clusters can be represented in a simplified manner without Coulomb amplitude as the square of the sum of the amplitudes of scattering particles on the absorbent black core and absorbing black components - alpha-clusters

$$\sigma'(\theta) = D_0 \left| \sum_{i=1}^{n} A_i(R_i, \theta) \right|^2 = D_0 \left| \sum_{i=1}^{n} a_i \cdot J_1(kR_i\theta) \right|^2,$$

where D_0 - the normalization factor; $A_i(R_i,\theta)$ – amplitude at the i-th cluster substructure of the nucleus; a_i – relative statistical weight of diffraction scattering at the i-th cluster of the nucleus; n - number of cluster structures in the nucleus. A global analysis of the angular distributions, apparently, clearly shows the existence of spatially separate alpha clusters evident in the effect of rise cross sections.

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FRAGMENTATION OF CARBON IONS AT 0.3-2.0 GeV/n: COMPARISON WITH THE MODELS OF ION-ION INTERACTIONS

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Momentum distributions of hydrogen and helium isotopes from ^{12}C fragmentation at 3.5° were measured in FRAGM experiment at ITEP TWA heavy ion accelerator on Be target. At energies 0.3, 0.6, 0.95 and 2.0 GeV/nucleon the momentum spectra of fragments span the region of fragmentation peak as well as the cumulative region. The differential cross sections cover 6 orders of its magnitude. The spectra were compared to the predictions of four ion-ion interaction models: LAQGSM03.03, SHIELD-HIT, QMD and BC. The data were also analyzed in the framework of thermodynamic approach where temperatures of nuclear matter in fragmentation and cumulative regions were obtained and the dependence on projectile energy was studied.

STUDY OF PROJECTILE FRAGMENTATION OF ^{40}Ar ON ^{9}Be TARGET AT 40·*A* MEV

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The projectile-like fragments emitted at forward angles were studied for the reaction ^{40}Ar (40·*A* MeV) + ^{9}Be. Their velocity, isotope and charge distributions have been measured. The experiment was performed at the wide aperture kinematics separator COMBAS at Flerov Laboratory of Nuclear Reactions of Joint Institute for Nuclear Research (FLNR, JINR) [1]. Peripheral nuclear collisions at Fermi energies are of interest to produce new elements far from the stability line. Velocity distributions of individual isotopes show the contribution of two reaction modes: direct break-up at beam velocities and dissipative scattering which leads to a lower energy tail. Transport theories such as Boltzmann-Nordheim-Vlasov (BNV) approach can be used to describe this latter type of process [2]. To compare with the experiment one has to take into account the evaporation from excited pre-fragments. This is done with the use of Statistical Multifragmentation Model (SMM) of Bondorf, Mishustin and Botvina [3]. The results of calculations were compared to the experiment.

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LIGHT HADRON PRODUCTION IN Cu+Au COLLISIONS AT 200 GeV

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The purpose of the high energy nuclei collision experiment is the creation of quark-gluon plasma (QGP) in a laboratory and investigation of its properties. From the previous studies [1], various results, which indicate the creation of QGP, have been reported. According to these results, it was found out that the QGP appears to be not a gas-like form of matter as originally was expected but strong-coupled QGP which seems to be nearly ideal fluid with very small viscosity reaching thermal equilibrium soon after the collision. We are now at the stage where detailed characteristics of QGP are being studied. One of the signal which indicates the strong-coupled QGP is the suppression of the high pT particle production. The cause of the suppression lies in high transverse momentum partons which are experiencing energy loss in dense QGP matter.

The Relativistic Heavy Ion Collider (RHIC) [2] at Brookhaven National Lab allows nuclear matter to be studied at extremely high temperatures and energy densities. The flexibility of RHIC to collide asymmetric nuclei such as Cu+Au at 200 GeV can provide controlled asymmetry in geometry and density both in the transverse and longitudinal plane, allowing us to systematically investigate the effects of initial geometry and density on particle production.

The results for light hadron production obtained from PHENIX [3] experiment at RHIC collider will be presented in the talk: spectra as a function of centrality, nuclear modification factors R_{AA} and particle ratios such as proton/pion, and antiproton/proton will also be shown. The comparison with other colliding systems such as Au+Au will be carried out.

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MECHANISMS OF HYDROGEN ISOTOPE FORMATION DURING PREEQUILIBRIUM STAGE OF STOPPED PION ABSORPTION REACTION

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Results on the investigation of the spectra and the yields of the hydrogen isotopes formed in stopped pion absorption by nuclei are presented. This study is based on the experimental results obtained on the pion channel of PNPI synchrocyclotron using the semiconductor spectrometer [1]. Unique data on charged particle formation following pion absorption on 17 target nuclei in wide mass range ($6 < A < 209$) have been obtained. Spectra were measured in energy range from 10 MeV to the kinematic threshold (~ 100 MeV).

Phenomenological model developed by us [2,3] has been used for data analysis and separation of different stages' contributions: primary pion absorption on intra-nuclear clusters, pre-equilibrium processes (pick-up, knock-out, coalescence, scattering of primary particles) and evaporation. Contributions of these stages in the yields have been defined. It was shown that pre-equilibrium processes have a dominant contribution in the particle formation.

The analysis of the A-dependences of the yields allows to specify the main mechanisms of the formation of hydrogen isotopes during the pre-equilibrium stage. Assuming that for deuterons the main mechanism is pick-up by primary nucleon near the nucleus surface we manage to describe successfully the A-dependence of yields (with 10-15% error). It was shown that for tritons the deuteron pick-up by primary neutron near surface is dominant only for heavy nuclei while for light and medium nuclei other processes are need to take into account. Contributions of scattered primary tritons and knocked-out tritons are analyzed. The emperical dependence was proposed which allows to describe triton yields with 10-15% error.

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RECENT RESULTS ON $\pi^+\pi^-$ ELECTROPRODUCTION OFF PROTONS

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Measurements of $\pi^+\pi^-$ electroproduction cross sections represent an important part of the program to study the structure of nucleon resonances with CLAS Ref. [1]. This program extends the study of nucleon resonance transition amplitudes (electrocouplings) to masses up to 1.8 GeV and to photon virtualities (Q^2) up to 5.0 GeV^2. These data provide access to the active degrees of freedom in the N* structure at different distance scales, and allow the study of non-perturbative strong interaction mechanisms that are responsible for the formation of the ground and excited nucleon states Ref. [2].

In this talk, we will present cross section measurements of the process $ep\rightarrow ep\pi^+\pi^-$ that continue our previous studies of this exclusive channel using the CLAS detector Ref. [3, 4]. Our preliminary data provide complementary kinematical coverage of $1.4 < W < 1.8$ GeV and $0.4 < Q^2 < 1.1$ GeV^2, in comparison with previously available measurements, and enable much finer binning in Q^2. This kinematical region covers high lying nucleon resonances such as $S_{31}(1620)$, $S_{11}(1650)$, $D_{33}(1700)$, and $P_{13}(1720)$, whose hadronic decay widths into $\pi\Delta$ and ρp can be extracted from the same data set, as these resonances decay preferentially to $N\pi\pi$ final states. Furthermore, electrocouplings of the $S_{11}(1650)$ and $F_{15}(1685)$ resonances previously measured in $N\pi$ electroproduction will be obtained independently from the $N\pi\pi$ data.

The analysis of these data within the framework of the JLAB-MSU reaction model (JM) Ref. [5] will improve our knowledge of the Q^2 evolution of the $\gamma_v NN^*$ transition amplitudes considerably, in particular for resonances with masses above 1.6 GeV.

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ESTIMATES OF EXCLUSIVE CHANNEL CROSS-SECTIONS FROM THE CLAS MESON ELECTROPRODUCTION DATA

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The special approach has been developed for evaluation of π^+n, π^0p, ηp, $\pi^+\pi^-p$, $K^+\Lambda$, $K^+\Sigma^0$ exclusive channels contributions to inclusive F_1 and F_2 structure functions from the data collected with the CLAS detector at Jefferson Laboratory and stored in the CLAS Physics Database [1]. The contributions of all these exclusive channels to the inclusive structure functions F_1 and F_2 were obtained from the CLAS experimental data and interpolated over the kinematic region of the invariant masses of the final hadron systems (W) from the thresholds to 2 GeV and the photon virtualities from 0.2 to 5 GeV^2. Information on exclusive channel contributions allows us to compute fully integrated cross-sections of all aforementioned exclusive channels in the resonance excitation region and at photon virtualities which correspond to the transition from combined contribution of both meson-baryon and quark degrees of freedom to the resonance structure toward the dominance of quark degrees of freedom.

The results obtained are of particular interest for interpretation of experimental data on inclusive and semi-inclusive electroproduction in N^* excitation region. They are also important for preparation of the future experiments on the hadron structure studies with the CLAS12 detector after the completion of the 12 GeV Upgrade project at Jefferson Laboratory [2, 3].

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NEW RESULTS OF NUCLEON RESONANCES STUDIES IN PHOTO AND ELECTROPRODUCTION OF CHARGED PIONS IN CLAS

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A broad scientific program of exploration of nucleon exited states (N*) spectrum and structure is carried out in Jefferson Laboratory[1]. Detailed information of N* structure and spectrum gives access to fundamental mechanisms of strong interaction in the domain of large quark-gluon coupling constant. Unique combination of continuous electron beam and CLAS [2] detector made it possible for the first time to study photo and electroproduction of nucleon resonances in exclusive channels.

The reactions of single and double pion production give the most significant contribution to the total cross section of photo and electroproduction of pions. Double pion channel offers preference when studying high-lying resonances with masses larger than 1.6 GeV because these resonances decay mostly to two pions. Also, this channel is most preferable for searching the “missing” N* states.

The preliminary analysis of CLAS data on double pion photo and electroproduction was completed. In case of photoproduction due to large statistics it was possible to extract one and two-fold differential cross sections with the bin width of CM-energy – 25 MeV.

Both photo and electroproduction will be analyzed in the framework of the phenomenological model JM [3].

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$\pi^+\pi^-$p ELECTROPRODUCTION OFF THE BOUND PROTON IN RESONANCE REGION WITH CLAS

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Experimental data on nucleon excitations showed evidence for possible modifications of the ground and excited nucleon states inside the deuteron. One of them comes from the comparison of the inclusive structure functions F_2 off the proton and off the deuteron at different photon virtualities [1, 2]. The F_2 structure function off the deuteron inside resonant peaks is getting increasingly damped as the photon virtuality increases. Another indication of the same effect can be seen in W-dependence of total photoabsorption cross sections for the free proton and deuteron [3], where the structure of the second resonance region becomes less pronounced for deuteron. All these effects cannot be explained by Fermi-motion alone and are related to the influence of nuclear medium on the production mechanisms.

We are planning to extract from the CLAS data integrated and differential cross sections of the γ_v p(n) $\rightarrow$ p(n)$\pi^+\pi^-$ reaction at 1.3 GeV < W < 1.825 GeV, 0.4 GeV^2 < Q^2 < 1 GeV^2 and compare them with cross sections of the same process on the free proton [4]. The difference between these two sets of cross sections allows us to investigate the initial and final state interactions for this exclusive channel inside the deuteron target and for the first time to explore possible modification of N* electrocouplings inside the deuteron. Furthermore, the analysis of the γ_v p(n) $\rightarrow$ (n)$\pi^+\pi^-$ reaction allows us to make the first step towards an investigation of $\pi^+\pi^-$ n (p) electroproduction.

In this talk we are going to present details of data analysis and preliminary integrated and differential cross sections of the γ_v p(n) $\rightarrow$ p(n)$\pi^+\pi^-$ reaction. Physics analysis of these results will allow us to extend the phenomenological approach for the extraction of resonance parameters from $\pi^+\pi^-$p electroproduction data off free protons [5] to that off nucleons bound in deuterium target.

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CROSS SECTIONS OF THE REACTION $^{115}In(\gamma, \gamma')^{115m}In$ IN THE *E*1 GIANT RESONANCE REGION

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Isomeric metastable states of nuclei, having spins, which differ essentially from spins of ground states, and relatively high times of life $T_{1/2}$ may be populated in reactions of inelastic photon scattering off nuclei (reactions $(\gamma, \gamma')^m$). $(\gamma, \gamma')^m$-reactions were studied at photon energies E_γ in the region of the Electric Dipole Giant Resonance (*E*1GR) using registration of produced activities for a set of medium-heavy and heavy nuclei (see [1] and references therein). In each such a case a cross-section $\sigma(\gamma, \gamma')^m$ has a peak at E_γ near a threshold of (γ, n)-reaction, caused by increasing of a total absorption cross section σ_{total} and growing of probability to populate an isomeric state from one hand and steep growing of competition from the neutron channel of *E*1GR-decay with increasing of E_γ on the other hand.

But in some of these studies (especially for ^{115}In [2]), made at cyclic electron accelerators with internal radiators, it was also reported about the second peaks in $\sigma(\gamma, \gamma')^m\{E_\gamma\}$ at E_γ higher than for σ_{total}-maximum in the region of *E*1GR, what was considered [3] as a big surprise for physics of photonuclear reactions even in spite of some attempts for explanations [4].

In our measurements in the region of *E*1GR [1] it was shown for the case of ^{115}In that yield of $(\gamma, \gamma')^m$-reaction after its growth, connected with the first peak in $\sigma(\gamma, \gamma')^m\{E_\gamma\}$, is almost constant, and that the pointed out second peak in $\sigma(\gamma, \gamma')^m\{E_\gamma\}$ with integral value, comparable with that for the first peak, is not observed. Later there was reported in [5] about the similar results for the reaction $(\gamma, \gamma')^m$ as for ^{115}In as for ^{103}Rh. The results [1, 5] permit to suppose that this old disturbing question in physics of photonuclear reactions may be removed from the agenda. In any case it is a difficult task to find mistakes in experimental works made in other laboratories, but it seems to be a possible reason for these discrepancies troubles for cyclic electron accelerators with monitoring of electron and bremsstrahlung beams from internal radiators (see e.g. [6]). For external electron beams and radiator, which were used in [1, 5], monitoring of electron and photon beams seems to be much more trustworthy.

It is important to note that mentioned above yield features of $^{115}In(\gamma, \gamma')^{115m}In$ – reaction and value of $T_{1/2} \cong 4.486$ h for ^{115m}In permit to suggest using of In foils as monitor ones in activation studies of photonuclear reactions for many cases.

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MULTINUCLEON PHOTONUCLEAR REACTIONS ON ^{209}BI: EXPERIMENT AND EVALUATION

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Determination of the cross sections of photonuclear reactions with several nucleons in the final state poses a serious problem. A large part of experimental cross sections of reactions with 1–3 outgoing neutrons obtained with quasimonoenergetic annihilation photon sources using method of photoneutron multiplicity sorting [1] do not satisfy the objective criteria of reliability introduced in [2]. It was shown that the problem of separation of reaction channels with different neutron multiplicities can be overcome using a new experimentally–theoretical approach for evaluation of partial reaction cross sections.

Reliability of the channel separation can be verified experimentally using the photon activation technique which allows to identify individual partial reactions by the final nuclei they produce. In this work a bismuth target was irradiated with bremsstrahlung photons produced using the electron beam of the 55 MeV racetrack microtron RTM-55 [3]. Using a high-purity germanium detector, spectra of induced activity were measured and yields of photonuclear reactions up to (γ, 5n1p) and (γ, 6n) on the ^{209}Bi isotope were calculated.

Experimental yields of photoneutron reactions were compared to the results of a previous measurement [4] and to the predictions of evaluation [2, 5, 6]. Shortcomings of the photoneutron multiplicity sorting techniques, that were used to measure a large part of photoneutron reaction cross sections, are discussed.

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NEGATIVE CHARGED PION PRODUCTION ON A DEUTERON BY QUASI-REAL PHOTONS

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Experimental differential cross sections of photoproduction of negative pions on a deuteron have been obtained. A special feature of the experiment reported here is the detection of both proton in the final state of the reaction, and with large values of the momenta. The experiment was performed on an internal target of the VEPP-3 electron storage ring. In the approximation of zero scattering angles of the electrons, we investigate the reaction of production of π^- mesons by quasi-real photons. Coincidence detection of two protons with large momenta suppresses the mechanism of quasi-free photoproduction by increasing the relative contribution of more complex reaction mechanisms. The kinematics of pion photoproduction on a deuteron is fully reconstructed from the measured energies and proton emission angles. The calculated photon energies lie in the range 290 – 900 MeV. The theoretical model [1] lying at the basis of the generation of events takes into account the contribution of the diagrams of the impulse approximation and the diagram of pion-nucleon and nucleon-nucleon rescattering. The elementary amplitude of photoproduction of a pion on a nucleon in the model takes into account the Born contributions, the contributions of the six nucleon resonances, and the exchange contributions of the vector mesons ρ and ω. The agreement of the experimental data with the theoretical predictions arrived at within the traditional framework of the impulse approximation with πN and NN rescattering speaks of the fact that the contributions of all the most important resonances from second resonance region are taken into account in the elementary amplitude of pion photoproduction on a nucleon.

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MEASUREMENTS OF THE TENSOR ANALYZING POWER COMPONENT T_{20} OF COHERENT PHOTOPRODUCTION OF NEUTRAL PION ON TENSOR-POLARIZED DEUTERON AT THE VEPP-3 STORAGE RING

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The experiment on measurements of the tensor analyzing power T_{20} of coherent photoproduction of neutral pion on a tensor polarized deuterium target ($\gamma \rightarrow d'\pi^0$) is described. Measurements covered two kinematic ranges: the photon energy range E_γ = 200 – 500 MeV and neutral pions emission angle in range = 100° – 140°, E_γ = 200 – 500 MeV and = 60° – 65°.

In the experiment we use cryogenic deuterium polarized atomic beam source, manufactured in BINP, which allows to get the thickness of the polarized target $5*10^{13}$ at/cm^2.

The detectors register deuterons and 1 or 2 photons from π^0 decay in coincidence. Neutral pion detector arm consists of electromagnetic NaI/CsI calorimeter, covering Θ = 50° – 150° and detect 1 or 2 photons from π^0 decay. Two deuteron detector arms consists of the wire chamber and plastic scintillators, covering Θ = 20° – 30° and Θ = 60° – 70°.

The measurements of the degree of target polarization and of the experiment luminosity were done by detecting the elastic electron-deuteron scattering at low momentum transfer.

Preliminary results on the measurements of the tensor analyzing power component are presented and are compared with several theoretical predictions.

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INDEPENDENT FISSION YIELD MEASUREMENTS WITH JYFLTRAP

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A novel technique has been developed at the Accelerator Laboratory of the University of Jyväskylä to determine the independent isotopic fission product yields [1]. It combines the chemical universality of the ion guide method with the unique properties of a Penning trap. The former allows producing ions from the isotopes of all elements. The latter provides unambiguous identification of the isotopes. The mass resolving power in this experiment was about 10^5 with the excitation time 400 ms. Such a high mass resolving power was sufficient to distinguish individual nuclides. In some cases it was even possible to separate isomeric and ground states. The yields are based on the ion counting rates after the mass separation.

In the report a brief description of the experimental method will be given. Experimental data on proton-induced fission of ^{232}Th at 25 MeV primary beam energy will be presented in comparison with theoretical calculations [2].

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THE NEUTRON MULTIPLICITY STUDY AT SPONTANEOUS FISSION OF SHORT-LIVED ISOTOPES ($Z > 100$) USING VASSILISSA RECOIL SEPARATOR

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Recoil in – flight separator VASSILISSA [1] is widely used for the synthesis and study of decay properties of heavy and superheavy nuclei. For the registration of heavy ER in the focal plane of the separator, a new system with a 16-strip detector assembly, 60x60 mm^2 in size, and surrounded by backward detectors was developed. For the purpose of the study of spontaneous fission of short-lived SF isotopes in more detail a neutron detector consisting of 54 ^{3}He filled counters was mounted around the focal plane detector chamber of VASSILISSA separator. Neutron detectors with ^{3}He filled counters placed in a moderator are typically used for experimental studies of prompt spontaneous fission neutrons because of their constant high efficiency in a broad range of neutron energy (in thick detectors).

In the last ten years we carried out several experiments aimed to investigate properties of short-lived SF isotopes. The neutron-deficient isotope ^{246}Fm, produced in the complete fusion reaction ^{40}Ar + ^{208}Pb, was investigated in the year 2008 [2]. In the year 2010 we carried out an experiment aimed at investigating the properties of spontaneous fission of neutron deficient isotopes of ^{252}No and ^{244}Fm produced in the reaction with ^{48}Ca, ^{40}Ar-beam and ^{206}Pb-target. The main goal of the experiment was to determine the neutron multiplicity at spontaneous fission of these isotopes. From the experimental data for the first time the average number of neutrons per spontaneous fission of ^{244,246}Fm, formed in reactions ^{40}Ar(^{206,208}Pb, 2n), was determined (= 3.3 ± 0.3 and = 3.6 ± 0.5 respectively). The average number of neutrons from spontaneous fission of ^{252}No, formed in the reaction ^{48}Ca(^{206}Pb,2n) was equal to 4.06± 0.09. This value is in good agreement with that from literature (4.15± 0.30).

The new focal plane detector based on double-sided multistrip (48 x 48 strips) Si plate (DSSD) is described and future experiments are discussed.

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PRODUCTION OF CUMULATIVE PROTONS IN HADRON AND NUCLEUS-NUCLEUS COLLISIONS AT HIGH ENERGIES

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The processes of production cumulative protons in ^{16}O p-collisions at 3.25 GeV/c in π^{-}C collisions at 40 GeV/c, pC interactions at 4.2 and 9.9 GeV/c, ^{4}HeC and CC collisions 4.2 *A* GeV/c and in pNe interactions at 300 GeV/c.

Inclusive cross sections of cumulative protons and their invariant structure functions on the cumulative number ($\beta = (E\text{-}P\cos\theta)/m_N$, where *E*, *F* and θ – are the energy, momentum and angle of proton emission, m_N – nucleon mass) in the $\beta > 1.2$ satisfactorily described by an exponential function of β. The values of the slope parameter for all of the events are on average 8.1 ± 0.1. They were independent of the type of projectile, target nucleus and primary energy.

The fraction of events with the formation of cumulative protons for the same target nucleus was found to depend on the type of incident particle (pion or proton), but independent of the baryon mass of the projectile (^{4}He or C).

The average multiplicity of cumulative protons for the same target nucleus was independent of the type of incident particles (pions, protons, ^{4}He or C). Dependence of the average multiplicity of cumulative protons from the mass number of the target nucleus A satisfactorily described by a power function $<n_{\text{cum}}> = b\, A^{\alpha}$ with parameter values $b = 0.724 \pm 0.035$ and $\alpha = 0.154 \pm 0.015$. The exponent is close to the value of $\alpha = 1/6$. Hence, setting the average number of intranuclear rescattering $<\upsilon> \sim A^{1/3}$, we obtain the dispersion $D\,(\upsilon) \sim A^{1/6}$, i.e. equal to the number fluctuations of the nuclear density.

Thus, the formation of cumulative protons occurs on the script of "cold" model, characterized by fluctuations in the density of nucleons in the nucleus in its ground state, and the interaction of the incident hadron with this dense cluster (fluctuons). An additional argument in favor of the production of cumulative protons occurs at the above scenario, is the independence of the share of cumulative events for the target of the carbon nucleus of the mass number of the primary nucleus. This result is proof that it is carried out "cold" scenario of cumulative protons.

ISOMER RATIOS FOR PRODUCTS OF PHOTONUCLEAR REACTIONS ON ^{121}Sb

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Using of high energy gamma-quanta as projectiles in nuclear reactions has some essential advantages for study of nuclear structure and nuclear reaction mechanisms. Indeed, gamma-quanta do not introduce large angular momentum and do not cause an additional contribution to excitation energy of compound nucleus due to absence of projectile's binding energy. In addition, the precise non-discrete control of the incident gamma-quanta energy is possible. Very limited experimental data for photonuclear reactions in the energy range 30-100 MeV for testing newly developed and available theoretical models was the the major motivation for the present work.

Experimental measurements and deriving isomer ratios for products of photonuclear reactions with multiple particle escape on antimony have been performed using bremsstrahlung with end point energies 38, 43 and 53 MeV. We used metallic antimony targets of natural isotopic abundance to study reactions ^{121}Sb(γ,3n)^{118m,g}Sb and ^{121}Sb(γ,5n)^{116m,g}Sb. For the products of (γ,5n) reaction one had to take into account an interfering contribution of ^{116m,g}In nucleus from ^{121}Sb(γ,nα)^{116m,g}In reaction. Method of induced activity measurement was utilized and for acquisition of instrumental gamma spectra we used HPGe spectrometer with 20% relative efficiency and energy resolution 1.9 keV for 1332 keV gamma line of ^{60}Co. Linear accelerator of electrons LU-40 was a source of bremsstrahlung. Energy resolution of electron beam was about 1% and mean current was within (3.8 – 5.3) μA. The reactions used (first column), isomer ratios (second column) and the endpoint energy of bremsstrahlung spectrum (last column) are given in the table below.

Reaction	$Y_h(E_\gamma)/Y_l(E_\gamma)$	$E_{\gamma max}$, MeV
^{121}Sb(γ,3n)^{118m,g}Sb	0.14 ± 0.04	38
	0.15± 0.01	43
^{121}Sb(γ,5n)^{116m,g}Sb	0.25 ± 0.03	53

These new isomer ratio results obtained are compared with theoretical predictions and discussed in the frame of mechanisms of nuclear reactions.

NEW EXPERIMENTAL DATA OF $^{54}Fe(n, \alpha)^{51}Cr$ REACTION CROSS-SECTION IN 4.5–7 MeV NEUTRON ENERGY REGION

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New experimental data of helium production reaction cross-section on nuclei of constructional materials is of importance for strength calculations for alloys with these materials. Iron is a part of almost all alloys in reactor construction. The ^{54}Fe isotope is the second in natural composition – 5.81% after ^{56}Fe isotope which is 91.75%. New experimental data of $^{54}Fe(n, \alpha)^{51}Cr$ reaction cross-section in neutron energy region from 4.5 to 7 MeV are represented in this work.

A STUDY OF ISOMERIC YIELD RATIOS IN THE $^{124}Te(\gamma,n)^{123m}Te$ REACTION IN THE GIANT *E*1-RESONANCE REGION

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The difficulty of measuring the isomeric yield ratios $d=Y_m/Y_g$ in the $^{124}Te(\gamma,n)^{123m}Te$ reaction stems from the stability of the ground state of the ^{123}Te nucleus, which disallows the simultaneous measurement of the isomeric Y_m and ground Y_g states excitation. To estimate the isomeric ratio we used the yield of the (γ,n) reaction, Y_n of the neighbouring nucleus ^{122}Te measured at the same time as the yield Y_m of the ^{123m}Te isotope. Since the characteristics of the giant dipole resonance in the tellurium isotopes changes slowly from nucleus to nucleus, such a procedure leads to the errors not worse than 2–3%. During measurements the activation technique was applied. To identify the decay of the isomeric state with $J^{\pi}=11/2^{-}$ of the nucleus ^{123m}Te ($T_{1/2}$=119.2 days) the E=247 keV gamma-line was used. The research was conducted on the bremsstrahlung gamma-beam of the microtron M-30 of IEP, NAS of Ukraine, in the region of 10–18 MeV.

The natural mixture of the tellurium isotopes comprises 0.8% of the stable ^{123}Te isotope. Therefore, though, in general, the $(\gamma,\gamma')^m$ reaction cross section is two orders of magnitude smaller than that of the (γ,n) reaction, we have made in the threshold region of the $^{124}Te(\gamma,n)^{123m}Te$ reaction a correction for the contribution of the $^{123}Te(\gamma,\gamma')^{123m}Te$ reaction, the yield of which was estimated separately.

As a result of measurements at the energies $E_{\gamma max}$=11.5 MeV, 12.5 MeV, 13.5 MeV, 14.5 MeV, 15.5 MeV, 16.5 MeV, 17.5 MeV, we have obtained the following values of the isomeric yield ratios $\eta=Y_m/(Y_m+Y_g)$, respectively: 0.040±0.004, 0.087±0.004, 0.105±0.006, 0.142±0.005, 0.156±0.005 and 0.179±0.007.

Theoretical calculations of the isomeric yield ratios of the $^{124}Te(\gamma,n)^{123m}Te$ reaction were carried out. Computations were performed using the TALYS-1.4 code. Comparison of calculated and experimental data indicates a satisfactory agreement.

STUDIES OF DEPENDENCE OF ISOMERIC YIELD RATIOS ON THE GAMMA QUANTA ENERGY IN THE $^{140}Ce(\gamma,n)^{139m,g}Ce$ REACTION

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The ^{140}Ce nucleus under consideration is a magical one having a neutron number N=82 and a completely filled $1h_{11/2}$ shell. Here we present the experimental results of studying the isomeric yield ratios $d=Y_m/Y_g$ in the $^{140}Ce(\gamma,n)^{139m,g}Ce$ reaction in the giant dipole resonance region. The experiments were carried out with the bremsstrahlung gamma-beam of the microtron M-30 of IEP, NAS of Ukraine, in the region of 10–18 MeV with a step of ΔE=0.5 MeV. The energy spread of the accelerated electron beam was not worse than 40 keV at the average 5μA current. In the experiments, the activation technique was applied. To study the decay of the isomeric ^{139m}Ce state ($T_{1/2}$=54.8 s) the E=754 keV gamma-line was used, while for the ground ^{139g}Ce state ($T_{1/2}$=137.6 days) – the 165.8 keV line. The measurements were carried out with a gamma-spectrometer on the basis of a semiconductor HPGe-detector with the 175 cm^3 volume.

The resulting experimental curve of the dependence of the isomeric ratios $d=f(E_{\gamma max})$ on the maximum energy of the bremsstrahlung spectra starting from the threshold has a growing trend and in the region of 18.0 MeV it reaches the value d=0.103(5). Experimentally the dependence of the isomeric ratios $d=f(E_{\gamma max})$ was approximated by a Boltzmann curve using the least-square method:

$$d=A+(B—A)/[1+\exp((E-E_0)/\Delta E_1),$$

here A, B, E_0, ΔE_1 being parameters. As a result of approximation the following values were obtained for the parameters: A=—0.0253±0.010, B=0.1123±0.0087, E_0=13.67±0.32 and ΔE_1=1.66±0.33.

The experimental isomeric ratios of the $^{140}Ce(\gamma,n)^{139m,g}Ce$ reaction were compared with the those measured earlier for the $^{138}Ce(\gamma,n)^{137m,g}Ce$ reaction [1]. The results obtained will be discussed at the Conference.

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YIELDS AND CROSS-SECTIONS OF THE (γ, n) AND (γ, p) REACTIONS ON THE Ti ISOTOPES IN THE GDR REGION

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Yields of the (γ, n) and (γ, p) reactions were measured on the stable Ti isotopes at the 55 MeV race-track microtron using registration of produced activities with a high-purity Ge γ-spectrometer (methodical details are similar to those in [1]). Results were analyzed together with available experimental data about yields and cross-sections for these reactions in the Giant Dipole Resonance (GDR) region from [2], taking into account gross-structure of the GDR, caused by nuclear deformation, isospin and cofigurational splitting [3].

For analysis of data there were also made calculations of cross sections for photonuclear reactions on the Ti isotopes using the nuclear reaction model [4].

Some results of data analysis for the integrated cross-sections of (γ, n) and (γ, p) reactions on even-even Ti isotopes are presented in the table. These results were obtained from experiments and model calculations and are presented in comparison with predictions of the dipole sum rule [5]. Incomplete exhaustion of the dipole sum rule is caused by the fact that the integrated cross sections from experiments and model calculations are for energies <~30 MeV. The fulfilled analysis shows that results of the present work permit to improve consistency of obtained earlier data.

Table. The model [4] and experimental integral (γ, n) and (γ, p) cross-sections on $^{46, 48, 50}$Ti and the percents of the dipole sum rule for them. The upper indexes "*" are used for the model and experimental results obtained in this work

Ti isotopes	Experiments			Model calculations		
	σ_{int}(γ,n), MeV·mb	σ_{int}(γ,p) MeV·mb	[σ_{int}(γ,n)+ σ_{int}(γ,p)], MeV·mb	σ_{int}(γ,n), MeV·mb	σ_{int}(γ,p), MeV·mb	[σ_{int}(γ,n)+ σ_{int}(γ,p)], MeV·mb
^{46}Ti	194	333	527 (76%)	250*	270*	520 (75%)
^{48}Ti	398	127*	525 (73%)	460*	100*	560 (78%)
^{50}Ti	473	96	569 (77%)	480*	20*	500 (68%)

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ELASTIC SCATTERING CROSS SECTION MEASUREMENT OF ^{13}C NUCLEI ON ^{12}C AT ENERGY 22.75 MeV

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Elastic scattering cross section of the ^{13}C at nuclei ^{12}C have been measured (heavy ion accelerator DC-60, Astana, Kazakhstan) at 22.75 MeV energies, in the laboratory system.

Experimental data shows that for the ^{13}C+^{12}C reaction is observed the rise of elastic differential cross sections at large angles. Previously anomalous scattering of the system ^{12}C + ^{16}O at energies near the Coulomb barrier has been systematically investigated [1]. A significant rise of the elastic scattering cross sections for backward angles was shown. It is completely determined by the alpha cluster transfer mechanism between the interacting nuclei. The experimental data in the framework of the phenomenological and semi-microscopic (potential convolution) optical model were analyzed. Optimal parameters of the interaction potential for the system ^{12}C +^{13}C were found. Experimental data reproduce by the parameters for the forward hemisphere. Anomalous behavior of ion scattering of ^{13}C on ^{12}C can be described by nucleon exchange mechanism [2] between the interacting nuclei calculated by DWBA. Figure 1 shows the experimental data of the elastic scattering cross section of the accelerated ions ^{13}C to ^{12}C at 22.75 MeV and result of the analysis. Differential cross sections can be describes by Rutherford scattering only for the front angles.

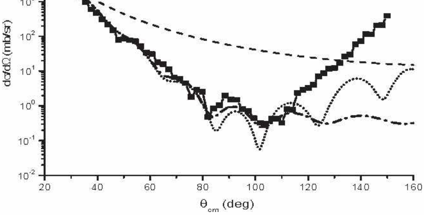

Fig. 1. The differential cross section of elastic scattering ^{13}C to ^{12}C nuclei at energy of 22.75 MeV.

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EXPOSURE OF NUCLEAR TRACK EMULSION TO ULTRARELATIVISTIC μ-MESONS

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Search for effects that are critical for the interpretation of the phenomenon of multiple fragmentation of nuclei can be complemented by exposure of nuclear track emulsion (NTE) to ultrarelativistic μ-mesons. Despite the widespread use of NTE, such an exposure appeared to be missed. In 2012 NTE was exposed at CERN to halo of a beam of μ-mesons with an energy of 160 GeV. When viewing about 300 stars produced in NTE were found with the number of target fragments of at least three (example in Fig. 1). Topology of stars is determined by the number strongly ionizing *b*-and *g*-particles (N_b and N_g). In 23 events the total number of tracks N_b and N_g (N_h) was not less than 12. Despite the limitations of solid angle in which tracks can be observed, one can conclude about facts of the formation of stars with high multiplicity, up to about half of the charge of heavy nuclei from the NTE. These preliminary observations suggest to be promising a full investigation of complete destruction of nuclei by м-mesons based on multilayer assemblies of thick layers of NTE. Among the stars significant contribution of events found that could be associated with the break-up $^{12}C \rightarrow 3\alpha$ ($N_b = 3$, $N_g = 0$) having the lowest threshold. Certainty in their interpretation on the basis of ranges of α-particles and their spatial angles of formation allows one to evaluate the nature of interaction.

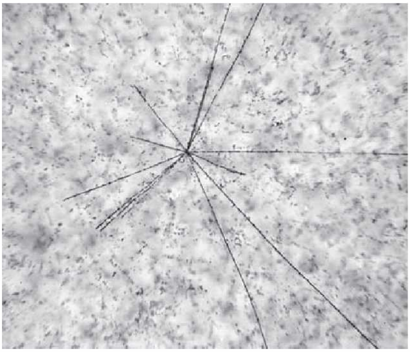

Fig. 1. Macrophotography of a star induced by a м-meson in it transversely exposed NTE.

NEW EXPERIMENTAL DATA FOR $^{53}Cr(n, \alpha)^{50}Ti$ REACTION

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(n,α) Reaction cross section data for chromium isotopes (^{50}Cr, ^{52}Cr, ^{53}Cr) are presented in this work

Measurements were carried out at the accelerator EG-1 IPPE. Ionization chamber with Frisch grid was used as a spectrometer. Created in IPPE digital signal processing method significantly reduced background from parasitic reactions and selected useful events

Measurements were made from 4.5 MeV to 7.15 MeV neutron energy region.

EXPERIMENTAL STUDY OF THE FRAGMENTATION OF RELATIVISTIC NUCLEI

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The results of the study of fragmentation of relativistic nuclei ^{6}Li [1], S [2], Pb [3], ^{10}B [4], ^{11}B [5], ^{14}N [6], ^{22}Ne [7], ^{16}O [8], with impulses from 2 up to 200 Gev/c per nucleon from nuclei in an emulsion. Experimental material consists in the measurement of angles in the plane of the emulsion. This angle is uniquely associated with the transverse momentum of fragments. The work shows that the process of fragmentation of the relativistic nuclei occurs rapidly, and the nucleus is still cool [9, 10]. The distribution of transverse momenta fragments is consistent, almost in all cases with the predictions of the model [11]. When fragmentation $^{16}O \rightarrow 4\alpha$ discovered that the proportion of events equal 5.4 10^{-3} of all observable events, goes through the channel $^{16}O \rightarrow 2\,^{8}Be \rightarrow 4\alpha$. This was the first time us channel. These can be events of coherent electromagnetic interaction of nuclei ^{16}O with the photo emulsion [12].

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EXCITATION OF ISOMERIC STATES IN REACTIONS (γ,n) AND (n,2n) ON ^{76}Ge, ^{82}Se AND ^{81}Br

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In the present work results of investigation of the isomeric yield ratios Y_m/Y_g and cross-section ratios σ_m/σ_g of the ^{76}Ge(γ,n)^{75m,g}Ge, ^{76}Ge(n,2n)^{75m,g}Ge, ^{82}Se(γ,n)^{81m,g}Se, ^{82}Se(n,2n)^{81m,g}Se ^{81}Br(γ,n)^{80m,g}Br and ^{81}Br(n,2n)^{80m,g}Br are presented. The isomeric yield ratios were measured by the induced radioactivity method.

Samples of natural Se have been irradiated in the bremsstrahlung beam of the betatron SB-50 of Institute of Applied Physics of National University of Uzbekistan in the energy range of 10÷35 MeV with energy step of 1 MeV. For 14 MeV neutron irradiation we used the NG-150 neutron generator of Institute of Nuclear Physics.

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 yields of the metastable state decays were evaluated by using the 254 keV (^{73m}Se, J^{π}=1/2^{-}, $T_{1/2}$=38.9 m) and 103 keV (^{81m}Se, J^{π}=7/2^{+}, $T_{1/2}$=57.3 m) γ-rays. The yields of the ground state decays were evaluated by using the 361 keV (^{73g}Se, J^{π}=7/2^{+}, $T_{1/2}$=7.1 h) and 275 keV (^{81g}Se, J^{π}=1/2^{-}, $T_{1/2}$=18.5 m) γ-rays.

FORWARD-ANGLE VALUES OF POLARIZATION-TRANSFER (PT) COEFFICIENTS FOR THE $^{16}O\ (\vec{p},\vec{p}\,')^{16}O\ (4^-, T = 1)$ AND $^{28}Si\ (\vec{p},\vec{p}\,')^{28}Si\ (6^-, T = 1)$ REACTIONS

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Unnatural-parity transitions at extremely forward angles (at and near zero degrees) are characterized by the fact that the D_{NN} value should be practically equal to the D_{SS} value. This may be due to the circumstance that in this case the $\hat{N}$ direction is basically identical to the $\hat{S}$ direction [1] (owing to the symmetry around the scattering axis). Our calculations (Fig.) at $\theta_{c.m.} = 1^\circ$ with the program DWBA 91 from Raynal and with the Geramb *DD* forces (PH, solid curves) and the Nakayama–Love no*DD* interaction (NL, dashed curves) confirm this for the stretched isovector 4^-, $T = 1$ (18.98 MeV) transition in ^{16}O.

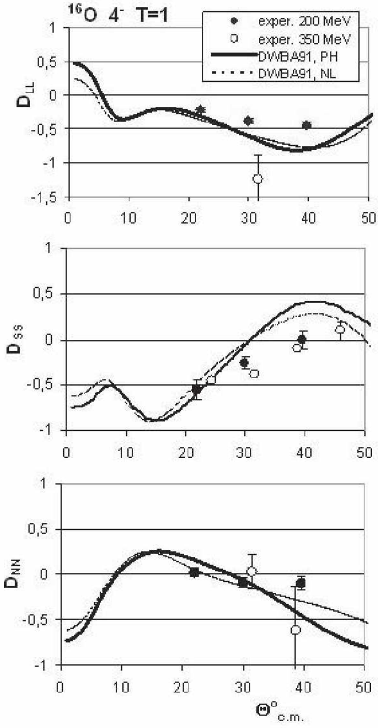

Fig. *The calculations (curves) and experimental data (dots) are shown. The measurements at E_p = 200 MeV (dark dots) are taken from [2] – D_{ll}, D_{SS}, and from [3] - D_{NN}. The measurements at 350 MeV (open dots) are from [4]. The angles for 350 MeV have been multiplied by the coefficient $\kappa = (350 / 200)^{1/2} = 1.32$. All the calculations have been made at E_p = 200 MeV.*

In the case of the PH force, $D_{NN} = -0.73$, and $D_{SS} = -0.74$. The quantity Σ, as a linear combination of the PT coefficient D_{ii} (called total spin transfer [1]), i.e. $\Sigma = [3 - (D_{NN} + D_{SS} + D_{LL})] / 4$, is equal to 1 for spin-flip ($\Delta S = 1$) transitions and 0 for non-spin-flip ($\Delta S = 0$) transitions, if the spin-orbit interaction is negligible. This may occur in the $(\vec{p}, \vec{p}')$ process at $\theta \approx 0^\circ$. In our calculations at $\theta = 1^\circ$, Σ was equal to 1.00 for both PH and NL forces. The relation

$$D_{NN}(0^\circ) = \pm [1 + D_{LL}(0^\circ)] / 2 \quad (1)$$

is also well-known [1]. The plus sign in it refers to natural-parity, and the minus sign refers to unnatural-parity transitions. In our calculations at $\theta = 1^\circ$, this relation in a digital representation was as follows: – 0.730 ≈ – 0.734 for PH force, and – 0.614 ≈ – 0.618 for NL interaction.

Therefore, all the calculated combinations of the PT coefficients D_{ii} at and near zero degrees are in a good agreement with the corresponding theoretical relations [1]. Moreover, the calculations using DWBA 91 provide a satisfactory description of the experimental measurements D_{ii} (Fig.), obtained in the region of maximal differential cross sections.

We have also performed a similar study of the $T = 1$ stretched 6^- state at 14.35 MeV in ^{28}Si, using PT coefficients from $(\vec{p}, \vec{p}')$ measurements at 200 MeV [3] and 500 MeV [5]. Our analysis, using the program DWBA 91 and PH forces, has revealed that $D_{NN}(0^\circ) = D_{SS}(0^\circ) = -0.52$. The quantity Σ appears to be practically equal to 1 (0.98), and equation (1) in a digital representation gives the following: – 0.521 = – 0.521.

The main qualitative features of the measured and calculated PT coefficients for the 6^-, $T = 1$ excitation (not shown) and these of the corresponding data for the 4^-, $T = 1$ excitation (Fig.) in the region of maximal differential cross sections are principally of a similar character. This is also an important guide.

Therefore, we have confirmed the suggestion [5, 6] that D_{SS}, D_{LL} and D_{NN} should resemble each other for all isovector stretched states, since the characteristics of D_{ii} depend primarily on the isovector stretched-state assumption and the sampled properties of the force. Thus, for pure stretched states of high spin, the qualitative shapes of D_{ii} should be approximately independent of the nucleus and are similar over a wide range of energies. Lastly, we would like to emphasize that, as D_{SS}, D_{LL} and D_{NN} are very insensitive to the type of distortion used [6] all these common characteristics should become most apparent for scattering at and near $\theta_{c.m.} = 0^\circ$ in the excitation of all the $T = 1$ stretched states.

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CADMIUM ISOTOPE PHOTODESINTIGRATION

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Yields of different multiplicity photonuclear reactions on were measured by method of induced activity for three different cadmium targets - cadmium natural isotopic mixture, ^{116}Cd and ^{112}Cd isotopes. As a source of high energy *X*-rays we used bremsstrahlung radiation with end point energy 55 MeV.

Experiment was conducted on race-track microtron RM-55 accelerator [1]. The yields of photonuclear reactions for several channels of excited states of cadmium isotopes in the energy range up to 55 MeV were measured for the first time.

First time obtained decay channels ^{112}Cd(γ,n)^{111m}Cd, ^{112}Cd(γ,p)^{111}Ag, ^{112}Cd(γ,pn)^{110m}Ag.

Comparison of experimental data and theoretical calculations by combined model of photonuclear reactions [1] and TALYS program [2] demonstrates rather good description of experimental results for photoneutron reactions for heavy cadmium isotopes. For channels with proton emission only model [1] is in according with experimental data. Model [2] doesn't take in account specific features of $T_>$ isospin component decay of Giant Dipole Resonance, and underestimate proton emission channel.

For light isotope ^{106}Cd theoretical calculations are in contradiction with experimental data. Probably this can be explained by specific features of shell structure of ^{106}Cd, which is situated near the β-stability boundary.

For isotopes ^{115}Cd and ^{104}Ag isomeric ratios were calculated. Theoretical calculations [2] are in reasonably good agreement with experimental data.

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SEARCHING FOR NEW LONG LIVED ISOMERS IN THERMAL FISSION OF ^{235}U

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Shape isomers in the fissioning nuclei (fissioning isomers) are known to be due to the metastable energy states in the second minimum of the fission barrier of some heavy nuclei. Shape isomeric states of the different nature namely nuclear quasi-molecular states forming at the descent from the barrier and leading to the ternary fission were predicted in [1]. The life time of such states depend from the constituents involved and can exceed some msec. We are searching for the isomeric states predicted in the experiment at the IBR-2 impulse reactor. The preliminary results obtained will be reported.

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FORMATION MECHANISMS OF INCLUSIVE CROSS-SECTIONS OF (p,xp) AND (p,$x\alpha$) REACTIONS ON Cu NUCLEUS

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The development of the new generation of nuclear energy systems with a high level of safety (Accelerator Driven System (ADS)), consisting of a proton accelerator, the neutron production target and sub critical reactor are deployed in many countries. At creation of such devices for correct modeling of the neutron flux the data on the spectral composition and angular distributions of secondary protons and light charged particles produced by primary proton beam are required. Copper was selected as one of the widely used constructional materials in various nuclear facilities.

Inclusive spectra of protons and α-particles emitted from proton induced reactions on Cu nucleus at E_p=30 MeV in angular range 15÷135° with the step 15° was received on isochronous cyclotron U-150M of Institute of Nuclear Physics. The thicknesses of two silicon detectors were equal to 30 micron and 2000 micron for reaction Cu(p,$x\alpha$). In case of reaction Cu(p,xp) thin silicon detector of 100 micron and CsI(Tl) detector of full absorption (2.5 cm) were used. The solid angles subtended by a telescope of detectors were equal to $\Omega=5.34\cdot10^{-5}$ sr and $\Omega=4.62\cdot10^{-5}$ sr respectively. The self-supporting foil of Cu with thickness of 2.7 mg/cm^2 was used in these experiments.

The energy calibration of a spectrometer was carried out on kinematics of levels of residual nuclei in the reaction ^{12}C (p,xp) and protons of recoil. The total system energy resolution, equal to 400 keV, mainly has been determined by the beam energy resolution. The energy dispersion of beam was equal to 0.4 %. The whole systematic error was less than 10 %. The statistical uncertainties were less than 10 % for protons and less than 20 % for α-particles.

The analysis of the experimental results has been conducted in the Griffin exciton model [1] of the preequilibrium decay of nuclei. The code PRECO-2006 [2], which describes the emission of particles with mass numbers from 1 to 4, has been used in our theoretical calculations. A satisfactory agreement between experimental and calculated values in the energy region corresponded to the pre-equilibrium mechanism has been achieved.

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INVESTIGATION OF REACTIONS ON ^{112}Sn NUCLEUS INITIATED BY ^{3}He IONS OF 50 MeV WITH EMISSION OF DEUTERONS, TRITONS AND α-PARTICLES

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Investigation of the mechanisms forming the inclusive cross sections of nuclear reactions induced by charged particles of low and medium energy remains an urgent task of experimental nuclear physics. In addition to its importance for fundamental research, information on the inclusive reaction cross sections has been widely applied use, such as designing of hybrid nuclear power plants.

The purpose of this work has been the experimental investigation of inclusive spectra of deuterons, tritons and α-particles emitted from ^{3}He induced reactions on ^{112}Sn nucleus at E_{3He}=50 MeV in angular range 15÷150° with the step 15° on isochronous cyclotron U-150M of Institute of Nuclear Physics. The standard two-detector telescope has used for registration and identification of product of nuclear reactions. The self-supporting foil of ^{112}Sn with thickness of 1.88 mg/cm^2 has used in these experiments.

The analysis of experimental cross-sections of reactions is carried out in accordance with exciton model for pre-equilibrium nuclear reactions that describes the emission of particles from an equilibrating composite nucleus. Additional components are calculated semi-empirically to account for direct nucleon transfer reactions and direct knockout processes involving cluster degrees of freedom. A satisfactory agreement between experimental and calculated values has been achieved.

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THEORY OF ATOMIC NUCLEUS AND FUNDAMENTAL INTERACTIONS

COORDINATE ASYMPTOTICS OF WAVE FUNCTIONS OF THE THREE AND FOUR PARTICLE SYSTEMS WITH SHORT-RANGE INTERACTIONS

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The coordinate asymptotics of the wave functions of the three and four particle systems is studied with the help of Faddeev and Faddeev-Yakubovsky equations. The most complicated case of states with all particles in the continuum is considered. Among different asymptotic configuration the two specific ones are considered in details, i.e. the sector where the distances between all the particles are large and the sector where the two of particles are close whereas the others are at large separations. Besides the standard terms describing the incident and scattered fluxes, the asymptotic behavior of the wave functions contains the number of terms which decrease at large separations of particles slower than respective spherical waves. These terms correspond to processes of single, double and triple rescattering of particles.

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NUCLEAR VERTEX CONSTANTS AND ASYMPTOTIC NORMALIZATION COEFFICIENTS OF ^{16}O BOUND AND RESONANT α +^{12}C STATES FROM EFFECTIVE-RANGE AND PADÉ APPROXIMATIONS

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The radiative capture reaction ^{12}C(α,γ)^{16}O is a key nuclear process for the creation of oxygen in stellar nucleosynthesis. This defines the abundance ratio ^{12}C/^{16}O for helium burning in stars. To calculate the cross-section of this reaction one needs to know the asymptotic normalization coefficient (ANC) of the radial wave function for the ground ^{16}O state.

We calculate the renormalized Coulomb-nuclear constants for the vertex ^{16}O$\leftrightarrow\alpha$+^{12}C and the ANC for the wave functions of the ground state ^{16}O (J^{π}=0^{+}) and for the two subthreshold bound states with a total angular momentum of J^{π}= 1^{-}, 2^{+}. We use the analytical continuation method developed in [1]. We also apply this method to the resonances. In the states J^{π}= 0^{+}, 1^{-} we use the effective-range function $K_L(E)$ (L is the orbital momentum, E is the α-particle energy) expanded up to E^2, and in the state J^{π}=2^{+} we use the Padé-approximant for $K_2(E)$. In the energy region considered, the latter has two poles whose positions we find from the results of paper [2]. We expand the numerator $N(E)$ of $K_2(E)$ up to E^4.

To fit the parameters of $K_L(E)$, we include in the input data not only the Coulomb-nuclear phase shifts, but also the ^{16}O binding energies for the ground and excited states, and the energy and width of the resonances. We borrow the results of the phase shifts calculation from the R-matrix approach [2], which agree well with the experimental data [3]. The nucleus ^{16}O has quite a rich spectrum. The one channel approximation in our approach means that the poles considered have to be reproduced just for the channel α+^{12}C and must not contradict the α^{12}C scattering phase shifts energy behavior for a concrete state. So we ignore the α particle structure, which is reasonable for a low-energy region. The fitted sets of the $K_L(E)$ parameters well describe the phase shift results of the paper [2]. Every J^{π} state is treated separately. The energy dependence of the functions $K_L(E)$ with the orbital momenta L =0 and 1 are nearly linear, whereas the function $K_2(E)$ is much more complex. The preliminary results for the bound ground ^{16}O state and resonant states with L =0 and 2 are presented in [4].

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FEATURES OF THE PROTON SINGLE-PARTICLE SPECTRA OF Ni, Zn, AND Ge ISOTOPES NEAR THE PROTON DRIP-LINE

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The proton single-particle energies of Ni, Zn, and Ge isotopic chains were calculated from the stable isotopes to the near proton drip-line isotopes ^{50,52}Ni, ^{56,56}Zn, and ^{60,62}Ge experiencing delayed proton decay. Calculations were carried out using dispersive optical model [1] with the parameters physically reasonably extrapolated by the method [2, 3] from ones obtained from the analysis of the experimental data for stable isotopes.

In the proton single-particle spectra of Ni isotopes, there are evidences of the Z=28 and N=28 shell closures in $^{56}_{28}\mathrm{Ni}_{28}$. Spectrum of $^{58}_{30}\mathrm{Zn}_{28}$ isotope with N=28 demonstrates features characteristic for the near magic nucleus. The results of calculations predicts the proximity to closure of $2p_{3/2}$ subshell in $^{64}_{32}\mathrm{Ge}_{32}$ isotope with N=Z=32 indicating probable submagic properties of this nuclide. It was obtained, that closeness of the Fermi energy to half the sum of the last mostly occupied proton subshell and the first mostly unoccupied proton subshell is a common feature of $^{56}_{28}\mathrm{Ni}_{28}$, $^{58}_{30}\mathrm{Zn}_{28}$, and $^{64}_{32}\mathrm{Ge}_{32}$ nuclei (see Fig.1).

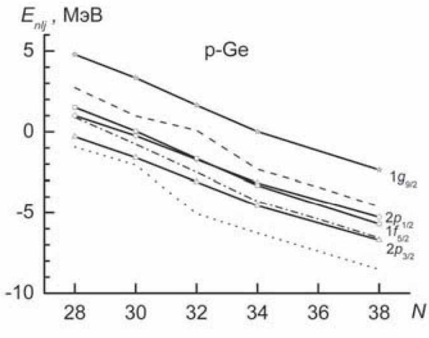

Fig. 1. Evolution of the proton single-particle energies of the neutron deficient Ge isotopes. Solid lines – calculation with DOP, dashed line – proton separation energy (with the opposite sign) from (N,Z+1) nuclei, dotted line – the same from (N,Z) nuclei, dashed-dotted line – the Fermi energy.

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PROTON DISPERSIVE OPTICAL POTENTIAL OF EVEN-EVEN Sn ISOTOPES WITH $100 \leq A \leq 132$

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Proton shell structure of even-even Sn isotopes was studied in a lot of works. The most precise data on proton single-particle energies E_{nlj} and occupation probabilities N_{nlj} for stable Sn isotopes were obtained (see [1] and references therein) by the joint evaluation of the stripping and pick-up reactions data [2] on the same nucleus. In [3], scattering data and bound state data were analyzed by the dispersive optical model (DOM) and obtained magnitude of the proton imaginary surface potential of stable Sn isotopes was more than 2 times greater than that of neutron.

In the present paper, available data on E_{nlj} for stable Sn isotopes and $^{100,132}Sn$ were analysed by DOM with the parameters which are determined by the method [4,5]. Calculated energies E_{nlj}^{DOM} agree with the data [1] within experimental uncertainties and demonstrate Z=50 shell closure in the region $100 \leq A \leq 132$. Obtained imaginary part of the dispersive optical potential corresponds with the standard asymmetry dependence of the global parameters of optical model potential [6]. A comparison with the predictions of various theoretical calculations was carried out.

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STUDY OF THE PROTON SHELL STRUCTURE EVOLUTION OF EVEN-EVEN Zr ISOTOPES WITH $50 \leq N \leq 82$ WITHIN DISPERSIVE OPTICAL MODEL

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The method to determine the parameters of dispersive optical potential (DOP) was proposed in [1, 2] for unstable spherical and close to them even-even nuclei. The method is based on the analysis of the available experimental data on single–particle energies E_{nlj} and occupation probabilities N_{nlj} for single-particle orbits and subsequent extrapolation of the parameters to the region of unstable nuclei. The extrapolated parameters are corrected in order to achieve an agreement between the calculated number of protons (neutrons) and Z (N) of the nucleus.

The method was used to calculate E_{nlj}^{DOP} and $N_{nlj}^{BCS}(E_{nlj}^{DOP})$ of the proton single-particle states in even-even Zr isotopes with $50 \leq N \leq 82$. The resulting single-particle energies agree with those calculated using various parameterizations of the Skyrme forces [3] within 10-15%. Single-particle energies $E_{2p_{1/2}}^{DOP}$ and $E_{1g_{9/2}}^{DOP}$ are close to the evaluated or predicted proton separation energies (with the opposite sign) from (Z=40, N) and (Z=41, N) nuclei correspondingly. This result evidences in favor of N=40 subshell closure throughout the Zr isotopic chain with $50 \leq N \leq 82$.

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SHELL STRUCTURE OF Cd ISOTOPES: DESTRUCTION OF MAGIC NUMBER $N = 64$

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On the basis of data on neutron stripping and pick-up reactions, estimates of the populations of neutron orbits in even-even stable isotopes of Cd were obtained. Using the method of joint analysis of the stripping and pick-up data [1] the most accurate values of the occupation numbers and energy locations of ^{114}Cd neutron orbits were obtained. The obtained results were used to explain the sequence of spin and parity of the ground states of Cd isotopes. It is shown that the 'weak' closure of the orbits $d_{5/2} - g_{7/2}$ which takes place in the Sn isotopes is destroyed in a specified Cd isotope. Magic number $N = 64$ manifested itself in isotopes of Sn disappears in other isotopes with distance from $Z = 50$. This result explains the features of the graphs of the first 2^+ states of isotopes with Z near $Z = 50$.

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DETERMINATION OF THE PHONON AMPLITUDES EMPLOYED IN BOSON EXPANSION THEORIES

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Low-lying states linked up by strong enough $E2-$transitions can be interpreted as superposition of many collective phonon configurations $(D^{+})^{nd}$. In Boson Expansion Theories these phonons are mapped onto quadrupole boson operators, e.g. in [1] $D^{+} \rightarrow d^{+}\sqrt{1-\hat{n}_{d}/\Omega} \sim d^{+}s$, $\hat{n}_{d}$ is the number operator of $d-$boson, Ω is their maximum number, s is a scalar auxiliary boson of the Interacting Boson Model. Wave functions in such approach are found as solutions of the boson Hamiltonian (H_{B}). Theoretical calculations of H_{B} parameters begin with a choice of the $D-$phonon operator for which we use the form of the Quasiparticle Random Phase Approximation (QRPA): $D_{\mu}^{+} \sim \sum(\psi_{12}a_{1}^{+}a_{2}^{+} + \varphi_{12}a_{\bar{2}}a_{\bar{1}})$ where amplitudes ψ, φ determine its two-quasiparticle composition. However, in contrast to QRPA where ψ, φ are defined for a one-phonon state, we search them taking into account many phonon (boson) structure of the collective states. With this object we minimize over ψ and φ a functional Φ comprising the expectation value of H_{B} (parameters of which are functions of ψ, φ and effective quasiparticle interactions) and some additional conditions, details can be found in [2]. Thus, equations for ψ, φ involve the boson expectation values (BEV) such as $< n_{d} >$, $< d^{+} \cdot d^{+}ss + \mathrm{H.c.} >$ and others, i.e. the equations allow for the many boson structure of states. One of the addition conditions in Φ fixes the value of $\xi = \sum\varphi^{2}/\sum\psi^{2}$ to be $\ll 1$, that gives the possibility, first, to employ the usual QRPA calculations and, secondly, to obtain the selfconsistent description of ψ, φ and BEV, i.e. the H_{B} parameters calculated with final values of ψ, φ give such BEV which being substituted into equations for ψ, φ lead to the same values of parameters. Such selfconsistency is impossible in the Tamm-Dankoff method, i.e., when $\varphi \equiv 0$. Calculations for Xe isotopes have shown that ξ cannot be larger than 0.065 and a reasonable agreement between calculations and all experimental data can be attained with $0.012 < \xi \leq 0.050$. A part of these calculations for ^{122}Xe is given in the table (E in MeV, МэВ, $B(E2)$ in $\mathrm{e^{2}fm^{4}}$).

	$E(2_1^+)$	$E(2_2^+)$	$E(4_1^+)$	$B(E2:2_1^+ \rightarrow 0_1^+)$	$B(E2:4_1^+ \rightarrow 2_1^+)$
Exp.	0.331	0.843	0.828	2890^{+125}_{-165}	4150^{+190}_{-180}
$\xi = 0.0145$	0.330	0.838	0.882	2920	4360
$\xi = 0.02$	0.339	0.843	0.894	2860	4270
$\xi = 0.03$	0.329	0.858	0.866	2800	4210

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NUCLEON-PAIR SHELL MODEL CALCULATIONS IN GENERALIZED SENIORITY BASIS

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In the phenomenological calculations, the interacting boson model (IBM) parameters are usually adjusted so as to give a best fit to a series of nuclei, with smoothly varying parameters. In general the observed variations in the parameters, as a function of *N* and *Z*, agree qualitatively with a zerothorder estimate based on the seniority scheme.

Several attempts have been made to calculate the model parameters from a more detailed microscopic approach [1]. One of the largest deviations from the simple seniority estimate was made in these calculations as coming from the coupling of the *SD* – subspace to the full shell model space. In these and subsequent calculations the effects of the neutron – proton interactions on the microscopic structure of the bosons have not been considered. Furthermore, in these calculations was neglectes the fluence of the Pauli principle on the *d*–boson structure. Calculations for deformed nuclei, using the Hartree-Fock-Bogoliubov method indicate that the microscopic structure of the bosons is strongly affected by the neutron-proton interaction.

In this paper a detailed calculation of the parameters will be presented by applying the nucleon-pair shell-model [2]. This model has the advantages that the diagonalization of the Hamiltonian is carried out exactly in the fermion space without any mapping procedure. For applying the nucleon-pair shell model to the ruthenium isotopes in *SD* – subspace. In this paper we attent to study the effects of the single – particle energy splitting and the goodness of *SD* -subspace.

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SD-NUCLEON-PAIR SHELL DESCRIPTION OF THE COLLECTIVE EXCITATIONS OF SPHERICAL NUCLEI

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The desciption of the collective properties of nuclei of medium and heavy atomic weight in the exact shell-model spaced remain very difficult problem because of their huge size. In recent years, therefore, the methods of cutoff of the Hilbert space have been used to optain a collective paired subspace with a small number of degrees o freedom [1, 2], which provided a fruitful explanation of the considered phenomena.

In this paper, we give a microscopic justification of the interacting boson model (IBM) for the description of low-energy collective excitations of the nucleon systems, and it is provided quite well by taking into account the *S* and *D*–paired shell states in them. In addition, this allows to avoid the well – known computational difficulties in the microscopic examination of the *s* and *d* –bosons of IBM as mappings of the *S* and *D* pairs of valents nucleons in nuclei.

As the mapping method of the fermion pair states in the boson the Otsuka – Arima – Yakello (OAY) method is taken. In this model space the Hamiltonian of the system is easily diagonalized and it satisfactorily reproduces the spectra and electromagnetic transition probabilities of vibrational, γ – unstable nuclei. Thus the microscopic phenomenological model is constructed for the nuclear system, the free parameters of the model are calculated as the fermionic matrix elements of the pair forces of nucleon interaction.

The theory is applied to studying the properties of even spherical isotopes of $^{102,\ 104,\ 106,\ 108}$Pd.The energy states and relative values of the reduced probabilies of γ – transitions are compared with experimental data.

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EXCITED STATES OF ^{65}Cu

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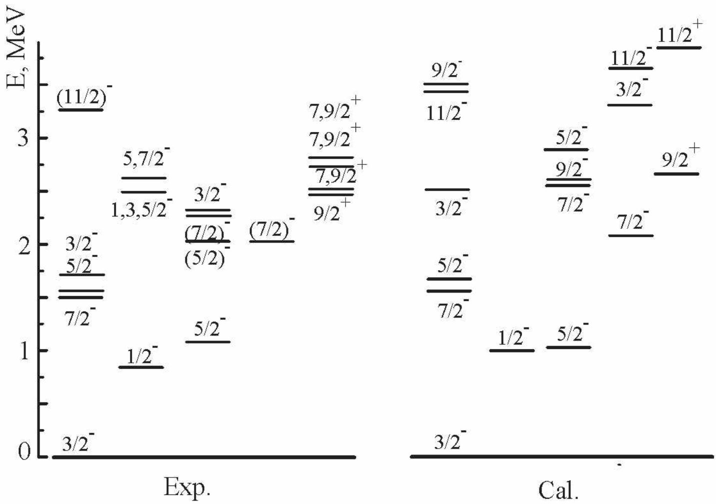
The energies, spectroscopic factors, magnetic dipole and electric quadrupole moments of the ground and excited states of ^{65}Cu, as well as reduced probabilities of electromagnetic transitions between them have been calculated in the framework of dynamic collective model [1].

It differs from other nuclear models by the possibility of uniform description of spherical, transitional and deformed nuclei and consideration of the influence of vacuum fluctuations of quasiparticles on the renormalization of one-particle moments and effective forces, as well as the influence of the Pauli principle on the formation of the collective and quasiparticle modes and their interconnection. Multy-phonon states (up to ten phonons) of main band of even-even core are taken into account.

In figure the part of level scheme of ^{65}Cu is presented. For the low-lying



states we distinguish five bands in this isotope, formed by coupling of $3/2_1^-$, $1/2_1^-$, $5/2_1^-$, $7/2_1^-$ and $9/2_1^+$- states with collective states of the main band of the core. Results of the calculations well describe experimental data.

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β-DECAY $^{65}Ni \to ^{65}Cu$

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β^--decay $^{65}Ni \to ^{65}Cd$ has been described by means of the method offered in [1]. Quasiparticle and multy-phonon states (up to ten phonons) of main band of even-even core, as well as influence of vacuum fluctuations of quasiparticles to reduced probabilities of beta-transitions are taken into account.

The β transitions with maximum intensity and probability occur from the ground state of ^{65}Ni, the main contribution in which gives neutron one-particle state $f_{5/2}$, to $3/2_1^-$, $5/2_1^-$ and $7/2_1^-$ states of ^{65}Cu, the main contributions in which give the proton one-particle states $p_{3/2}$, $f_{5/2}$ and $p_{3/2}$ accordingly.

The comparison of experimental and calculated $\lg ft$ are present in the table.

I^π	$3/2_1^-$	$5/2_1^-$	$7/2_1^-$
E	0	1115.6	1481.8
I,%	60	10.18	28.4
$\lg ft$, exp.	6.6	6.1	4.9
$\lg ft$, cal.	6.6	6.3	4.6

The renormalization of weak interaction constants in this calculation was the same as for the nuclei with $31 < A < 231$. Hence, it does not depend of Fermi surface of nuclei, so and from Fermi and Gamow-Teller resonances.

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ANALYSIS OF THE EXCITED STATES IN EVEN-EVEN Dy ISOTOPES WITHIN IVBM

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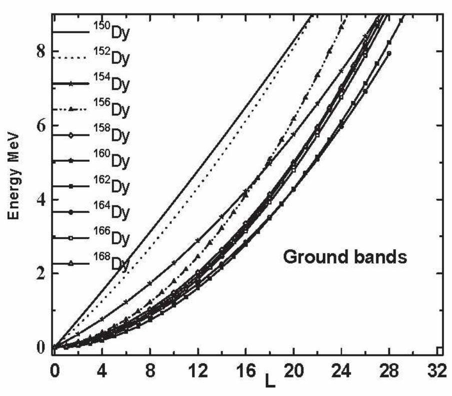
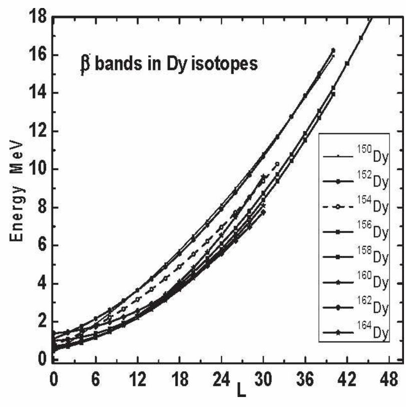
The spectra of the excited states of the even-even Dy isotopes are studied relatively well and the corresponding experimental data obtained from β decay and other reactions are presented in NNDC tables.

Except the common characteristics like charge number, even number of neutrons and the ground states with $K^{\pi}=0^{+}$ these isotopes differ by number of neutrons and eventuality by deformation.

We analyze the peculiarities in behavior of rotational bands in Dy isotopes and the energies of the excited states with the same spin depending on the neutron number. The analysis is performed within the framework of Interacting Vector Bosons Model (IVBM) [1].

In figures below are shown the results for the theoretical description of the ground and β – bands energies with the corresponding values of the average deviation per point for all the isotopes under consideration.





$\Delta_{AV} = 0.0008\ MeV.$ $\Delta_{AV} = 0.0017\ MeV.$

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PHENOMENOLOGICAL DESCRIPTION OF THE COULOMB ENERGIES FOR MEDIUM-HEAVY AND SUPERHEAVY NUCLEI

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Coulomb energy $E_C(A, Z)$ – is one of the main characteristics of the nucleus, determining its binding energy. In the experiment, may determine the difference of the Coulomb energies of neighboring nuclei isobars:

$$\Delta E_C(A, Z) = E_C(A, Z+1) - E_C(A, Z),$$

which is obtained from the simple relations [1] of the analog resonances energies measurements in charge-exchange reactions. For the Coulomb displacement energies $\Delta E_C(A, Z)$ systematic several approaches were used. First, is a relation:

$$\Delta E_C(A, Z) = a_T\,(Z + 0.5)A^{-1/3} f(A) + b_T \quad \text{(MeV)}, \qquad (2)$$

where $f(A)$ is radius correction function. For $f(A) = 1$ the relation (2) goes into the semi-empirical Jänecke formula [2] parameterized by Anderson, C. Wong and McClure [3]. These parameters were determined from experimental data many times in different approaches [4]. In this paper we use the new database for more than 400 nuclei and focuses on medium-heavy nuclei. Approximation accuracy is not worse than 100 keV that is better than calculations within microscopic theory [5].

In this paper also analyzes the group theory approach to the description of the Coulomb energies of medium-heavy nuclei in the framework of $SU(4)$ symmetry. In [6] were obtained for the parameters of the theory for nuclei up to A = 60. We analyzed heavier nuclei up to A = 244. For heavy nuclei region deformation is taken into account, which strongly affects the ΔE_C value.

Approximation of Coulomb displacement energy ΔE_C was interpolated for superheavy nuclei (SHN), where is no experimental data. Deformation was taken into account with the predicted parameters β_2 and were considered only SHN, located on the line of beta-stability. Note that for heavy nuclei $SU(4)$-symmetry should be restored [7] and analysis of ΔE_C values was conducted in two approaches.

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SUPERFLUIDITY OF HEATED FERMI SYSTEMS IN STATIC FLUCTUATION APPROXIMATION

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The strongly excited systems have an extremely high level density and therefore some problems concerning to realistic calculations in the framework of microcanonical ensemble appear in their theoretical studies. Due to this fact, it seems more expedient to use the statistical description. Therefore, building an effective statistical theory, which describes wide range of phenomena in heated Fermi systems, is a very actual problem.

During the investigations of the properties of high excited finite Fermi systems the methods and approximations developed for weakly excited systems (at T=0) are usually generalized. But many of the assayed approximations does not allow to take correctly into account the correlation effects of different types, which can play an important role at explaining the observable statistical properties.

For investigations of the thermodynamical properties of heated finite Fermi systems we suggest the original method, i.e. the method of statistic fluctuation approximation (SFA). This method is based on the replacement of the square of the deviation from the mean value of the local field operator by the mean value of that square. In this replacement the exact quantum mechanical spectrum of the local field is replaced by its distribution, for which we can count the moments of second order. As a result it becomes possible to consider the fluctuations of local field. As it is shown by calculations of thermodynamical characteristics of different many-body systems with strong interactions, it becomes sufficient for correct consideration of correlation effects.

For Fermi systems, which is in a bound state due to the two-particle interactions, in a framework SFA we obtain closed self-consistent system of equations for calculating the correlation functions, average energy, chemical potential, entropy and other characteristics as temperature functions with including paring between particles. Also the influence of the fluctuations to temperature behavior of the energy gap and the thermal capacity is demonstrated.

PARTICLE-HOLE STRUCTURE OF FINITE SYSTEMS WITH PAIRING

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In order to ascertain how many particle and hole pairs appear in finite superconducting or superfluid systems at various particle numbers N and pairing strengths g in the BCS Hamiltonian (H_{BCS}) the eigenfunctions of H_{BCS} with a fixed N are constructed as superposition of two particle–two hole excitations. For an even system with $(\Omega_p+\Omega_h)$ two-fold degenerate levels among wich Ω_h levels are occupied at $g=0$ and Ω_p ones are vacant $(N=2\Omega_h)$ such functions e.g. for zero seniority can be written in the form

$$|\Psi\rangle=\beta_0\left\{1+\sum_{n\geq 1,s,t}\beta_{st}(n)B_s^+(n)\tilde{B}_t^+(n)\right\}|\tilde{0}\rangle, \tag{1}$$

$|\tilde{0}\rangle$ is the Hartree—Fock vacuum, $B_s^+(n)=\sum_{\mu_1\ldots\mu_n}\alpha(\mu_1\ldots\mu_n)p_{\mu_1}^+p_{\mu_2}^+\cdot\ldots\cdot p_{\mu_n}^+$, $p_\mu^+=a_\mu^+a_{\bar{\mu}}^+$, a_μ^+ is a particle creation operator in state μ, $\bar{\mu}$ is a time conjugated state. $\tilde{B}_t^+(n)$ is analogous with $B_t^+(n)$ but is composed of hole creation operators $\tilde{p}_\nu^+=\tilde{a}_\nu^+\tilde{a}_{\bar{\nu}}^+$. In the particle-hole $(p-h)$ representation H_{BCS} is divided into H_p, H_h and particle-hole interaction v:

$$\begin{gathered}H_p=\sum_{\mu=1}^{\Omega_p}(\varepsilon_\mu-\lambda)n_\mu-gP^+P;\quad H_h=-\sum_{\nu=1}^{\Omega_h}(\varepsilon_\nu-\lambda)\tilde{n}_\nu-g\tilde{P}^+\tilde{P};\\ P^+=\sum_\mu p_\mu^+;\quad \tilde{P}^+=\sum_\nu \tilde{p}_\nu^+;\quad v=g\left(P^+\tilde{P}^++\tilde{P}P\right);\end{gathered} \tag{2}$$

$$\left[H_p,B_s^+(n)\right]=E_s(n)B_s^+(n);\ \left[H_h,\tilde{B}_t^+(h)\right]=\tilde{E}_t(n)\tilde{B}_t^+(n). \tag{3}$$

For systems with equidistant levels at $\Omega_p=\Omega_h$ and $\lambda=(\varepsilon_F+\varepsilon_{F+1})/2$ sets of $E_s(n)$ and $E_t(n)$ coincide. Energies of zero seniority states and amplitudes $\beta_{st}(n)$ in (1) $(n\geq 1, b_{st}(0)=1)$ are determined by the system of equations:

$$\begin{gathered}\beta_{st}(n)\left[E_s(n)+\tilde{E}_t(n)-E\right]+g\sum_{s't'}\beta_{s't'}(n+1)\langle sn|P|s'n+1\rangle\langle tn|\tilde{P}|t'n+1\rangle+\\ +g\sum_{s't'}\beta_{s't'}(n-1)\langle s'n-1|P|sn\rangle\langle t'n-1|\tilde{P}|tn\rangle=0;\\ E=\sum\left[\beta_{st}(n)\right]^2\left[E_s(n)+E_t(n)-E\right]+\\ +2g\sum\beta_{st}(m)\beta_{s't'}(m+1)\langle sm|P|s'm+1\rangle\langle tm|P|t'm+1\rangle.\end{gathered} \tag{4}$$

Eqs. (4) include $p-h$ transfer matrix elements, e.g. $\langle sm|P|s'm+1\rangle = \langle\tilde{0}|B_s(m)PB^+_{s'}(m+1)|\tilde{0}\rangle$. Energies $E_s(n)$ and $\tilde{E}_t(n)$ standing in Eqs. (3), (4) can be calculated by means of recurrent procedure: at first for all n e.g. particle operators $B^+_s(\omega,n)$ are defined for ω levels $\left(\Omega_p > \omega \geq n, B^+_s(\omega=n,n) = p^+_1 p^+_2 \dots p^+_n\right)$, after that operators $B^+_s(\omega+1,n)$ are expressed through $B^+_{s'}(\omega,n)$ and $B^+_{s''}(\omega,n-1)$:

$$B^+_s(\omega+1,n) = \sum_{s'}\psi_{ss'}(n)B^+_{s'}(\omega,n) + \sum_{s''}\psi_{ss''}(n-1)B^+_{s''}(\omega,n-1)\,p^+_{\omega+1}.$$

Amplitudes $\psi(n)$, $\psi(n-1)$ and eigenvalues $E_s(\omega+1,n)$ are found with the help of equations:

$$\psi_{ss'}(n)\left[E_{s'}(\omega,n) - E_s(\omega+1,n)\right] - g\sum_{s''}\psi_{ss''}(n-1)\langle n-1s''|P(\omega)|ns'\rangle = 0,$$

$$\psi_{ss''}(n-1)\left[E_{s''}(\omega,n-1) + E_{\omega+1} - E_s(\omega+1,n)\right] - g\sum_{s'}\psi_{ss'}(n)\langle n-1s''|P(\omega)|ns'\rangle = 0.$$

Thus, several additional diagonalizations are required to solve Eqs. (4). However, at high enough particle numbers (that occures in deformed nuclei and nano-clusters) and at realistic values of g transfer matrix elements between states $|s_0 n\rangle$ and $|s'_0 n+1\rangle$, where s_0, s'_0 correspond to states with minimal energies at given n and $n+1$, considerably exceed those between other states [1]. This paves the way to obtain approximate solutions with smaller amount of diagonalization.

The work is supported by the SPbSU grant No. 11.38.648.2013.

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PROPERTIES OF ROTATIONAL BANDS OF ISOTOPES Yb

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Present paper focuses on low–lying states of positive parity of isotopes ^{170,172,174}Yb. The calculation is conducted by utilizing a phenomenological model [1] which accounts Coriolis mixture all of the experimentally known low-lying rotational bands states with $K^{\pi}<3^{+}$. Experimentally observed K–forbidden transitions as well as non–adiabaticities of energy and in ratios of $E2$- transitions can be explained by Coriolis mixture states.

The calculations have been carried out for the ^{170,172,174}Yb isotopes. All experimentally known rotational bands of positive parity with $K^{\pi}<3^{+}$ have been included in basis states of Hamiltonian.

The reduced probability of $E2$-transitions and reduced probability of $M1$- transitions from the states I_iK_i to the level I_fK_f band are calculated. The reduced probabilities of $E2$ – transitions for ^{172}Yb are presented in Tables 1.

The experiment suggests that $m=5$ band with $K^{\pi}=0^{+}_{m}$, one band $\ell=1$ with $K^{\pi}=2^{+}_{\ell}$, and $\nu=19$ with $K^{\pi}=1^{+}_{\nu}$ states in ^{170}Yb [2]. These all $n=m+\ell+\nu=25$ rotational bands have been included in the basis states of Hamiltonian (1). For the isotopes ^{172,174}Yb, basis states of Hamiltonian include $n=m+\ell+\nu=15$ ($m=5$, $\ell=2$ and $\nu=8$) and $n=m+\ell+\nu=22$ ($m=5$, $\ell=2$ and $\nu=15$), correspondingly [3,4,5].

The energy and structure of wave functions of excited states are calculated. The reduced probabilities of $E2$– and $M1$– transitions are also calculated and comprised with experimental data which are gives satisfactory result.

Table 1. Reduced probability of $E2$– transitions in the ^{172}Yb

$I_iK_i \to I_f0_f$	Exp. [6]	Theory	$I_iK_i \to I_f0_f$	Exp.[4]	Theory
$22_1 \to 00_1$	74.6(57)	82	$20_2 \to 00_1$	14 (1)	13
$\to 20_1$	121 (12)	130	$\to 20_1$	45 (7)	23
$\to 40_1$	6.8 (7)	8.6	$\to 40_1$	142 (20)	74
$32_1 \to 20_1$	152 (11)	154	$20_3 \to 00_1$	0.4 (1)	3.6
$\to 40_1$	79 (6)	73	$\to 20_1$	0.6 (4)	3.0

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OSCILLATIONS OF THE INERTIA MOMENT OF A FINITE FERMI SYSTEM IN THE CRANKING MODEL FRAMEWORK

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In this work we present new analytical method for calculating the dependence of the moment of inertia of a heated finite nucleonic system on the chemical potential in the framework of the cranking model. In our calculations we use the standard Mellin transformation method, which allows us to split the moment of inertia into two components, smooth and oscillating. Obtained explicit analytic expressions for these components, which hold in the entire interval of temperatures and deformation parameters, allow us to study (without numerical computations) important pecularities of the dependences of the moment of inertia on the number of particles, temperature, and deformation. In particular, we showed that the oscillations of the moment of inertia increase depending on the chemical potential at spherical limit $\omega_{x,y} \rightarrow \omega_z$ and decrease rapidly as the temperature increase.

We also calculate the rigid-body moment of inertia that is realized when the condition of statistically equilibrium rotation holds. It is also shown that the oscillations dependent on the chemical potential are also involved in this case. However, the oscillations for the rigid-body moment of inertia are manifested to be weaker and do not disappear in the spherical limit at zero temperature. The method of splitting physical quantities into smooth and oscillating components developed in this work can be also applied to other systems in which complicated nonmonotonic behavior of physical characteristics is caused by the boundedness of the system geometry or the motion of particles.

DESCRIPTION OF ELECTROMAGNETIC AND STRONG INTERACTIONS IN ROTATING FRAMES AT COLLISIONS OF HIGH ENERGY NUCLEI

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Peripheral collisions of high energy nuclei can be characterized by large angular momenta. Such collisions are planned to be studied at the NICA accelerator complex at JINR. When nuclei rotate with a very large angular velocity [1,2], a description of physical phenomena in a rotating frame is rather helpful. For such a description, we use the initial covariant Dirac equation defining electromagnetic and gravitational (or inertial) interactions of a spin-1/2 fermion. To provide a phenomenological description for strong interactions, we add conventional vector and scalar confining potentials (Coulomb plus linear ones) to this equation. We perform the Foldy-Wouthuysen (FW) transformation by the method [3] applicable for a relativistic particle in strong external fields. The derivation of the relativistic FW Hamiltonian makes it possible to give a detailed quantum-mechanical analysis of the problem and to obtain a unambiguous classical limit of the initial equation. The obtained results show a strong influence of the rotation on the motion of quarks and the dynamics of their spins.

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DIPOLE RESONANCE SPLITTING AND SHELL STRUCTURE PECULIARITIES OF ^{52}Cr NUCLEUS

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Microscopic description of giant resonances and resonance of higher multipolaties (MGR) in ^{52}Cr and ^{54}Fe nuclei was performed in the multiparticle shell model (MSM). The resonances in nuclear excitations cross sections according to MSM are results of doorway-states' collectivisation. This approach was quite successful in interpretations of the main peaks locations on the energy axis for magic nuclei but not for the even-even non-magic ones. Some advance in the interpretation of MGR fragmentation could be attained in the Particle-Core Coupling Version of MSM (PCC SM). PCC SM takes into account the spreading of hole configurations among the states (A-1) daughter nuclei [1]. A full set of basic configurations generating E1 resonances could be obtained from the hole state distribution's analysis revealed in pick-up reaction spectroscopy. This method allows to get a realistic description of E1 resonance in ^{54}Fe nucleus [2]. The ^{54}Fe nucleus has two additional protons in comparison with ^{52}Cr in unfilled $1f_{7/2}$ subshell. The spectroscopic factors' distributions in both nuclei show considerable fragmentation of $1f_{7/2}$ subshell as well as deeper subshells. The energy splitting of subshells revealed in the pick-up reaction spectroscopy of ^{52}Cr together with isospin splitting are the main sources of strengths of E1 resonance fragmentation. The results of PCC SM calculations based on spectroscopy [3] and the comparison with experiment [4] are shown in the Fig.1.

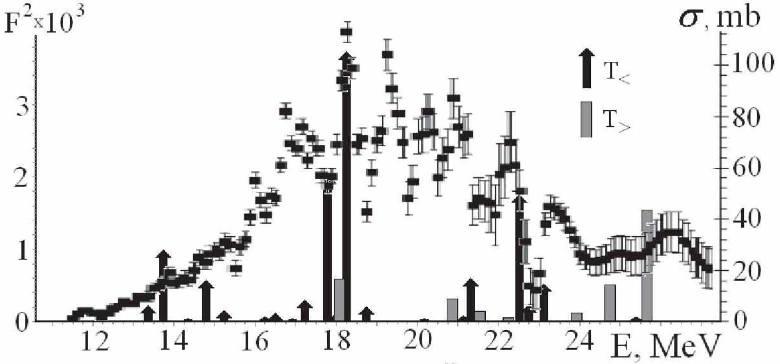

Fig. 1. E1 resonance in ^{52}Cr nucleus.

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ON PROPERTIES OF HIGH-ENERGY ISOSCALAR MONOPOLE (p-h)-TYPE EXCITATIONS IN MEDIUM-HEAVY MASS SPHERICAL NUCLEI

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Continuing interest in experimental and theoretical studies of high-energy isoscalar monopole (ISM) (*p-h*)-type excitations in medium-heavy mass nuclei is due to the possibility of extracting information concerning the nuclear matter incompressibility coefficient. The strength distribution, corresponding to the external field r^2Y_{00}, directly determines the incompressibility modulus. To deduce this strength from experimental (α, α')-reaction cross sections, it is usually assumed that the ISM strength is concentrated in a vicinity of the ISM giant resonance (ISGMR) and the properly normalized collective model transition density of the ISGMR can be used in the analysis of experimental data (see, e.g. Ref. [1]). However, due to Landau damping the radial dependence of the (semi)microscopic transition density is changed with increasing of the excitation energy from the ISGMR to its overtone.

In the present work we use the (*p-h*) dispersive optical model developed recently to describe in a semi-microscopic way, and in average over the energy, the main properties of high-energy (*p-h*)-type nuclear excitations [2]. Within the model the main relaxation modes of these excitations (Landau-damping, coupling with the single-particle continuum, the spreading effect) are commonly taken into account. Using this model, we evaluate the energy-averaged ISM double transition density (i.e., the product of transition densities taken at different points). Being doubly convoluted with an external ISM external field, the double transition density determines the corresponding energy-averaged strength function. We hope that the suggested approach can be exploited in description of the corresponding experimental data with the use of the method developed in Ref. [3].

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ON DAMPING OF THE GAMOW-TELLER RESONANCE IN ^{118}Sb

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The unique experiment on observation of the Gamow-Teller resonance (GTR) with the resonance ^{117}Sn(p, n_{tot}) - reaction [1] and intention to repeat this experiment soon [2] stimulate us to extend the previous study of this GTR [3]. The new point consist in estimation of the "elastic" partial proton width for each GTR component observed in Ref. [1]. To formulate the appropriate method, we first simplify the standard version of the "charge-exchange" continuum-quasiparticle-random-phase approximation (pn-cQRPA) of Ref. [4] considering only high-enough excitation energies. Keeping in this case only the particle-hole component of the free two-quasiparticle propagator taken in a simplified form, we satisfactorily reproduce in calculations of the GTR strength functions for the $^{116,\ 118,\ 120}$Sn parent nuclei the results obtained in Ref. [3] within the "exact" version of the pn-cQRPA. Within this approach we further formulate the non-standard version of the simplified pn-cQRPA and take phenomenologically into account the spreading effect in the "pole" approximation. In applying to the GTR in doubly-closed-shell parent nuclei (i.e. in the absence of nucleon pairing) such a method is described in Ref. [5]. As a result, we estimate the "elastic" proton widths of the two-bump GTR in the ^{118}Sb compound nucleus and compare these quantities with the corresponding data of Ref. [1].

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SPIN POLARIZATION OF NUCLEONS. LIMITS OF LOW AND HIGH TEMPERATURES

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The problem of spin polarization of nucleons is important in astrophysics for the explanation of magnetic fields of some types of astrophysical objects. At the densities of the order of nuclear saturation density this problem is applied to neutron stars [1], and the results are very model-dependent. At lower densities this problem is applicable to white dwarfs and type II Supernovae.

The magnetic fields of white dwarfs can be explained by magnetic flux conservation at contraction, common envelope and accretion in close binary systems, rotation, hydromagnetic dynamo [2,3], but for white dwarfs with hydrogen envelopes (DAH and DAP white dwarfs) such explanations can be added by spin polarization of protons in outer melted layers.

The magnetic fields of type II Supernovae can be explained by asymmetric collapse with jets and rotation, Rayleigh-Taylor and Kelvin-Helmhottz hydromagnetic instabilities [4], but these explanations can be added by spin polarization of protons and neutrons, though the lifetime of such systems is small [5].

Neutron-proton system with contact nuclear spin-isospin-dependent interaction was considered at densities 2 and more orders lower than nuclear saturation density at high and low temperatures through minimal energy density at finite spin polarization degrees and through Stoner criterion. Stoner criterion was found through the poles of magnetic susceptibility of the system and through the negative sign of energy density fluctuations dependent on spin density fluctuations of nucleons on the basis of the algorithm for 1-component cold Fermi-gas [6]. The importance of Coulomb exchange and correlation energies consideration was shown. Spin polarization initiation was found to be energetically preferable at proton and neutron densities of the orders of 10^{30}-10^{31} cm^{-3} and 10^{35}-10^{36} cm^{-3}. The existence of the first region of densities was shown to be due to Coulomb exchange energy, and the influence of Coulomb correlation energy was shown to be negative.

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BETA-DECAY RATES OF SHORT-LIVED NEUTRON-RICH NUCLEI, INVOLVED INTO THE R-PROCESS

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Beta-decay rate is one of the main nuclear parameters of neutron-rich nuclei. It is very important for astrophysical r-process nucleosynthesis. For beta-decay rates predictions for neutron-rich nuclei models of beta strength-function are usually used [1,2]. In this work for the beta-decay rates calculations we used the beta-strength function model in which strength-function was derived in the framework of quasiclassical approach, based on the finite Fermi-systems theory. On the basis of the model the consequent calculations of neutron emission and beta-delayd fission probabilities were derived recently for actinides [3]. The consistent calculations of beta-dacy rates based on the same model are needed for predictions of heavy and superheavy abundances in the r-process nucleosynthesis. New calculations became actual when it was shown [4] that the values of beta-decay rates strongly depend on abundances of rare earth elements, forming in nucleosintesys in very high neutron environment.

The compare of preditions with experimental data and utilization of uptodate atomic mass preditions [5] let us correct the parameters of the model for extended calculations of beta-rates for the region of actinides, involved into the r-process.

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β-DECAY RATES AND TENSOR CORRELATIONS

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One of the successful tools for the studies of Gamow-Teller (GT) strength distributions is the quasiparticle random phase approximation (QRPA) with the self-consistent mean-field derived by the Skyrme interaction. These QRPA calculations allow one to relate the properties of the ground states and excited states through the same energy density functional. Making use of the finite rank separable approximation (FRSA) [1, 2] for the residual interaction enables one to perform Skyrme-QRPA calculations in very large two-quasiparticle spaces. The FRSA has been extended to accommodate tensor correlations to mimic the Skyrme tensor interactions [3]. In this report the tensor correlation effects on β-decay half-lives are studied within the approach. Using the wide range of the parameter space of the isoscalar and isovector tensor term [4] we concentrate on the correct amount of the integral GT strength within the properly calculated Q_{β}-window for the case of doubly magic nucleus ^{132}Sn.

The comparison between experimental the energies of 1^{+} states of ^{132}Sb, the log ft values and those calculated with the Skyrme interactions are discussed.

Taking into account of the tensor terms results in a reduction of beta-decay half-life. The inclusion of the residual tensor interaction terms is essential.

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THE RIGHT-POLARIZED NEUTRAL (ANTI)LEPTONS IN THE SOLAR NEUTRINO FLUX

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In the present work, a development [1], the flavor structure of solar neutrino is investigated.

The possibility of changing the flavor of solar electron neutrinos ν_e is directly related to their helical properties. If the helicity changes (scenario of magnetic reorientations), within the left-polarized neutrino concept the "solar messengers" can be transformed into a right-polarized neutral particles, i.e. into an antineutrino of second and third generations ($\tilde{\nu}_\mu^R$ and $\tilde{\nu}_\tau^R$). Part of the neutrino flow from the Sun is likely to undergo conversion also into related antineutrino $\tilde{\nu}_e$. At the same time, according to the four-component theory, a change of the helicity leads to the conversion of solar neutrinos into a muon (right-polarized) neutrinos ν_μ. Consequently, it is possible, that if the helicity changes, the solar neutrinos can reach an electron target in the $\{\nu_e^L, \tilde{\nu}_e^R, \tilde{\nu}_\mu^R, \tilde{\nu}_\tau^R\}$ or $\{\nu_e^L, \tilde{\nu}_e^R, \nu_\mu^R, \tilde{\nu}_\tau^R\}$ states of the wave (anti)neutrino packet.

The electroweak (SM) spectrum of recoil electrons containing admixture muon and tau components is obtained and analyzed for the scattering of monoenergetic beryllium solar neutrinos with energy of 0.862 MeV on an electron target. These components correspond to the above predictions for neutrino states with contents of neutral leptons in the ratios given by the total SM-cross sections with threshold of 0.25 MeV from final electrons.

The results of quantitative analysis and graphical image of the cross sections are presented in the form of tables and figures. For sake of comparison, all the figures show curve which characterized the successful (i.e. with flavor conservation) arrival of solar electron neutrinos on the Earth.

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THE DISCOVERY OF GLOBAL ANISOTROPY OF PHYSICAL SPACE AND NEW NON-GAUGE INTERACTION: FUNDAMENTAL EXPERIMENTS, THEORETICAL DESCRIPTION AND PRACTICAL APPLICATION

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An experimental studies of attraction of very weak paramagnetic (WP) probes located inside high current solenoids with strong uniform fields (B up to 15 T), using torsional and high noise-stability piezoresonance weights, showed that the WP material in certain regions of the solenoid is not attracted to it, but is repelled. Such repulsion zone moves over the aperture of the solenoid with a speed of 15°–18° per hour. These experiments, carried out from 1987 to 1994 at the experimental bases IAE named after I.V. Kurchatov and IOFRAN, using the direction of the vector potential of the solenoids in the zone of repulsion, allowed to unveil for the first time the anisotropy of physical space, which the one from coauthors identified with the direction of the cosmological vector potential A_g – a new fundamental vectorial constant, introduced in [1]. The analysis these experiments created a theory of byuon [2]. That is a theory of "life' of special discrete objects (byuons) from which the surrounding space and the world of ultimate particles form. The expression of byuons includes the vector A_g (astronomical coordinates in the second equatorial system: $\alpha \approx 293° \pm 10°$, $\delta \approx 36° \pm 10°$ where α is the right ascension and δ is the declination).This theory created a basing of new force nature because part of ultimate particles mass is proportional to modulus summary potential A_Σ ($|A_\Sigma| \leq |A_g|$). The present report is devoted the universal anisotropic property of global anisotropy of physical space and new interaction in nature in a wide range of dimensions based on analyzing fluctuations in the intensity of the β- decay (10^{-17}cm) [3,4], α-decay of radioactive elements (10^{-13} cm) [5], motion of pulsars [5] (size of our Galaxy (10^{22}cm) and anisotropy of cosmic rays up to ultrahigh energies [5] (size of our Universe 10^{28} cm). The report is devoted a practical using of new force for motion in space too. The one-year long experiment carried out in Italy (2012–2013) to study the use of a new force of nature in the form of thrust for a spherical ship (model of spacecraft), identified a direction in the physical space with the coordinates $\alpha \approx 300°–310°$, which is very close to the earlier results. The results of the experiments are on the order of ten times greater than the experimental error [6].

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THE METHOD OF UNITARY CLOTHING TRANSFORMATIONS: VERTEX RENORMALIZATION IN THE OPERATORS OF NUCLEON-NUCLEON INTERACTION

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In the instant form of relativistic quantum dynamics for a system of interacting mesons and nucleons, where amongst the ten generators of the Poincar′e group (П) only the Hamiltonian H and the boost operator B carry interactions, we have proposed [1] a constructive way of ensuring the relativistic invariance in field models with cutoffs in momentum space. Moreover, in combination with the method of unitary clothing transformations [2] the proposed approach enables us to get the interactions between the clothed particles (in particular, physical mesons and nucleons) simultaneously in the H and B. The derived interactions are hermitian and energy independent that do them helpful in practical calculations in nuclear physics. In addition they include recoil effects.

As an illustration we will show for the neutral pion and nucleon fields coupled via the pseudoscalar (PS) Yukawa-type interaction how the vertex renormalization problem can be considered in the framework of the method of unitary clothing transformations (UCT method). In the instant form of relativistic dynamic the total Hamiltonian and boost generators take on the same sparse structure in the Hilbert space of hadronic states [1]. The expression obtained by us for the charge shift in the first non-vanishing order (in the third order of the coupling constant) arises due to the cancellation of the vertex counterterm with the corresponding operators structure in these multiple commutators of the generator of the clothing unitary transformation. On the energy shell the derived expression is expressed via the three-dimensional integrals on certain Lorentz-covariant quantities, providing the momentum independence, and coincides with this one found within the Dyson-Feynman approach.

Along with it, we have developed off-energy-shell diagram technique in the UCT method which simplifies us to constructing of a new family of hermitian and energy-independent operators of relativistic interactions having the off-energy-shell structures in a natural way.

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GROUND STATE MULTIPLET SPLITTING ESTIMATION BASED ON NUCLEI MASSES

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Recently the ground state multiplet formed in nuclei with the pairs of identical nucleons over the magic core was studied. It was shown that ground state multiplet splitting corresponds to the magnitude of nn or pp-pairing Δ_{NN} in even-even nuclei. This value can be obtained from nuclei masses data through the even-odd staggering effect [1].

The structure of ground state multiplet in atomic nuclei with double magic core and two identical valence nucleons was obtained by using the residual pairing δ-interaction. Calculations with the strength of δ-interaction determined by the nucleons pairing Δ_{NN} are in a good accordance with experimental data without any fitting procedure [2].

The approach mentioned above is fruitful for investigations of systematic of even-even nuclei with several pairs of identical nucleons over the magic core. Moreover the existence of ground state multiplet in odd-odd nuclei with the magic core and the np-pair gives a possibility to study isospin dependence of nucleons pairing too as it show pairing not only in the even *J*, but in the odd *J* states.

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CAPABILITIES OF NUCLEAR ELECTRON SPECTROSCOPY IN THE STUDY OF NON-STATIONARY PROCESSES IN CONDENSED MEDIA

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Nonstationarity of the processes is characterized by the time variability of their parameters. Implementation of precision nuclear-spectroscopic experiments requires high quality sources production and deep understanding of the processes ongoing in its material. It turned out that this is particularly important in the case of applying the sources in the form of rare earth oxides, where nonlinear dependence of their properties from ordering and disordering of structural formations is evident. Displaying the dielectric-ferroelectric phase transition is undoubtful. Based on the analysis of studies and other types of electron emission (Auger electrons and field-emission electrons) of the decay of radioactive isotopes of lutetium fraction in the oxide form on platinum substrate we can assume the formation of the atomic clusters source in the matrix, similar to toroidal quadrupoles of the structures.

The toroidal quadrupole can be represented as two closed solenoids with opposite toroidal moments, i.e. with an opposite current direction in the turns. The values of static quadrupole toroidal moments haven't been obtained yet. In our experiments it was estimated that the toroidal splitting M_4- and M_5-subshells of ytterbium into sublevels occurs in the superstrong magnetic field (B=10^4-10^5Tl). The thorough quantitative evaluation of the nature and the extent of the toroidal splitting would allow us to estimate the limits of weak interaction violating the temporal invariance.

The displaying of formations in the solid matrix of radioactive sources of atomic clusters in the nanometer range and in the nanostructures with closed magnetic flux, i.e. in the form of toroids was clearer observed in the decay of Lu→Yb and Lu→Hf.

The experimental data obtained by the methods of field-emission spectroscopy have shown that some of the toroidal clusters have the magnetic nature. At the same time, the experiment also points to the process of nuclear segnetization in nuclear oxides. This suggests the possibility of formation of electric dipole toroidal moments and conversion of the last into quadrupole ones.

ALPHA-STABILITY OF SUPERHEAVY NUCLEI

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As it was shown in [1], in the region limited by magic numbers, the energy of beta-decay changes as a linear function of the charge Z, in particular for heavy nuclei [2] ($Z > 82$, $N > 126$)

$$Q_{\beta\pm} = \pm k(Z - Z^{*}) - D, \qquad (1)$$

where $Z^{*} = \alpha A + \beta$ is the beta-stability line; numerically $k = 1.13$ MeV, $\alpha = 0.35$, $\beta = 9.9$, D (parity correction) is 0.75 MeV for odd nuclei and 2.1 MeV for even nuclei. $Q_{\beta\pm}$ is connected with total energy of nucleus E: $Q_{\beta\pm}(A, Z) = E(A, Z) - E(A, Z+1) - E_e$ (E_e – energy of electron). From this and (1) it follows that $E(A, Z)$ is a quadratic function of Z:

$$E(A, Z) = E_0(A) - k/2\,(Z - Z^{*} - 1/2)^2 - DZ. \quad (2)$$

The energy of α-decay $Q_\alpha(A, Z) = E(A, Z) - E(A-4, Z-2) - E_\alpha$ (E_α is the energy of α-particle is reduced to expression

$$Q_\alpha(A, Z) = Q_0(A) + 2k\alpha\,(1 - 2a)\,Z \qquad (3)$$

and therefore $Q_\alpha(A, Z+1) - Q_\alpha(A, Z) = 2k\alpha\,(1 - 2a) = 0.65$ MeV, independently of parity of nucleus. This result agrees well with energy of α-decay of heavy and superheavy nuclei [3,4], and this allows to calculate the energy reduced on the line of beta-stability, Q^{*}_α. Dependence of Q^{*}_α on A, shown in the Fig. 1, determines the overall stability of superheavy nuclei.

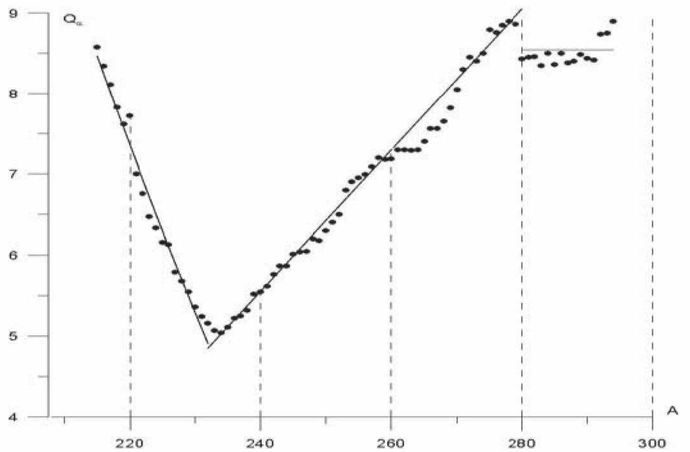

Fig.1 Stability of heavy nuclei to α-decay.

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BETA-STABILITY OF SUPERHEAVY NUCLEI

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As it follows from analyses of experiment [1,2], in the region limited by magic numbers the energy of isobaric transition changes as linear function of distance from β-stability line Z^* [1]. So for heavy nuclei ($Z > 82$, $N > 126$) the energy of beta decay (in MeV) is [2]

$$Q_{\beta\pm}(A, Z) = \pm\, 1.13\,(Z - Z^*) + D, \qquad (1)$$

D is the parity correction: $D = 0.75$ for odd(Z)-even(N) nuclei and $D = 2.1$ for even(Z)-even(N) nuclei. Then

$$Z^*(A) = 0.36A + 9.1. \qquad (2)$$

Note, that due to relation $Q_{\beta+}(A, Z) = -Q_{\beta-}(A, Z-1)$ and $Q_{\beta-}(A, Z) = -Q_{\beta+}(A, Z+1)$ it is suffice to consider only nuclei of Z even. The confrontation of results of calculation (according to equation (1) and (2)) with experiment is presented in the Fig .1. As it is seen, a sufficiently high accuracy is assured, the rms deviation is about 0.2 MeV (and maximal deviation 0.5 MeV) at inclusion of all experimental data of the Table of Isotopes [3].

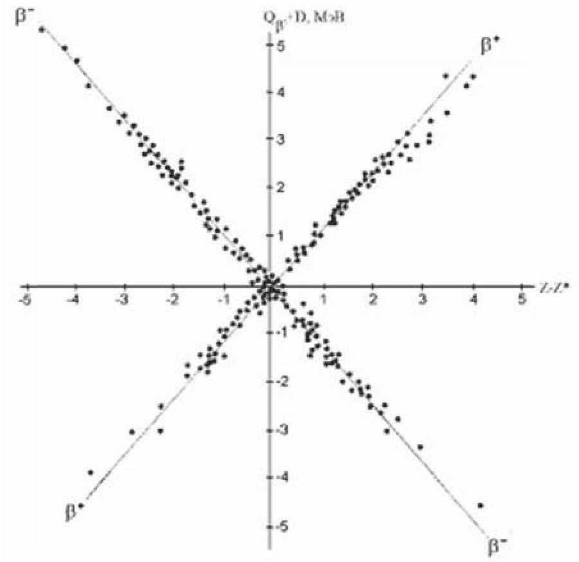

Fig.1. Dependence of Q_β on difference $Z - Z^*$.

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NUCLEAR SHELLS AND THE STRUCTURE OF THE ENERGY SURFACE OF HEAVY ELEMENTS

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We proceed from the idea issued from experiments [1] and shell model that it is possible to divide the nuclear binding energy surface into the regions inside of which the binding energy of both protons (B^p) and neutron (B^n) are presentable as a linear functions of number of protons (Z) and neutrons (N). Boundary lines between regions along Z or N are considered as (sub)magic numbers. The values of all parameters of energy surface and the (sub)magic numbers themselves were searched by means of solution of an inverse problem at requirement that these reproduce the experimental binding energy B^p and B^n for all heavy and superheavy nuclei compiled in [2] and in [3]. The final results for them are given in [1]. For convenience the results obtained for B^p and B^n are reduced on the line of beta-stability (see [1]). Now in the Fig. 1 the reduced energies B^n are presented: the lower curve refer to (even Z-even N) nuclei; the next line above- to odd-even nuclei; then follows line of odd-odd nuclei and the last - of even-odd ones; moreover the line denoted as C corresponds to the values averaged over all parities. As it is seen from Fig. 1, after magic number $N = 126$ (fall, -2.1 MeV), the most important subshells are $N = 152$ (–0.4 MeV), $N = 162$ (–0.2 MeV) and $N = 170$ (+0.2 MeV). For protons after shell $Z = 82$ (fall, –1.6 MeV) the most important subshells are $Z = 100$(–0.4 MeV) and $Z = 92$(–0.3 MeV), see [1].

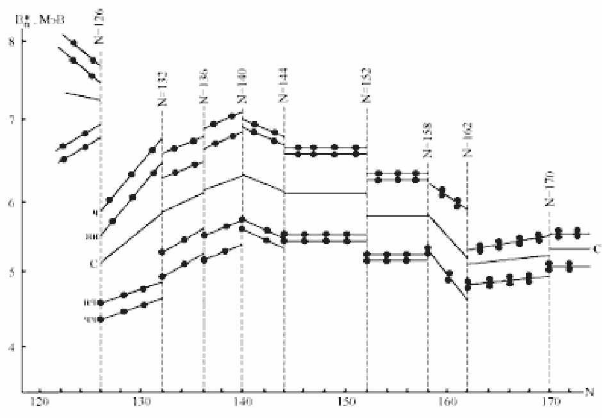

Fig. 1. Reduced binding energy of neutron. Neutron shell effects.

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CLUSTER MODEL OF FORMATION OF SUB-NUCLEAR AND SUB-ATOMIC OBJECTS

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This work describes the development results on asymptotic model [1] of the formation dynamics for the objects (clusters) of sub-nuclear (quark) and subatomic (nuclear) matters. The suggested formalism makes it possible to describe in an adequate way the final outcomes of the well-known catastrophic phenomena in the world of elementary particles. Mass parameters of different processes of approaching the equilibrium in nuclear reactions are calculated.

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ROTATING SKYRMIONS OF THE (2 + 1)-DIMENSIONAL SKYRME GAUGE MODEL WITH A CHERN–SIMONS TERM

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The (2 + 1)-dimensional Skyrme gauge model [1] with a Chern–Simons term [2] is considered. The presence of the Chern–Simons term makes possible the existence of two dimensional skyrmions in this model that carry magnetic flux and have electric charge and nonzero angular momentum [3]. It is shown that the model also admits the existence of two dimensional skyrmions with nonzero phase frequency of rotation. Due to the nontrivial topological properties of the model, the magnetic flux, electric charge, and the angular momentum of a two dimensional rotating skyrmion turn out to be related to each other. Analytic and numerical investigations of the properties of rotating two dimensional skyrmions are carried out.

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DOES THE «ISLAND OF STABILITY» EXISTS?

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In the work [1], basing on experimental data for nuclear mass in the region of mass number $5 \leq A \leq 257$, values of Francini-Radicati factor R were calculated. These calculations allowed to estimate the bounds of realization of Wigner's spin-isospin $SU(4)$-symmetry in atomic nuclei. On the basis of Wigner's mass formula for the factor R, developed the expression which depend on isospin and takes into account odd-even fluctuation of the mass and therefore describes distribution of nuclei into three groups of Wigner's kind. The analysis of calculated values of R factor using Student's t-criteria allowed to state that the violated Wigner's spin-isospin $SU(4)$-symmetry restored only for nuclei with odd A mass numbers, isospin $T_z \geq 53/2$ and the level of significance $\alpha < 0.01$. The obtained data justify that the Wigner's symmetry is not restored in real and artificial even-even nuclei and especially in odd-odd nuclei however general tendency of restoration also visible.

A number of experimental facts justify restoration of Wigner's spin-isospin $SU(4)$-symmetry in the region of super-heavy nuclei: 1) asymptotic convergence of Gamov-Teller Resonance and Analogue Resonance in the region of heavy nuclei [3, 4]; 2) decrease of experimental values of the energy of spin-orbit interaction for nuclei with number of neutrons $N > 146$ up to ~100 KeV [5]; 3) results of statistical analysis applying Student's t-criteria that evidencing about restoration of $SU(4)$-symmetry for the nuclei with odd A mass number and isospin $T_z \geq 53/2$ [1]; 4) visible tendency of restoration of Wigner's symmetry for nuclei with even A in line with the growth of isospin T_z [1]. Wigner's symmetry restored due to elimination of spin-orbit splitting. The hypothesis of the «stability island» is not justified because it assumed significant spin-orbit splitting in this region.

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THE SUPERSELECTION MODEL FOR THE ALGEBRA OF CANONICAL ANTICOMMUTATION RELATIONS IN THE FRAMEWORK OF C*-CROSSED PRODUCT

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The purpose of the present work is the study of properties of the algebra of canonical anticommutation relations (CAR) of finite fermi-systems in presence of the superselection rules. The general mathematical theory for it was developed by S. Doplicher and J. Roberts in the early 90s [1]. For it we suggest to construct the so-called crossed product of the CAR-algebra (algebra of observables), embedded in Cuntz algebra by the recursive fermion construction [2], with semigroup of its endomorphisms and receive more expanded algebra- the C*- field algebra of considering system. It will allow to define the compact group of the internal (gauge) symmetry of the system as group of automorphisms of this field algebra. The C*-category of the representations of this group defines superselection sectors and according to the Doplicher-Roberts duality [1], is dual object to the C*-category representations of the algebra of observables.

We also find irreducible representations of the embedded subalgebra, which from the physical point of view correspond to the superselection sectors, which are indexed by values of electric charge. Also it is shown that unitaries which intertwine different sectors correspond to field operators of the field algebra.

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PHOTON SPIN, WIDTH OF OSCILLATOR ENERGY LEVEL AND GIANT DIPOLE RESONANCE STRUCTURE

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In development of investigation microscopic mechanism of photoabsorbtion, it was gotten theoretic reasons supporting conception about needle-shaped construction of photon, [1,2], which A.F. Ioffe and N.I. Dobronravov found experimentally near hundred year ago.

Feynman path integral method it has been gotten wave function of oscillator, stepped up, with external periodic force.

In spite of this approach correspond to dipole excitation, result wave function has not define energy, and has not define square full axial moment of inertia.

In this case probability amplitude depends on strength photon electric field and length photon train.

Selection rules for energy may be get, if define excitation energy as square product of strength photon electric field and length photon train.

It may be getting selection rules for projection axial moment of inertia to direct photon motion, [3]. Selection rules for square full axial moment of inertia is not verified.

Result wave function may be useful for description photo-excitation of nucleus giant dipole resonance and its decay: photo-neutron, [4], and photo-proton, [5], reactions.

As result cross photon train define cross-section interaction.

It turns out that half-width of single-particle resonance near four time more than gamma-width decay.

Giant dipole resonance look like collection of Z single-particle resonance with width near 50eV. It integral cross-section reasonably go with sum rule.

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SPIN OBSERVABLES IN PD-SCATTERING AND TEST OF *T*-INVARIANCE

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A novel test of time-reversal invariance in proton-deuteron scattering is planned as an internal target transmission experiment at COSY [1]. The *P*-even *T*-odd observable is the polarization correlation $A_{y,xz}$ in scattering of polarized proton beam (polarization P_y) off polarized deuterium target (tensor polarization P_{xz}). This observable provides a real null test of time-reversal invariance for *P*-parity conserving processes [2]. In order to clarify role of the background conditions of this experiment, it is necessary to know the magnitude of several *T*-even *P*-even spin-observables in pd-scattering at energy about 100-200 MeV that is the region of the planned experiment. In the present work, we apply the Glauber-Sitenko theory of multiple scattering for calculation of the differential spin observables of elastic pd-scattering and the total pd-cross sections for polarized proton and deuteron. Actually, we use the formalism of Ref. [3] and develop it for inclusion of Coulomb effects and *T*-odd p*N*-amplitudes. Furthermore, we properly modify the formalism of Ref. [3] to provide a comparison with existing experimental data [4,5]. The results of our calculations for unpolarized differential cross section, vector A_y and tensor A_{ij} analyzing powers, spin correlation parameters C_{ij}, $C_{ij,k}$ and spin-transfer coefficients $K_j^{i'}$ in forward hemisphere are found in reasonable agreement with the data [4,5] obtained at 135 MeV and 250 MeV. We show that Coulomb effects improve agreement with the data at those energies at small angles. The total hadronic polarized cross sections σ_1, σ_2, σ_3 (as defined in Ref. [6]) are calculated using the generalized optical theorem. The energy dependence of the *T*-odd total cross section $A_{y,xz}$ is obtained within the double scattering mechanism for the forward pd elastic scattering amplitude. The obtained result for σ_1 put a strong restriction on the magnitude of the false vector polarization of the deuterium target ($<10^{-6}$). This restriction is caused by the requirement to reach a planned accuracy of 10^{-6} of the $A_{y,xz}$ measurement in the experiment [1].

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ON LONGITUDINALLY POLARIZED ELECTRON SCATTERING OFF POLARIZED PROTON TARGET

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In the previous work [1] we have derived general expressions for the differential cross section of elastic scattering of longitudinally polarized $(\zeta = \pm 1)$ electron off the polarized $(\vec{s})$ proton target. Right-left asymmetry $A_{RL}(\vec{s};E,q^2)$ was studied in the next cases of the proton spin orientation with respect to incident electron moment: $\vec{s} \parallel \vec{k}$ and $\vec{s} \perp \vec{k}$.

Here we study another type of scattering asymmetry, namely, target proton spin asymmetries: parallel $A_p^{\parallel}(\zeta;E,q^2)$ and orthogonal $A_p^{\perp}(\zeta;E,q^2)$, in dependence of incident electron helicity ζ.These asymmetries in the case of unpolarized electron scattering were investigated in [2].

$$A_p^{\parallel}(\zeta;E,q^2) = \frac{b_{ep}(E,q^2) + c_{ep}(E,q^2)\cos(\theta) + \zeta\left(b_{ep}^h(E,q^2) + c_{ep}^h(E,q^2)\cos(\theta)\right)}{a_{ep}(E,q^2) + \zeta a_{ep}^h(E,q^2)},$$

$$A_p^{\perp}(\zeta;E,q^2) = \sin(\theta)\frac{d_{ep}(E,\tau) + \zeta d_{ep}^h(E,\tau)}{a_{ep}(E,q^2) + \zeta a_{ep}^h(E,q^2)},$$

with θ being a polar angle of the scattered electron.

These formulas include various correlation functions, defined in [1]. Parity violating single spin correlation functions $a_{ep}^h(E,q^2)$, $b_{ep}(E,q^2)$ and $c_{ep}(E,q^2)$ in the absence of weak interactions can arise only due to anapole G_{1p} form factor of the proton. For the time reversal violating orthogonal asymmetry is responsible electric dipole G_{2p} form factor of the proton thru triple vector correlation functions $d_{ep}(E,q^2)$ and $d_{ep}^h(E,q^2)$.

We show, that comparative study of the right-left asymmetry $A_{RL}(\vec{s};E,q^2)$ and target proton spin asymmetries $A_p^{\parallel}(\zeta;E,q^2)$, $A_p^{\perp}(\zeta;E,q^2)$ of the angular distribution of the scattered electrons can provide further information about anapole and electric dipole proton form factors, as well as of possible deviations from the Standard Model (SM) of electroweak interactions.

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CONTRIBUTION OF HIGHER MULTIPLICITY COLLISIONS IN ELASTIC p^{6}He, p^{8,9}Li SCATTERING IN THE FRAMEWORK OF THE DIFFRACTION THEORY

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With the formation of radioactive beams the structure of unstable isotopes has been extensively studied experimentally in inverse kinematics. The isotopes of helium and lithium are unique and very interesting example for accurate microscopic theoretical studies. The easiest doubly-magic nucleus ^{4}He is the core of heavier isotope ^{6}He, the last two neutrons of which form a halo, related to the famous ^{11}Li; ^{8}Li and ^{9}Li are supposed to have one- and two-neutron skin.

Representing the Glauber operator of multiple scattering on nucleons in the alternative form of scattering series on clusters (and nucleons), we have calculated the contribution of single-, double- and triple- collisions at the energies E = 70, 700 and 1000 MeV/nucleon to the differential cross section of protons scattering on ^{6}He, ^{8}Li and ^{9}Li nuclei. The three-particle wave functions of nuclei in α–n–n- (for ^{6}He) [1], α–t–n- (for ^{8}Li) [2] and α–t–2n- (for ^{9}Li) [3] models were used in calculation. It is shown that the differential cross section of single scattering dominates in the area of small angles, where the contribution of two- and triple collisions is less by the order and two orders of magnitude. After the first interference minimum the contribution of double scattering becomes dominant, after the second minimum triple scattering begins to dominate.

The interference minima are partially filled by the contribution of higher order collisions. The calculation in single-scattering approximation (in so-called optical limit) overestimates data at small momentum transfers and quickly drops at larger ones. Contributions of higher order collisions reduce the cross section at small momentum transfers and make contributions at larger ones that lead to a better description of experimental data.

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EXCITED STATE OF ^{15}C $J^{\pi} = 5/2^{+}$ NUCLEUS AND INELASTIC SCATTERING OF PROTONS

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The inelastic scattering amplitude (to the level $J^{\pi} = 5/2^{+}$) of protons on neutron-excess ^{15}C nucleus in the inverse kinematics was calculated within the framework of the Glauber diffraction theory. The terms of the first and second order were took into account in the operator of multiple scattering. We used the wave function (WF) of ^{15}C in a many-particles shell model [1]. The ground state of ^{15}C $\left(J^{\pi}, T = 1/2^{+}, 3/2\right)$ is 98% determined by the WF *s*-component, the first excited state $\left(J^{\pi}, T = 5/2^{+}, 3/2\right)$ is determined more than 90% by *d*-component. The main difference between the WFs of ground and the first excited states of ^{15}C nucleus is the location of the last neutron: when it fills the $2s_{1/2}$-orbital, the mean square radius of the last neutron and the total neutron density increases sharply compared with the case when the last neutron fills the $1d_{5/2}$-orbital (R_h = 3.845 fm for $1d_{5/2}$, R_h = 5.666 fm for $2s_{1/2}$ [2]). The reason is that the WF has one additional node at the $2s_{1/2}$-orbital that defines great extension of WF on the coordinate compared to the $1d_{5/2}$-orbital.

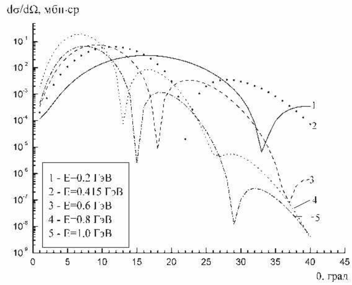

Figure. Differential cross-sections of inelastic $p^{15}C$-scattering at various energies.

The figure shows the DCS at the energies from 0.2 to 1.0 GeV/nucleon. At zero angle the scattering DCS tends to zero due to orthogonality of initial and final states WFs. With increasing of collision energy the diffraction peak narrows and there is more expressed diffraction pattern: if there are two minima at $\theta \sim 0°$ and 33° for E = 0.2 GeV/nucleon, then with increasing energy the minima are shifted to smaller scattering angles and their number increases.

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PHASE TRAJECTORIES OF THE NUCLEAR SYSTEM IN THE PROTON INDUCED MULTIFRAGMENTATION PHENOMENA. MECHANICAL BREAKDOWN

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There are well established statistical/dynamical nuclear MF models but a number of questions still remains unsolved [1]. It is necessary to have the overall picture of the phenomenon for better understanding the nature of the physical processes ongoing in the system. The aim of the work is to proceed with the general macroscopic picture of the proton-induced nuclear multifragmentation rather than its microscopic description or precise quantitative calculations. Based on the thermodynamic analysis of the proton-induced multifragmentation phenomena the most appropriate decay channel is chosen. Macroscopic analysis of the suggested decay channel is done in order to check the possibility of the mechanical breakdown of the heated system. In order to do this the simple "classical mechanical" model corresponding to isochoric heating at the start with the adiabatic expansion to follow is introduced. Namely it is the breakdown of the spherical system with high pressure in the inner part and the outer shell in the ground state, possibly with a wake left behind the projectile in the first stage of the process. In this work we try to use as simple model (corresponding to the appropriate phase trajectory of the nuclear system) that represents the single-phase process in the small inner part of the system as possible allowing straight forward thermodynamic analysis in order to have the clear macroscopic picture of the phenomenon. Based on a simple thermodynamic model preliminary quantitative calculations of corresponding macroscopic parameters (energy, pressure) are done and therefore the model verification on macroscopic level is held. It is shown that on macroscopic level the mechanical breakdown of the thermodynamic system in a single-phase [2] process that may be followed by metastable boiling is a good and quite adequate candidate for explaining the proton-induced multifragmentation phenomena.

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BIREFRINGENCE OF DEUTERONS IN AN UNPOLARIZED TARGET: THEORY AND EXPERIMENT

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The interaction of light and anisotropic matter depends on the polarization of light. For example, the birefringence effect can be observed when light is transmitted through a plate of Iceland spar because two unequal refractive indices correspond to the components of light with polarizations parallel and orthogonal to the crystal plane. The interaction of light and optically anisotropic matter is also accompanied by the dichroism effect: differential absorption of light rays having different polarizations. As a result of the development of the wave-particle duality concept, many notions and phenomena from optics were expanded to particle physics.

In this regard, the quasi-optical birefringence effect of particles with spin $S \geq 1$, which was predicted in [1], is of particular interest. For particles with the rest mass $m \neq 0$, the birefringence effect occurs even in a uniform, isotropic medium because of the inherent anisotropy of particles with spin $S \geq 1$ (as contrasted to those with spin 0 и 1/2). The feature of quasi-optical birefringence effect is the presence such dichroism type in which a transmitted unpolarized particle beam acquires tensor polarization [1, 2], along with that in which particle polarization is converted from vector to tensor and vice versa.

First experiments on birefringence of deuterons involved measuring their spin dichroism effect. The experiments, carried out by the international Collaboration at the accelerator of the University of Cologne (Germany), used an unpolarized deuteron beam of energy 5—20 MeV and carbon targets of thickness up to 188 mg/cm^2. Tensor polarization of the deuteron beam transmitted through the target has a magnitude from +0.02 to –0.1, depending on the energy and the target thickness [3]. These experiments discovered the spin dichroism effect as well as revealed the sign reversal of the effect with varying beam energy. It was found out that the sign reversal of spin results from the Coulomb-nuclear interference of deuteron-carbon interaction [4].

Further spin dichroism experiments were performed at the Nuclotron in JINR (Russia) using a 5 GeV/s deuteron beam and carbon targets of thickness 140 g/cm^2. The magnitude of tensor polarization was 0.3 [5], and its experimentally determined sign coincided with theoretical prediction. We report a theoretical study of the deuteron birefringence effect for energies from 5 to 20 MeV and the experiments on spin dichroism measurements for high and low energies.

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THE ANALYSIS OF (t, p) REACTIONS ON ^{16}O NUCLEUS

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The (t, p) reaction on ^{16}O nucleus with excitation of the low levels of formed nucleus ^{18}O was studied in [1] experimentally in details. It was shown that within the assumption of dineutron transfer as whole it is impossible to get the complex adequate description of the experimental angular distributions in the frame of DWBA by means of a variation of optical potentials parameters and introduction of normalizing coefficients.

The (t, p) reaction on light nuclei leads to formation of a neutron-rich nuclei. The nucleus ^{16}O is the second after ^{4}He doubly magic nucleus. It is necessary to expect that as well as in case of a nucleus ^{6}He, excess neutrons may have two spatial configurations differing in the position of the neutrons with respect to the core - a two-neutron configuration, and a cigar-like configuration [2]. To each of configurations there corresponds the formation mechanism: the dineutron configuration will be formed by one-step reaction mechanism (fig. 1*a*), and cigar-shaped by two-step reaction mechanisms of sequential neutrons transfer (fig. 1*b*).

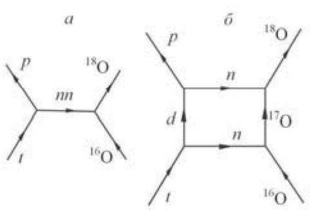

Fig. 1. Diagrams illustrating the mechanisms of transfer dineutron cluster in ^{16}O (t, p)^{18}O reaction: a- stripping dineutron, b- independent neutron transfer.

We carried out the analysis of angular dependences of ^{16}O(t, p)^{18}O reaction cross sections taking into account one - and two-step mechanisms [2]. Results show that the coherent sum of both mechanisms of excess neutrons transfer allows to describe the reaction cross section without introduction of additional normalizations.

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THE RESONATING GROUP MODEL DESCRIPTION OF THE RADIATIVE CAPTURE REACTION $^3He(\alpha,\gamma)^7Be$

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The radiative capture reaction $^3He(\alpha,\gamma)^7Be$ plays an important role in the stellar kinetics and significantly contributes to ^7Li production in the Big Bang nucleosynthesis. Abundance of this isotope, in turn, is an important indicator of barion-photon ratio in the Universe. Capability of various experiments to measure the cross sections, *S*-factors, and branching ratios of population of ^7Be levels at astrophysical energies is limited because of the smallness of the cross sections. Therefore, calculations of these values are one of the hottest points of theoretical nuclear astrophysics.

A microscopic approach to the discussed problem using the algebraic version of the resonating group model (AVRGM) [1, 2] is built. The modified Hasegawa-Nagata *NN*-potential [3] is involved in the calculation. Two adjustable parameters – the oscillator radius r_0 and the intensity of central Majorana forces g_c were tuned to reproduce the energies of ^4He, ^3He, and ^7Be (in the ground and first excited states) nuclei [4, 5] together with the experimental data for the *S*-factor [6–8]. As these results as the ones concerning reaction $^3H(\alpha,\gamma)^7Li$ obtained by us earlier [9] demonstrate a good agreement with the experimental data and confirm a capability of the AVRGM to be used to account the properties of astrophysical fusion reactions.

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THEORETICAL DESCRIPTION OF SCATTERING IN 3*N* SYSTEM WITH ACCOUNT OF DIBARYON CHANNELS AND 3*N* FORCES

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Faddeev equations (FE) describe excellently the scattering processes in 3*N* systems at low energies. However, at higher energies the standard FE technique faces a number of problems. For example, the results of rigorous Faddeev calculations for *N*d scattering begin to deviate substantially from experimental data already at $E_{\text{lab}} \approx 150$ MeV. Although the inclusion of three-body forces is obviously necessary at such energies, the account of conventional 3*N* forces (emerging from the intermediate Δ-isobar production via two-pion exchange) does not help remove the observed discrepancies.

On the other hand, at higher energies we deal with the shorter *NN* distances where quark degrees of freedom (d.o.f.) should be manifest. In the dibaryon model proposed by the Moscow–Tuebingen group quark d.o.f. are taken into account through the formation of an intermediate 6*q* bag dressed by a strong scalar field. In contrast to the conventional meson-exchange potentials, which describe the *NN* scattering up to 350 MeV lab energy only, in the dibaryon model the empirical *NN* phase shifts were fitted in the energy interval 0-1000 MeV. Furthermore, the above mechanism of the short-range *NN* interaction leads to the emergence of new types of three-body forces. The ground states of ^{3}H and ^{3}He nuclei were described in this model very well [1], but the 3*N* scattering problem was not rigorously considered in the dibaryon model before (the only qualitative results for pd elastic scattering were presented in [2]).

We modified the standard FE for 3*N* system by incorporating the "internal" (dibaryon) channels and also by taking into account the new three-body forces which emerge from the dibaryon mechanism. The resulted equations may be written and solved in a multichannel formulation or, alternatively, in the 3*N* channel only, after exclusion of the dibaryon d.o.f. In the latter case we have the standard FE which however contain the non-conventional energy-dependent effective interactions. The first iterations of the modified equations give the leading mechanisms (with proper relative phases) for 3*N*-scattering processes at higher energies (~ 1 GeV). Some examples of such mechanisms for *N*d scattering will be given in the talk.

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^{8}B + ^{58}Ni INTERACTION AT LOW ENERGIES

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Many experimental and theoretical efforts have been devoted in recent years to study the properties and interactions of exotic proton-halo nucleus ^{8}B [1–3]. Some evidences have been presented showing that for the proton-halo ^{8}B projectiles on a ^{58}Ni target at several energies near the Coulomb barrier, the resulting excitation function shows a striking enhancement associated with the exotic structure of ^{8}B with respect to that for normal projectiles. Some evidence was also presented that the sum of the fusion and breakup yields saturates the total reaction cross section.

In this presentation, we report the results of the ^{8}B+^{58}Ni system analysis with the method of continuum-discretized coupled channels (CDCC) in the energy interval 18 – 28.4 MeV in laboratory system, which is below and above the Coulomb barrier ($V_{c.m.}$ = 20.8 MeV). We carried out the CDCC calculations of the breakup, fusion, and elastic scattering of ^{8}B on ^{58}Ni, and compared the results with the differential cross sections and the excitation functions measured in Refs. [1, 2].

In our analysis, we studied the coupling between breakup, fusion and elastic scattering and the influence of the ^{7}Be core – target optical potential (OP) and p-target OP on the breakup and fusion cross sections. For this aim, the data on the elastic scattering for the ^{7}Be + ^{58}Ni and ^{8}B + ^{58}Ni systems, breakup, and the fusion and reaction cross sections [1, 2] were analyzed. The energy dependence of OPs was controlled by comparison of the energy dependences of the real and imaginary volume integrals. Finally, we have reproduced the experimental fusion and total reaction cross sections and have predicted their behavior at low incident energies.

A theoretical analysis within the CDCC model was made for breakup of ^{8}B using more extended model space as that in [3]: inelastic excitations in the ^{7}Be-proton system from the ground state to excited states with orbital angular momenta L = 0–5 and energies up to 8 MeV in the continuum were taken into account. We found a considerable coupling between breakup, fusion and elastic scattering and were able to adjust completely the experimental breakup, fusion, and total reaction cross sections in the mentioned earlier energy interval, simultaneously with the ^{8}B–^{58}Ni elastic scattering differential cross sections.

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THE FEATURES OF THE NON-EQUILIBRIUM EQUATION OF STATE IN HEAVY-ION COLLISIONS AT INTERMEDIATE ENERGIES

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In the development of the approach in [1] for the description of heavy–ion collisions, we proposed to use the method of moments for solving the kinetic equation, which gives, for the first moments with weights $1, \vec{p}, p^2$, equations of the hydrodynamic type, allowing us to find the distribution function of the nucleons, $f(\vec{r}, \vec{p}, t)$ (where $\vec{r}$ is the spatial coordinate , $\vec{p}$ is the momentum , and t is the time). At the same time, we used a non–equilibrium equation of state to describe the hydrodynamic evolution of a system of the «hot spot» type, according to which $f(\vec{r}, \vec{p}, t)$ is associated with an equilibrium component, $f_0(\vec{r}, \vec{p}, t)$, and a non–equilibrium component $f_1(\vec{r}, \vec{p}, t)$:

$$f(\vec{r}, \vec{p}, t) = f_1 \cdot q + f_0 \cdot (1-q),$$

where q is the relaxation factor. Here, $f_1(\vec{r}, \vec{p}, t)$ is given in the form of a Fermi–ellipsoid in the momentum space, which is a convenient parameterization of the excitations in the Fermi–liquid theory, and $f_0(\vec{r}, \vec{p}, t)$ is given as the equilibrium Fermi–sphere. In this approach, the account of the non–equilibrium component has led to a successful description of the heavy–ion collision dynamics, in particular to the description of the energy spectra of protons emitted at various angles [1–4].

In the present paper we develop a method for the calculation of the factor q by taking the moment from a kinetic equation with weight $p_x^2 - (p_y^2 + p_z^2)/2$ that determines the degree of anisotropy of the distribution function, $f(\vec{r}, \vec{p}, t)$. We found that $q = 1$ on the shock wave during the compression stage in the energy range ~10–100 MeV/nucleon and that q decreases with increasing energy, which results in an increase of the isotropy of the function $f(\vec{r}, \vec{p}, t)$ at higher intermediate energies, in accordance with experimental data on the proton spectra.

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NUCLEAR GLUON DISTRIBUTION AT SMALL *X* FROM PHOTOPRODUCTION OF J/ψ IN ION ULTRAPERIPHERAL COLLISIONS AT THE LHC

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Distributions of quarks and gluons in nuclei describe the structure of nuclei in Quantum Chromodynamics (QCD) and play an essential role in phenomenology of hard processes with nuclei measured at Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC). At high energies, nuclear parton distribution functions (PDFs) are suppressed by nuclear shadowing compared to those of the free proton, but the suppression magnitude is presently poorly constrained by the data, especially for the gluon distribution.

Ion ultraperipheral collisions (UPCs) at the LHC offer a unique possibility to study photon-nucleus and photon-proton collisions at unprecedentedly high energies [1]. The recent LHC data on coherent photoproduction of J/ψ in Pb-Pb UPCs [2,3] is analyzed and the nuclear suppression factors $S(W=92\ \text{GeV})=0.61$ and $S(W=20\ \text{GeV})=0.74$ are extracted [4]. (Here W is the photon-nucleon invariant center-of-mass energy.) It is shown [4,5] that in the framework of perturbative QCD, S is equal to the gluon shadowing factor and can be described well by the theoretical approaches predicting significant nuclear gluon shadowing at $x=0.001$ and $x=0.02$ ($x=M_{J/\psi}^2/W^2$).

In symmetric UPCs, both nuclei can serve as a source of photons and as a target, which leads to theoretical ambiguity and limitations in the probed small x. This difficulty can be overcame by considering UPCs accompanied by electromagnetic excitation of one or both nuclei with the subsequent forward neutron emission [6]. It is shown [7] that this method allows one to probe the nuclear gluon distribution down to $x=10^{-4}$.

Incoherent J/ψ photoproduction in Pb-Pb UPCs was also measured at the LHC [2]. The cross section of this process is calculated in the framework of the leading twist theory of nuclear shadowing and compared to the data [7].

The rapidity and momentum transfer distributions of coherent J/ψ photoproduction in proton-Pb UPCs is calculated [8]. It is shown that after a cut excluding small momentum transfers, this process gives a possibility to study the proton gluon distribution down to $x=10^{-5}$.

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NEW APPROACH TO FOLDING WITH THE COULOMB WAVE FUNCTION

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A promising way to account for the Coulomb interaction in integral equations of the quantum few-body problem is the transition from the free Green function to the Coulomb one. To this end one should fold kernels of the integral equations with the Coulomb wave functions [1, 2]. This is a rather intricate and time consuming computing problem.

In the present work a new approach to folding a function with the Coulomb wave is proposed. The method is based on expanding the partial-wave Coulomb scattering function in the configuration space in a series of spherical Bessel functions. This allows one to significantly simplify the calculations. To test the method, a simple trial function is chosen for which the folding with the Coulomb scattering wave function can be calculated analytically. Such a choice allows us to estimate the accuracy of the expansion used. Specifically, we choose a partial-wave component of the simple pole propagator proportional to the Legendre function of the second kind Q_l, with l being the orbital angular momentum. In the following table the relative difference between the exact value of the folding and the value obtained by replacing the Coulomb partial wave function by a finite number of terms of the series is presented for different values of l and the Coulomb parameter η.

l	η	Number of terms									
		1	2	3	4	5	6	7	8	9	10
0	0.231	$5\cdot10^{-2}$	$2\cdot10^{-3}$	$2\cdot10^{-4}$	$1\cdot10^{-5}$	$6\cdot10^{-7}$	$2\cdot10^{-7}$	$2\cdot10^{-8}$	$3\cdot10^{-9}$	$6\cdot10^{-11}$	$2\cdot10^{-12}$
1	0.231	$5\cdot10^{-2}$	$2\cdot10^{-3}$	$3\cdot10^{-4}$	$2\cdot10^{-5}$	$1\cdot10^{-6}$	$5\cdot10^{-9}$	$2\cdot10^{-8}$	$4\cdot10^{-9}$	$3\cdot10^{-10}$	$5\cdot10^{-11}$
2	0.231	$5\cdot10^{-2}$	$2\cdot10^{-3}$	$4\cdot10^{-4}$	$3\cdot10^{-5}$	$3\cdot10^{-6}$	$2\cdot10^{-7}$	$2\cdot10^{-9}$	$2\cdot10^{-9}$	$4\cdot10^{-10}$	$8\cdot10^{-11}$
0	2.31	$5\cdot10^{-1}$	$1\cdot10^{-1}$	$2\cdot10^{-2}$	$2\cdot10^{-3}$	$4\cdot10^{-4}$	$1\cdot10^{-4}$	$7\cdot10^{-6}$	$6\cdot10^{-7}$	$1\cdot10^{-7}$	$1\cdot10^{-9}$

The values 0.231 and 2.31 chosen for η correspond to the proton-deuteron scattering at the center-of-mass energy of 300 keV and 3 keV, respectively. One can see that for $\eta = 0.231$ the two first terms of the series result in the accuracy within 0.002. For $\eta = 2.31$ the convergence is slower, however, even for this rather large value of the Coulomb parameter it is sufficient to take into account the first four terms in order to obtain the accuracy within 0.002. The obtained results allow us to conclude that the proposed method is promising in solving the integral equations for quantum systems of few charged particles.

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ANALYTIC REPRESENTATION OF THE AMPLITUDE OF MULTI-PARTICLE COULOMB BREAKUP

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In calculations of amplitudes of reactions with the yield of several charged particles in order to take into account Coulomb effects in the exterior one have to integrate numerically over the large but bound range of space. Therefore for the evaluations of such effects it is desirable to obtain analytical formulas. In the present work a general approach is developed for finding analytic approximations for amplitudes of direct Coulomb breakup of the light multi-cluster nucleus into three, four, and more charge particles in the Coulomb field of a heavy target nucleus. Effects of the excitation of target nucleus are neglected. Consecutive fragmentation of a projectile nucleus can be competing processes. Coulomb contribution of such reactions may be defined using the relevant amplitudes whose analytical form also was found by the author [1].

In this paper neglecting the interaction between light reaction's products and using zero-range model for the function of the bound state of the projectile we first lead the Coulomb breakup amplitude to the single spatial integral which contains the product of four wave functions of particles in the coulomb field of target nucleus. Then this integral is transformed into the triple contour integral. After that we by analogy write the four-fold contour integral, which corresponds to breakup into four charged particles. Further, using unlike to work [1] barely one infinitesimal linear-fractional transformation, we lead this integral to six-fold sum containing products of four Gauss hypergeometric functions with certain coefficients, from reducing of which (resetting to zero five earlier added parameters) we obtain the expression for the case of breakup into three particles. The last is represented in the form of the four-fold sum of the products of three Gauss hypergeometric functions which resemble in structure to those from the work [1].

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SELF-CONSISTENT DESCRIPTION OF PARTICLE -BOUND SYSTEM'S SCATTERING BY UNITARITY'S CONSERVING

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Recently a new method of self-consistent solution of the Schrödinger equation with a complex potential for quantum scattering problem has been proposed in the paper[1]. This report includes the method of Schrodinger equation's solution

$$[-\frac{\hbar}{2M}\Delta_{\vec{R}}+V(\vec{R},\vec{r})]e^{if(\vec{R},\vec{r})}\Phi_0(\vec{r})=(E-E_0)e^{if(\vec{R},\vec{r})}\Phi_0(\vec{r}) \qquad (1)$$

in the spirit of [1] for the scattering of a particle with mass m_1 on the two-particle system (m_2,m_3) with its own ground state function $\Phi_0(\vec{r})$ of the two-particle system with energy E_0. Reality of the function $f(\vec{R},\vec{r})$ ensures the conserving of it's unitary norm. In equation (1) there are complex potential $V(\vec{R},\vec{r})=v(\vec{R},\vec{r})+iu(\vec{R},\vec{r})$, where

$$v(\vec{R},\vec{r})=\mathrm{Re}V_{12}(\vec{R}-\frac{\mu}{m_2}\vec{r})+\mathrm{Re}V_{13}(\vec{R}+\frac{\mu}{m_3}\vec{r})+\frac{\hbar}{2\mu}[\vec{\nabla}_{\vec{r}}f(\vec{R},\vec{r})]^2,$$

$$u(\vec{R},\vec{r})=\mathrm{Im}V_{12}(\vec{R},\vec{r})+\mathrm{Im}V_{13}(\vec{R},\vec{r})-\frac{\hbar}{\mu}\vec{\nabla}_{\vec{r}}f(\vec{R},\vec{r})\cdot\vec{\nabla}_{\vec{r}}\ln\Phi_0(\vec{r})-\frac{\hbar}{2\mu}\Delta_{\vec{r}}f(\vec{R},\vec{r}),$$

$\vec{r}$ and $\vec{R}$ are Jacobi coordinates of particles relative motion in the pair (1, 2) and the motion of the particle 1 relative to the center of mass (2,3) correspondingly. μ and M are reduced masses. In the asymptotic case $\left(|\vec{R}|>>|\vec{r}|\right)$, we can write for the function $f(\vec{R},\vec{r})$ the Maclaurin series, for example, up to and including the second derivatives with respect to the coordinates of $\vec{r}(x,y,z)$

$$f(\vec{R},\vec{r})=f_0(\vec{R})+C(\vec{R})(x+y+z)+\frac{1}{2!}[B(\vec{R})(x^2+y^2+z^2)+2\tilde{B}(\vec{R})(xz+xy+yz)]....(2)$$

Expanding potential also in powers of these coordinates and equating in equation (1) the coefficients of the same powers of coordinates, we obtain a system of equations, from which we find $f(\vec{R})=\vec{Q}\vec{R}$, where $|\vec{Q}|^2=(E-E_0)$, $C(\vec{R})=\sqrt{-2\mu v(\vec{R},0)/3\hbar}$. The functions $B(\vec{R})$ and $\tilde{B}(\vec{R})$ are defined by $C(\vec{R})$ and also the coefficients of expansion potential. Reality of function $C(\vec{R})$ determines the sign of the potential $v(\vec{R},0)<0$.

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THE QUANTUM DESCRIPTION OF THE COUPLING WITH NEUTRON REARRANGEMENT CHANNELS IN FUSION REACTIONS IN THE VICINITY OF COULOMB BARRIER

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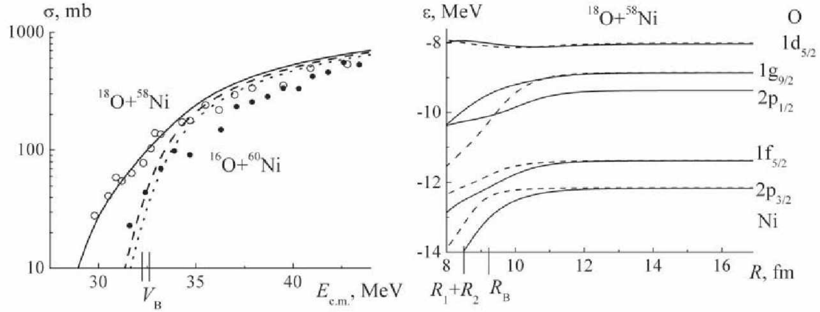
The quantum description of the coupling with neutron rearrangement channels in fusion reactions based on the expansion in series on two-centre wave functions was devised. Valence neutrons channels coupled equations were proposed in Ref. [1]. These equations were solved for reactions $^{18}O+^{58}Ni$, $^{40}Ca+^{96}Zr$, $^{32}S+^{96}Zr$ and some others. The enhancement of the fusion cross section for the reaction $^{18}O+^{58}Ni$ in comparison with reaction $^{16}O+^{60}Ni$ [2] (Fig. 1a) is explained by the neutron transitions to low-lied two-centered levels (Fig. 1b) near Coulomb barrier at central collisions. A comparison of the experimental data [2] with the calculation results demonstrates satisfactory agreement between them at energies near the Coulomb barrier (Fig. 1a).



a *b*

Fig. 1. (a)The experimental fusion cross section [2] of reactions $^{18}O+^{58}Ni$ (circles), $^{16}O+^{60}Ni$ (points) and calculation results: for $^{18}O+^{58}Ni$ with the neutron rearrangement $1d_{5/2}(O)\rightarrow 1g_{9/2}$, $2p_{1/2}$, $1f_{5/2}$, $2p_{3/2}$ of Ni channels coupling (the solid curve) and without this coupling (the dashed curve), for $^{16}O+^{60}Ni$ (the dotted curve), V_B is Coulomb barrier for spherical nuclei.
(b) Energies of two-centre states of the valence neutrons with angular momentum projections onto the inter-nuclear axis $\Omega = 1/2$ (full curves) and $\Omega = 3/2$ (dashed curves) in the $^{18}O + ^{58}Ni$ system versus the nucleus–nucleus distance R; R_B is the radius of barrier, R_1 and R_2 are radii of nuclei. The notation for states in the separated nuclei is indicated.

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THE DESCRIPTION OF CHARACTERISTICS OF TWO-PROTONS DECAY OF Fe-45 IN THE THEORY OF TWO-STEPS TWO-PROTON DECAY

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In the framework of the theory of two-steps two-proton decays of nuclei [1] taking into account only the virtual one-proton transitions of parent nuclei the total width of the two-proton decay of Fe-45 and the angular and energy distributions of the two emitted protons have been calculated. One-proton decay widths of the parent (Fe-45) and intermediate (Mn-44) nuclei have been found by use of the many-particle theory of one-proton decays of spherical nuclei [2] with taking into account the proton shell model potentials [2] and the Cooper pairing of protons by methods [3].

It is shown that the basic role in the formation of the total experimental width and experimental energy distribution of emitted protons for the two-proton decay of Fe-45 are played the shell model states $2s_{1/2}$ and $2p_{1/2}$, $2p_{3/2}$ of protons, but the contributions of proton states $1f_{7/2}$ and $1f_{5/2}$ can be neglected.

It is demonstrated that the experimental angular distribution of the emitted protons can be described with taking into account the interference of amplitudes of angular distributions of two-protons emitted from $2s_{1/2}$ and $2p_{1/2}$, $2p_{3/2}$ shell model states.

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THE ROLE OF WRIGGLING–VIBRATIONS OF FISSILE NUCLEI FOR THE FORMATION OF ANGULAR AND SPIN DISTRIBUTIONS OF NEUTRONS AND GAMMA-QUANTA EVAPORATED BY FISSION FRAGMENTS

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Spin matrix of density $\rho^{J'J}_{M'M}$ formed in the reaction of fission of oriented target nucleus by cold polarized neutrons compound nucleus, depending on the two possible values $J, J' = I \pm 1/2$ of its spin, can be presented by spin - tensor of the compound nucleus τ_{Qq} that is defined by the orientation parameters of the target nucleus and the incident neutron. Therefore, the order of orientation Q for τ_{Qq} can take both as even values, corresponding alignment, so and odd values, corresponding to the polarization of the compound nucleus.

Using the matrix $\rho^{J'J}_{M'M}$ and the methods of [1] the coefficients of a wide range of P - even , T - even, P - even T - odd, P - odd, T - even and P - odd, T - odd asymmetries in the angular distributions of binary fission fragments and prescission light particles (neutrons, gamma – quanta, light nuclei) for ternary and quaternary fission by cold polarized neutrons.

It has been demonstrated that the significant role in the formation of similar asymmetries in the angular distributions of evaporated from fission fragments gamma - quanta and neutrons plays wriggling - vibrations of the compound fissioning nucleus in the vicinity of its scission point, leading to the appearance of large values of fission fragment spins and spin- tensors of these fragments with even values of the order orientation corresponding alignment of these fragments.

At the same time, the lack of the polarization of fission fragments associated with odd values of orientation order for these fragments leads to the fact that the polarization of evaporated neutrons and circular and linear polarization of evaporation gamma - quanta can only occur due to the transfer fission fragments odd values of orientation order from the total spin matrix density of the compound fissioning nucleus, as noted in to [2].

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CLUSTERING MECHANISM IN FISSION AND CCT CHANNEL FORMATION

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In the microscopic description of complex nuclear fission process allowing the arbitrary shapes on the way to fission is very important**.** The ten-dimensional deformation space used in [1] is large enough to display the influence of the strong magic shells on the potential energy surface (PES). The non-restricted axial shape parameterization described in [2,3] gives us a unique possibility to look for exotic local minima on the potential energy landscape corresponding to the different clusters formation. General theoretic approach to the study of the both: binary partition and tri-partition by means of the fine multimodal PES landscape calculation does not require any specific change of the deformed nuclear microscopic potential parameters of the Saxon-Woods type.

The calculations show that the new ternary fission channel called Collinear Cluster Tripartition (CCT) [4,5] could be explained by formation of at least two magic deformed clusters inside the nuclear system. CCT local energy minima lay higher than binary ones and they could be understood as the most favorable deformation values on the static pass to fission within the tripartition PES channel. At high elongation values both fissioning systems ^{252}Cf and ^{236}U demonstrate possibility of several two-necked shape families corresponding to the different magic shells of future fission fragments. The new theoretical results for the clustering within the symmetrical fission valley could help to understand the variety of CCT fission channels obtained in the recent experiments [4,5].

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SUB-BARRIER INTERACTION OF DEUTERONS WITH ^{58,62}Ni, ^{124}Sn NUCLEI

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The deuteron elastic scattering differential cross sections measured on ^{58,62}Ni and ^{124}Sn nuclei at the energies 3.5, 4.5 and 5.16 MeV [1] and 4, 5 and 5.5 Mev [2] correspondingly, were analyzed in the framework of the optical model. At calculations the deuteron interaction potential with the nickel target nucleus was constructed as a sum of the constituting deuteron particles complex nuclear interaction potentials and small complex potential [3] takes into account the possibility of deuteron elimination from the elastic channel due to the Coulomb breakup reaction in the external electric field. In the case of tin nucleus the single folding model [4] for nuclear potentials construction was used. Using the nuclear interaction of the neutron and proton with the target nucleus at calculations allowed to match the measured and computed differential elastic scattering cross section (solid line in the Fig. 1). Calculations showed that at sub-barrier energies, the influence of breakup process on the elastic scattering cross sections formation is essential (dashed line in the Fig. 1).

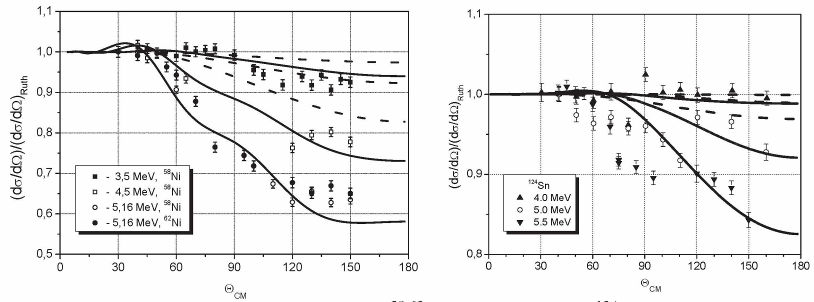

Fig. 1. The differential cross sections of ^{58,62}Ni (d, d) (left) and ^{124}Sn(d, d) (right) elastic scattering. The experimental values are denoted according to the figures scheme. The results of theoretical calculations are represented by lines.

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GENERALIZED APPROACH TO THE DESCRIPTION OF MULTI-STEPS DECAYS IN CHAINS OF GENETICALLY RELATED NUCLEI

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Traditional approach [1] to the description of the multi-steps decays in chains of genetically related nuclei suggests sequential character of these decays, which are considered as the following in time one to another allowed by energy one-step basic decays from the ground and excited states of nuclei in the chain under consideration. Such basic decays may include not only nuclear α-, β-, γ- decays and fission, but the decays with the emission of nucleons and clusters (light nuclei). Sequational multi-steps decays are analyzed by solving a system of coupled kinetic equations, which are constructed with taking into account the exponential character of the basic decays, which are due to the independence on time of partial widths of these decays. Development of the theory of double beta- [2] and the two-protons [3] decays of nuclei allowed to introduce the concept of virtual two-steps decays of nuclei, which occur as the two basic one-step processes, the first of which is associated with the decay of the initial nucleus with formation of a virtual states of the intermediate nuclei, and the second corresponds to the decay of the mentioned nuclei with the transition to the real state of the final nucleus.

In this paper the generalized approach to the description of multi-steps decays in chains of the genetically related nuclei with taking into account not only the sequantial decays, but also combinations of these decays with virtual multi-steps (two-steps, three-steps, etc.) decays is developed. It is shown that the taking into account of multi-steps virtual decays becomes necessary not only when the energy ban on some real basic one-step decays occurs, but and for sufficiently small positive energies of a such basic decays.

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CLUSTER EXCHANGE AND ANOMALOUS LARGE ANGLE SCATTERING

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The aim of the work is to investigate the influence of α-particle exchange on the angular distribution of elastic scattering $\alpha+^{16}O$. The exchange process $\alpha+(\alpha'+^{12}C) \rightarrow \alpha'+(\alpha+^{12}C)$ is considered to be the reason of pronounced enhancement of the backward angles differential cross section. Traditionally such the processes can be treated as heavy particle transfer in framework of DWBA [1, 2]. Here the alternative mechanism is considered: the interaction containing the α-particle exchange operator $\hat{P}_{\alpha\alpha'}$ is added to direct α–^{16}O potential. The resulting potential is nonlocal one and contains two types of interactions. The first corresponds to the situation when the exchanging particles interact via an effective potential $V_{\alpha\alpha}$. This part is similar to the knock-on exchange in the folding model with single nucleon exchange. But we take into account center of mass displacement which is not small for cluster exchange. For second type of the potentials exchanging particles don't interact. We use the cluster representation for the internal wave function of ^{16}O: $\varphi_{^{16}O} = S_\alpha^{1/2}\varphi_C\varphi_\alpha y(\mathbf{r})$, where S_α is $\alpha+^{12}C=^{16}O_{gs}$ spectroscopic factor**.** Then the exchange potentials directly depend on value S_α. The explicit expressions for exchange potentials can be found in [3]. The local approximations for nonlocal potentials were calculated using Wigner transformation [4]. The dependence of the local potentials on parity $(-1)^l$ is analyzed (l – angular momentum of the relative motion). The exchange interaction of first type can be both parity-dependent and parity-independent. The interaction of second type is only parity-dependent. Dependence on parity inevitably results in enhancement of cross section at backward angles.

Spectroscopic factor was adjusted to reproduce the experimental differential cross section. The defined values of S_α were compared with values from DWBA calculations.

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FOUR-DIMENSIONAL LANGEVIN DYNAMICS OF HEAVY-ION-INDUCED FISSION

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A four-dimensional dynamical model based on Langevin equations was developed and applied to study fission characteristics in a wide range of a fissility parameter and excitation energy [1].The evolution of three collective shape coordinates and K-coordinate (spin projection onto symmetric axis of fission nucleus) [2], were considered from the ground state deformation to the scission of compound nucleus into fragments. A modified one-body mechanism of nuclear dissipation with a reduction coefficient k_s of the contribution from a "wall" formula has been used in the study for modeling nuclear viscosity. The modeling of four collective coordinates allows calculating a wide set of experimental observables in fusion-fission reactions induced by heavy-ions [3]. The inclusion of K-coordinate in the dynamical consideration and use of the "chaos-weighted wall formula" with a deformation-depended scaling factor $k_s(q_1)$ lead to fairly good reproduction of variances of fission fragment mass distribution and prescission neutron multiplicity for a number of fissioning compound nuclei in a wide fissility range [4]. The four-dimensional dynamical calculations describe better experimental prescission neutron multiplicity and variances of fission fragment mass distribution for heaviest nuclei with respect to a three-dimensional dynamical model, where K-coordinate assumed to be equal to zero [5]. The estimate of a dissipation coefficient for the orientation degree of freedom $\gamma_K \simeq 0.77\ (\mathrm{MeV\ zs})^{1/2}$ is good for heavy nuclei and a larger value of $\gamma_K \simeq 0.2\ (\mathrm{MeV\ zs})^{1/2}$ is needed for the nuclei with mass $A_{CN} \simeq 200$.

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PROTONS SCATTERING ON ^{9}B, ^{9}Be ISOTOPES WITHIN THE DIFFRACTION THEORY

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An important trend in the field of fundamental nuclear physics at the present time is the study of nuclear reactions that occur in the nuclear reactors of new generation. Such challenges include the study of structure and properties of the isotopes of boron and beryllium, which are used in the reactors as the absorbent. Theoretical treatment of the experimental results of the processes of their interaction with protons and neutrons at intermediate energies may significantly broaden the base of nuclear data.

We study the scattering of protons on ^{9}B and ^{9}Be nuclei within the Glauber theory of multiple diffraction scattering. The wave functions (WF) of nuclei are calculated in the three-particles $2\alpha+N$-model [1] with the paired αN- and $\alpha\alpha$-interactions involving the states prohibited by the Pauli principle.

Using the WFs of ^{9}B, ^{9}Be nuclei in the calculation as an expansion by gaussoids and representation of the multiple scattering operator in the form, conjugates with three-particle WFs, make it possible to calculate the matrix elements analytically, without the loss of precision that occurs in case of multiple scattering series cutoff and calculation of multidimensional integrals.

The performed study has demonstrated a sensitivity of the differential cross sections of elastic scattering to the structure of nuclei and to the contribution of multiple collisions processes with the α-clusters and nucleon, being in their composition. Calculations were made at the energies E_p = 0.22 and 1.04 GeV, for which (for ^{9}Be nucleus) experimental data are available [2, 3]. The comparison with the calculation results of other authors was made which helped us to make conclusion about WFs quality and the benefits of the used method, it showed that the quality of the experiment description in the Glauber theory is of the same order as in the optical model.

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SEMIANALYTIC APPROXIMATIONS FOR THE AMPLITUDE OF THE ELECTRICAL BREAKUP OF TWO-CLUSTER NUCLEI

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A new method of accounting for the effects of interaction of two coupled charged particles (light two-cluster nucleus) with the electromagnetic field outside of the field of nuclear interaction during the breakdown with heavy nucleus is offered. It is suitable both for low energies and high, up to relativistic energies. The method is based on the DWBA post-form for the reaction amplitude, but neglected however the final state interaction between the products of breakup $c \to a + b$. Thus, the three-particle wave function of the final state is approximated by a product of functions of the scattering particles a and b in the Coulomb field of the target nucleus, depending on the Jacobi coordinates $\{\vec{r}_a, \vec{R}_b\}$. Region of the nuclear interaction is eliminated by introducing their some profiling function $f(R)$ in the form of a smooth step on the radial coordinate of relative movement of two colliding nuclei, and $f(R) \propto R^6$ when $R \to 0$. Further, the wave functions of the particles from the reaction and operators of interaction between these particles and the target nucleus are developed in powers of the relations $(\vec{r} \cdot \vec{R})R^{-2}$ and $r R^{-1}$ up to the 3rd order. Here $\vec{r}-$ Jacobi coordinate on the relative movement of the clusters. Then the product of powers of $\vec{r} \cdot \vec{\nabla}_R$, $\vec{r} \cdot \vec{R}$ and of the plane waves are expressed through the same powers of $\vec{r} \cdot \nabla_{k_a}$, $\vec{r} \cdot \nabla_{q_b}$ and of $-i\vec{r} \cdot \nabla_q$, where $\vec{k}_a$, $\vec{q}_b-$ Jacobi momentae and $\vec{q}-$ the transfered momentum. As a result the six-dimensional integral of the amplitude is factorized for the sum of the products of the 3-dimentional integrals over the space of the vector $\vec{r}$, each of them is a differential operator of the momentae $\vec{k}_a, \vec{q}_b, \vec{q}$ and of the volume integrals over the space $[\vec{R}]$ of the vector $\vec{R}$, each of them depends on the same momentae and on the momentum of projectile nucleus. After approximation of functions $f(R,n) = R^{-n} f(R)$ by the sums of exponential functions each integral over space $[\vec{R}]$ is expressed through the sum of volume integrals for which analytic representations are already known.

INVESTIGATION OF THE INFLUENCE OF NUCLEAR MATTER ON HARD LEPTON-NUCLEI AND HADRON-NUCLEI INTERACTIONS USING MONTE CARLO GENERATOR HARDPING

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Hadron and lepton production in hard interaction of high-energy particles with nuclei are considered in context of developing of Monte Carlo generator HARDPING (Hard Probe Interaction Generator). Such effects as energy losses and multiple re-scattering initial and produced hadrons and their constituents are taken into account. These effects are implemented in current version of generator HARDPING.

Data of experiments HERMES [1] (see Fig. 1) on hadron production in lepton-nuclei collisions and E866 [2] on muon pair production in proton-nuclei collisions were described with current version of generator HARDPING.

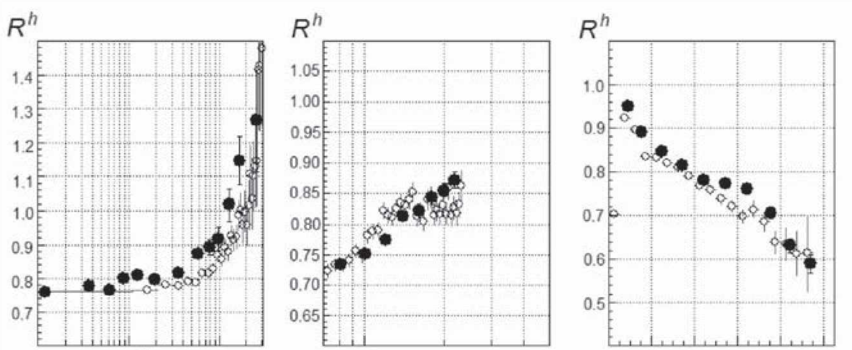

Fig. 1. Multiplicity ratio (Rh) of charged hadrons for krypton (Kr) and deuteron (D) targets as a function of pt^2, as a function of virtual photon energy (ν) and as a function of z_h at positron beam energy 27.6 GeV. The solid points correspond to HERMES data [1] and the open points are obtained by HARDPING.

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INFLUENCE OF ^{6}Li BREAKUP ON REACTION CROSS SECTION OF $^{12}C(^6Li, ^6Li)^{12}C$ AT 18–28 MeV/NUCLEON

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Differential cross sections of elastic scattering of 124 and 169 MeV ^{6}Li ions from ^{12}C nuclei [1] are calculated within diffraction model framework [2-4] where the ^{6}Li nucleus considered as a weakly bound two-clustered one ($^6Li \rightarrow \alpha + d$).

The calculations took into account the breakup channel under the kinematic conditions when the breakup products of ^{6}Li move with the same speed and in the same direction as the elastic scattered ptojectile.

It is shown that including of additional breakup channel into the calculations leads to filling of the diffraction minima that improves agreement with the experiments (Fig. 1).

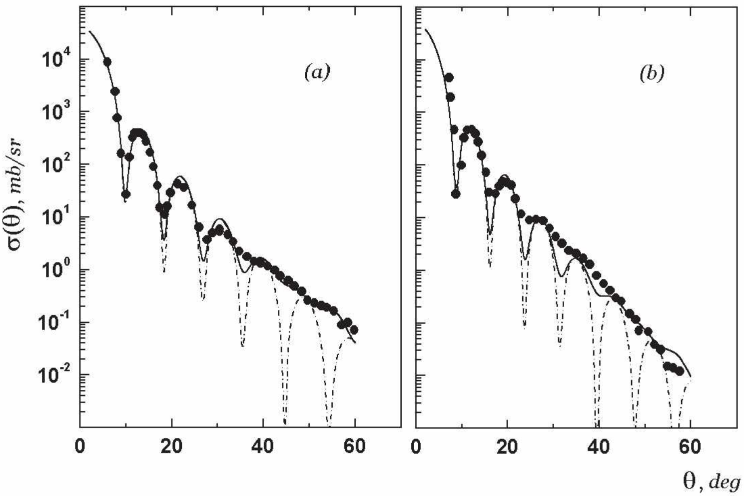

Fig. 1. Calculated cross sections of ^{6}Li scattering from ^{12}C at 124 MeV (a) and 169 MeV (b). Dash-dot curves correspond to "pure" elastic channel, solid curves correspond to taking into account breakup channel. Experimental data (points) were taken from [1].

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RELATIVISTIC INTERACTIONS IN MESON-NUCLEON SYSTEMS: APPLICATIONS IN THE THEORY OF NUCLEAR REACTIONS

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Starting from the primary Yukawa-type couplings between "bare" fermions (nucleons and antinucleons) and bosons (π -, η -, ρ -, ω - mesons, etc.) with the help of the method of unitary clothing transformations (UCTs), developed for the Dubna-Kharkov cooperation [1] and extended by the Kharkov-Padova group [2], we will show a new family of the interactions ("quasipotentials") between "clothed" particles responsible for physical processes in meson-nucleon systems. These quasipotentials are hermitian and energy independent that make them attractive in practical calculations. The corresponding four-operator interactions for the 2 ↔ 2 processes (such as *NN* → *NN* and anti*N*+*N* ↔ π+π) the five-operator interactions for the 2 ↔3 ones (such as *NN*↔ *BNN*) are derived along the chain: bare particles with bare masses → bare particles with physical masses → physical (observable) particles.

Further, in order to avoid ultraviolet divergences typical of local field theories, we prefer to handle the regularized contributions to the interaction Hamiltonian density by introducing some covariant cutoff functions in momentum space. Our consideration is compatible with the relativistic invariance requirements being fulfilled in the framework of an original procedure proposed to meet the Poincaré-Lie algebra [3]. When describing the *N-N* scattering below the pion production threshold, we have compared [4] our results with those by the Bonn group and obtained a fair treatment of the data. In addition, we will discuss a number of fresh ideas in studying the electromagnetic interactions with nuclei (in particular, the electron-deuteron scattering).

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EQUIPMENT, METHODS AND AUTOMATION OF NUCLEAR EXPERIMENTS, INTERACTION OF NUCLEAR RADIATION WITH THE MATTER AND APPLICATIONS OF METHODS OF NUCLEAR PHYSICS

DEVELOPMENT OF NEUTRON DETECTORS FOR THE STUDIES ON THE ACCULINNA AND ACCULINNA-2 SETUPS

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The correlation studies is very effective tool in the researches of the neutron rich nuclei (for instance ^{7}H, ^{10}He [1, 2]). It is often necessary to register neutrons together with other decay products in order to obtain these correlations. There is a good example of such research – it is planned study of ^{10}Li on the ACCULINNA and ACCULINNA-2 setups [3, 4]. We want to make the experiments for study of ^{10}Li ground and excited states in ^{9}Li(d, p)^{10}Li and in ^{11}Li(p, d)^{10}Li reactions, where registration of neutron from the decay of ^{10}Li should improve energy resolution. It was shown recently [5], that neutron detector based on the stilbene crystal is good enough in comparison with other types of neutron detectors (DEMON, LAND, MONA). As a result, several R&D works [5, 6] with different design of the neutron detector based on the stilbene crystal were tested and reported.

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NEW PHASE OF THE EDELWEISS DARK MATTER SEARCH EXPERIMENT

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The EDELWEISS program [1] searches for evidence of direct WIMPs scattering of Ge nuclei within HPGe crystals. The EDELWEISS detectors are Ge bolometers with simultaneous measurement of phonon and ionization signals. The comparison of the two signals provides an efficient event-by-event discrimination between nuclear recoils (induced by WIMPs) and electrons. To go beyond the present EDELWEISS sensitivity [2] and to be competitive with other experiments, a new phase (EDELWEISS-III) of the experiment is started. The EDELWEISS-III consists in an upgrade of both the EDELWEISS setup (cryogenic system, shielding, new fast data acquisition) and detectors. About 10 kg of new 800 g FID detectors were successfully commissioned in 2013 for its applicability in the EDELWEISS. The FID detector's technology developed by the EDELWEISS (all surfaces of detectors are covered by ring electrodes - fully interdigitized detectors) shows at least an order improvement of surface background suppression (Fig 1). In 2014 new 800 g FID detectors will be added progressively to the setup to enhance the sensitivity to WIMPs. The aim is to have in 2014 year 3500 kg.d with no surface background events at nuclear recoil band above 15 keV threshold. This will provide the sensitivity to WIMP-nucleon SI cross-section of better of the $4x10^{-45}$ cm^2 for a M_{WIMP} ~100 GeV/c^2 in successful competition with other world leading Dark Matter search experiments.

This work has been partly supported by RFBR.

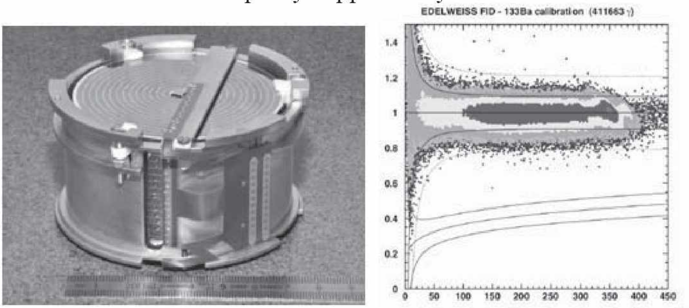

Fig. 1. Left: Photo of FID800 detector. Right: Calibration of the FID800 detector with ^{133}Ba. For all 411663 registered events their ionization yield (the vertical axis) versus recoil energy (in keV) is shown. The nuclear recoil band is shown by solid lines. Rejection factor better than 10^{-5} has been received.

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DEVELOPMENT OF SETUP FOR NEUTRINO-NUCLEUS COHERENT SCATTERING OBSERVATION

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Recent Neutrino and Dark Matter search experiments revolutionized detection of rear events and rear events with low energies in particular. Experiments achieved sensitivities on the level of several events per hundreds kg of detector's material per day with energy thresholds below of 1 keV. This opens a new unique possibility for experimental detection of neutrino-nucleus coherent scattering that was considered to be impossible so far.

The present project consists in using of low threshold HPGe detectors developed by JINR (Dubna) [1] for creation of a setup designated for first observation of neutrino coherent scattering of Ge. General conception of this project can be described as following:

1) Based on four point contact HPGe detectors with total mass of ~1400 g developed by JINR (Dubna) the spectrometer with energy threshold at ~300 eV is built. The constructed spectrometer (the cryostat, detector holders, etc) fulfills the requirements for low background experiments.

2) The background of the spectrometer is being studied in details at LSM underground laboratory using infrastructure of the EDELWEISS experiment [2]. The signal of light WIMPs recently reported by some experiments could be a source of background for observation of coherent neutrino scattering. Thus on this stage of the experiment an important goal is to set a limit or a value of such WIMPs' signal.

3) As a powerful neutrino source the experiment will use antineutrinos from one of the power-generating unit of Kalininskaya nuclear power plant. Therefore, after finishing the background studies the setup will be moved from LSM to the Kalininskaya power plant site where it will be deployed into improved low background shield of the GEMMA experiment [3]. Observation of coherent neutrino scattering will be checked using the differential method that compares the spectra measured at the reactor operation and shut down periods. For the setup set at a 10 m distance from the center of reactor core and with an energy threshold at ~300 eV several tenths of events of neutrino coherent scattering expected to be detected per day in the constructed setup with 4 HPGe low energy threshold detectors (450 g each).

This work is partly supported by RFBR.

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NEUTRINO FACTORY ON THE BASE OF INTENSE NEUTRON SOURCES

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The proposed neutrino factory is based on the lithium converter irradiated by an intensive neutron source. The powerful neutrino source (factory) is created under (n,γ)-activation of high purified ^{7}Li and subsequent β^--decay ($T_{1/2}$ = 0.84 s) of ^{8}Li with emission of high-energy $\tilde{\nu}_e$ with E_ν up to 13 MeV [1]. Such a $\tilde{\nu}_e$-spectrum gives a significant advantages (especially compare to $\tilde{\nu}_e$-spectrum from nuclear reactor) as the cross section of neutrino depends at the considered energy as $\sigma \sim E_\nu^2$ and rate of the neutrino interactions will increase strongly.

Different neutron sources can be utilized for lithium activation [1-3]. It can be the high-flux nuclear reactors (in a stationary mode) enclosed by lithium converter (i.e., the neutrino factory in a static regime of operation). But the advantages of ^{8}Li antineutrino spectrum will be more fully utilized in the scheme with pulse reactors, when $\tilde{\nu}_e$-flux from β^--decay of fission isotopes will be separated in time from neutrino of ^{8}Li decay. Another perspective regime is dynamical one, when an activated ^{7}Li is pumped in the close cycle through the active zone of the reactor and further is delivered close to the neutrino detector. Today the most perspective neutrino factory can be based on the tandem of lithium converter plus an accelerator and neutron generating target [3].

It was calculated the efficiency (number of ^{8}Li isotopes per neutron of the neutron source) of such an installations. It was considered the geometries of lithium converters. The functionals of the neutron field in the converter were simulated and parameters of the installation were proposed. Different types of converter matter were considered: the pure lithium in the metallic state and lithium chemical compounds. The most preferable is the D_2O-solution of LiOD, which allows to decrease the requirements in mass of high purified ^{7}Li isotope from tens to about three hundreds times. It was considered the neutron yield from targets (W, Pb) of the neutrino factory in the "tandem" scheme of proton accelerator (with energy of several hundreds MeV's) and the expected efficiency of the lithium converter were obtained. The conception of the proposed lithium converter [1-3] in the "tandem" scheme is included today to the project of the powerful source and proposed for neutrino investigations [4].

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TO THE NEW SOURCES FOR PHOTO-NUCLEAR REACTION STUDY

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Photo-nuclear reactions give important information on nuclear structure and excited states [1]. Their study, however are considerably hindered by the quality of accessible gamma beams. Namely, while bremsstrahlung radiation has very wide spectrum, gamma beams from both relativistic positron annihilation and tagged electron beams have low intensity [1]. We propose to develop sources of gamma radiation for photo-nuclear reaction study utilizing coherent effects in $e^{\pm}$ radiation in crystals and ordered structures of composed of nanoobjects, such as grapheme and nanotubes. Both narrow spectrum and high intensity of such sources will be ensured by correlated $e^{\pm}$ scattering by ordered atoms, characterized by both enhanced intensity and periodicity. Advantages of such sources will become most pronounced at high $e^{\pm}$ energies (a few GeV and more), they should be preferably realized in a spurious mode at the beams of X-ray lasers and linear e^{+}- e^{-} colliders.

First gamma-source we propose to use is crystalline undulator. This idea was put forward in Belarusian State University [2] and consists in using radiation preferably of more stably channeled e^{+} in the field of crystal planes periodically bent with some undulator period λ_{und}. Unique properties of such radiators are assured by the high strength of averaged planar field equivalent to hundreds Tesla as well as by small λ_{und} values, say, from dozens to hundreds μm. Ultra-relativistic particle oscillation frequencies are directly converted to that of gamma-radiation by Doppler effect [2,3]. The energy 5–20 GeV of the e^{+} beam of FACET [4] allows to cover the region 0.1÷10 MeV of gamma-quanta energy.

However the applications of crystal undulators are considerably limited by the need of positron beams, accompanying intense hard channeling radiation and limitations of the choice of undulator parameters by that of crystal lattice. To overcome this limitations we suggest to use a stack of graphene layers. The latter can consist of one or several graphene sheets, having a nanometer-scale thickness and average internal electric potential reaching 20 eV. Intrinsic grapheme corrugations will effectively smear out the internal atomic structure leaving inside the multilayer graphene sheets a smooth electric field equivalent to a few dozens of Tesla. Varying both the spacing between the graphene layers and direction of the e^{-} beam incidence on them one can adjust the gamma-quanta energy through the whole region of photo-nuclear reactions.

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PROSPECTS FOR THE METHODS OF RADIONUCLIDE PRODUCTION

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Over recent decades, the nuclear medicine is formed as a separate branch of the nuclear science. Among a variety of methods, the treatment of oncology events with proton and heavy- ion beams seems the most efficient way, but too expensive for the wide application, as well. Production and use of the radionuclide sources of radiation is definitely more economic, much lower in expenses as compared to the proton-synchrotron therapy, especially in account of the cost for the construction and infrastructure developments. The great number of radionuclides is known that allows a flexible choice of the concrete isotope and its production method individually for some definite treatment task. In literature, there are typically distinguished the therapeutic and theragnostic sources: the first ones serve for elimination of tumors due to the irradiation (external or internal), and second ones – for tomography diagnostics. The radionuclides for application in both modes are listed and characterized in the review article [1]. Various scientific and practical issues are addressed there to the production methods, to chemical processing of the active species, and even to the pharmaceutical preparations. Some cases of the "dual-purpose" isotopes are described in [1]. In the present report, only the methods of radionuclide production are stressed especially of those based on the application of low-energy electron accelerators, at $E_e \leq 25$ MeV. After the electron-beam conversion, an intense flux of bremsstrahlung could be created, and the photon induced reactions supply a great yield for many isotopes under selective choice of the target material for concrete-species production. Another, relatively inexpensive method involves the alpha-particle beams achievable at the moderate-energy cyclotrons with $E_\alpha \leq 10$ MeV/amu. Both kind accelerators are available at FLNR, Dubna, and the discussed methods could be developed for practical uses without significant investment of funds. Possibilities are described for production of isotopes applicable for radiotherapy of patients with isotopes emitting the low-energy electromagnetic radiation and also efficient for diagnostics with the positron-emission tomography (PET) or the single photon-emission computer tomography (SPECT). Isotope production with commonly-used economic accelerators is under scope. Innovating procedures are here proposed for optimization of the production methods, as follows: a) Method of the noble-gas target providing the fast transport and separation of definite isotopes; b) New variants of the "generator method" allowing chemical separation of the product from the target material; c) Advantages of the concrete isomeric species for careful treatment of the body tissues with soft β-, γ-, and Auger-electron radiation; d) Possibilities for studies of the special-element metabolism "in vivo" at low-mass content of the injected element. In general, this report is mostly addressed to the nuclear science and lower to the medicine.

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EXPERT SETUP TO STUDY EXOTIC RADIOACTIVITY

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The proposal EXPERT (EXotic Particle Emission and Radioactivity by Tracking) suggests a compact modular setup for conducting studies of extremely exotic nuclei using fragment separators Acculinna-2 in Dubna [1] and SuperFRS in Darmstadt [2]. In addition to the standard detectors for beam monitoring, the specific movable instruments are foreseen to be used: i) radiation-hard silicon strip detectors [3, 6]; ii) micro-strip silicon tracking detectors [4, 5]; iii) the NeuRad (Neutron Radioactivity) fine-resolution detector of neutrons [5]; iv) the GADAST (Gamma-ray Detectors Around Secondary Target) array [6] and v) the OTPC detector (Optical Time Projection Chamber) [7].

The setup aims at studies of the nuclear landscape beyond the proton and neutron drip-lines and intends to push researches up to limits of nuclear existence. By combining the EXPERT instrumentation in different scenarios, phenomena of radioactivity, resonance decays, beta-delayed decays and exotic excitation modes can be studied via observations of particle emissions: i) exotic 2p radioactivity studies and search for unknown types of radioactive decays - 4p, 2n, 4n. Studies of p, 2p, 4p, n, 2n, 4n resonance decays and continuum spectroscopy; ii) quest to discover the limits of existence of nuclear structure. Search for systems located far beyond the drip-lines aimed to answer for the question: "Where is the border line between a resonant behavior and continuum response of nuclear matter?"; iii) studies of beta-delayed particle (multi-article) mission from exotic isotopes near and beyond the drip-lines.

Feasibility of several such scenarios is confirmed by the recent works [4-7]. For the systems which ground states decay by (multi-) nucleon emission the proposed setup covers two important lifetime ranges of 1 s - 100 ns, and 1 ps-100 ns by applying the implantation-decay and decay-in-flight techniques, respectively. For the short-lived systems, the resonance properties and information about continuum dynamics is extracted on the basis of the angular correlations between the products. The suggested measurements are augmented with information about γ de-excitations and β-delayed particle emissions of the decay products.

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STRAW-DETECTOR WITH CATHODE READ-OUT

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The detectors based on thin drift tubes (straw) with a diameter of 4 to 10 mm are widely used nowadays as position-sensitive detectors, for example, in such experiments as SDC, ATLAS, COMPASS. These detectors have several advantages: high coordinate resolution (by measuring the drift time) of about 100 microns, track reconstruction efficiency close to 100%, the rate capability of 500 kHz per readout channel, simple design, and, consequently, relatively low cost. Additionally, the cylindrical geometry of the tube provides good mechanical properties at a low weight.

At present with the rise of beam luminosity of modern accelerators the rate capability becomes the most important detector parameter, which is achieved either by increasing the registration speed, or decreasing the detector size. This applies to the straw tubes, where the problem of reducing the rate per readout channel is usually solved by using tubes of smaller diameters.

We propose to solve the problem of increasing the straw tube rate capability by independent readout of avalanche-induced signals from electrically isolated segments on the cathode surface. The signal from an avalanche at the anode wire is induced on one or more segments of the cathode, depending on the diameter of the tube, the length of the segment and the place of formation of the avalanche. Information from the cathode segments is used both to determine the radial coordinate of the particle track by measuring the drift time of the primary ionization and to localize the position of the track along the straw by the number of the fired cathode segment [1].

Manufacturing of such segmented straw tubes became possible thanks to development of technology of ultrasonic welding of Mylar tape [2]. It should be noted that the tubes made by ultrasonic welding have thinner walls than ones produced by conventional tape winding technology. Such tubes can withstand pressure up to 8 atmospheres.

The proposed method for increasing the rate capability of straw detectors by using cathode segmentation has several advantages such as high "transparency" for particles, possibility to register two track coordinates at once and high manufacturability of ultrasonically welded straw tubes.

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TIME OF FLIGHT SYSTEM OF THE MPD

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The TOF system of MPD is the main detector for particles identification. In order to separate pions from kaons in the momentum range 0–2.5 GeV/c and protons from kaons in the range 0–4.5 GeV/c it should have time resolution better than 100 ps. The TOF system consists of a barrel with RPC detectors having the radius of 1,5 m and the surface of about 50 m^2 and covering the region $|\eta|<1.4$ and two End caps which cover the region $1.5 < |\eta| < 2$. A RPC has the active area of 600 x 300 mm^2 and strip readout.

The start signal is given by stations of Cherenkov quartz counters (FFD - Fast Forward Detector). The FFD consists of two sub-detectors FFDL and FFDR, arranged as arrays of modules and situated near the beam pipe at a distance of 75 cm to the left and to the right from the interaction region. Each sub-detector array has a hole for the beam pipe and a pseudorapidity acceptance of $2.3 < |\eta| <3.1$.

FLUCTUATIONS IN THE PROCESS OF CHARGE INDUCTION IN SEMICONDUCTOR DETECTORS WITH CYLINDRICAL GEOMETRY

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The energy resolution of a semiconductor detector is determined not only by the variance in the number of charge carriers produced by X-rays in detector volume, but also by fluctuations in the process of charge induction on the detector's electrodes. In this work, the formula for the generating function of the process of charge induction in semiconductor detectors with cylindrical geometry was derived. The formulae for the first two moments of the distribution function of the induced charge on the detector's electrodes were derived. These formulae are useful for analysis of the dependence of the energy resolution of semiconductor detectors with cylindrical geometry on the electron mobility-lifetime product and on the relative variance in electron lifetimes due to inhomogeneous of the charge transport in the semiconductor material.

GAS GAIN AND AGING RATE OF THE GAS DISCHARGE DETECTORS

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The results of the study of gas discharge detectors aging rate dependence from the gas gain have been presented. During the shot time aging tests in laboratory conditions to accumulate the dose equivalent to a few years of work in physical experiment a special accelerated regime have to be applied. This implies irradiation of the detector with high intensity radiation sources or with a particle accelerator beam that provides 0.5÷5 μA/cm of exposition current. At the same time an applied high voltage to the detector usually provides few times higher gas gain in compare with a normal working point, Ref. [1]. To study the anode swelling mode of aging, which appears at accumulated dose above 1 C/cm, both aging accelerating means were applied, Ref. [2]. Thus the extrapolation reliability of the laboratory test results on the real experiment is a goal of given study. Aging tests of the straw-tubes [2] were performed with a 60%Ar + 30%CO_2 + 10%CF_4 working gas mixture, which components are typical for the modern gas discharge detectors. The degradation study of the straws was carried out using three ^{90}Sr β-sources with a total rate onto one straw of 15 MHz. We chose the working points of the high voltage to achieve gas gains and irradiation currents over a broad range: 2×10^4, 5×10^4, 1×10^5 and 0.38 μA/cm, 0.97 μA/cm, 1.98 μA/cm, respectively. In Fig.1 (left) it is shown the gas gain degradation due to the anode wire swelling with accumulated dose. Fig.1 (right) shows the linear approximation of the aging rate - *R* (%/C/cm) dependence on the gas gain. As one can see *R* is stable and in average it is equal to $\langle R\rangle=6.87\pm0.13$. This let us to conclude that accelerated aging results can be extrapolated (gas gain of 5×10^4–1×10^5) to the physical experiment conditions (gas gain of 2×10^4).

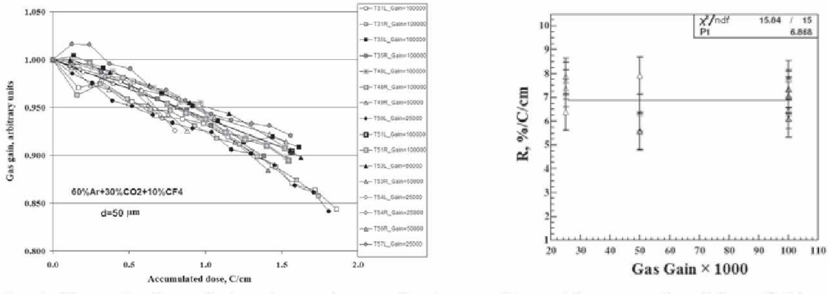

Fig. 1. Gas gain degradation due to the anode wire swelling with accumulated dose (left); swelling aging rate R(%/C/cm) dependence from the gas gain in the straw-tubes (right).

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TO THE INFLUENCE OF SINGLE SCATTERING ON NUCLEI ON THE EFFICIENCY OF THE FUTURE LHC CRYSTAL-BASED COLLIMATION SYSTEM

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The Large Hadron Collider provides unique conditions for experiments on coherent charged particles interaction with crystals. Due to record the proton energy of 7 TeV the significance of coherent interactions considerably increases in comparison with all the previous experiments. At the same time the r.m.s. multiple scattering angle on crystal atoms in amorphous direction becomes less than 0.5 μrad, what is considerably less than the critical channeling angle. That's why single scattering by nuclei becomes the main process of particle incoherent deflection in crystal.

We consider several types of scattering on nuclei: inelastic, diffractive, elastic nuclear and Coulomb scattering. While incident particles disappear under the inelastic scattering, the other scattering processes will considerably deflect them. Usually the deflection angle of either elastic or diffractive scattering is high enough for particle to achieve the collimator system used for the superconducting magnet and detector protection.

On the opposite, single Coulomb scattering angle is insufficient for immediate particle loss on the collimators. Nevertheless, a relatively high frequency of Coulomb scattering can prevent subsequent particle capture into the channeling regime supposed to be the most efficient mean of halo particle steering.

We simulate the LHC crystal-based collimation system comparing the contribution of different types of scattering in the collimation efficiency for different crystal alignment: channeling, volume reflection and amorphous orientation. We also reproduce this for multiple volume reflection in one bent crystal (MVROC) [1]. Additionally, we compare the collimation efficiency and analyze the role of scattering on nuclei for modifications of the channeling effect with crystal cut [2] and of the MVROC with either application of tungsten crystal instead of the silicon one or combined action of the MVROC and channeling [1].

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HEAT RESISTANT CARBON NANOTUBES BASED INORGANIC UNFIRED CERAMICS FOR NUCLEAR APPLICATION

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Many practical applications of modern nuclear science require the design and fabrication of new materials with controlled physical properties, including hardness, mechanical strength, high thermal stability, electrical conductivity, etc. Design and control of wide range of correlated material properties implies utilizing of composite materials, based on various types of host matrix and fillers. Because of their advances physical properties, first of all heat and fire resistance, phosphate based composites could be very interesting for different nuclear physics uses, e.g. as a matrix for fabrication of ionizing radiation shields. The composites based on phosphates filled with multi-walled carbon nanotubes (MWCNT) of different diameters were fabricated at low temperatures by energy-efficient method (see Fig.1a). It was observed experimentally and proved theoretically that the percolation concentration increases with nanotubes diameter (Fig.1b). Moreover, the absolute values of electrical conductivity have been observed to be higher for the case of using thinner MWCNTs. To conclude, it is possible to fabricate thermally stable material for nuclear physics applications, e.g. phosphate filled with boron compounds for producing effective neutron shields or for neutron collimation, allowing at the same time to organize nondestructive control due to addition of small amounts of third functional conductive filler, MWCNT.

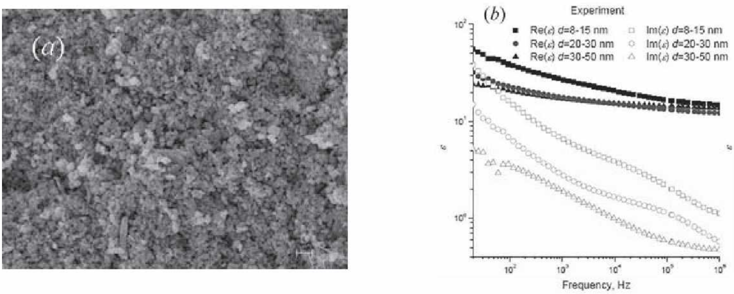

Fig. 1. (a) SEM image of phosphate filled with 1.5 wt.% of MWCNT; (b) Dielectric permitivity of 1 wt.% of MWCNT/phosphate composite vs frequency.

APPLICATION OF $^{27}Al(p,\gamma_2)^{28}Si^*$ (4.618 MeV) RESONANCE REACTION EXCITED AT PROTON ENERGY OF 2.489 MeV IN CALIBRATION EXPERIMENTS

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In this reaction the ^{28}Si level at the energy of 13.983 MeV with a width of 0.38 keV [1], [2] is excited. It discharges via gamma-quanta emission with the energies of 9.364, 2.839 and 1.779 MeV. By now [3] this reaction has been used to measure gamma-quanta recording efficiency of HPGe detector. In this paper its application for calibration of electrostatic accelerator energy scale is presented.

Dependence of gamma-quanta (2.839 MeV) yield from thick aluminum foil on a frequency of nuclear magnetic resonance (NMR) detecting element is presented in Fig.1. The detecting element of nuclear magnetic resonance measures magnetic induction of turning and analyzing accelerator magnet. A visible jump in gamma-quanta yield is due to the excitation of this resonance reaction. The work was aimed at the refinement of resonance position in the $^{9}Be(p,\alpha)^{6}Li^*$(3.563 MeV) reaction.

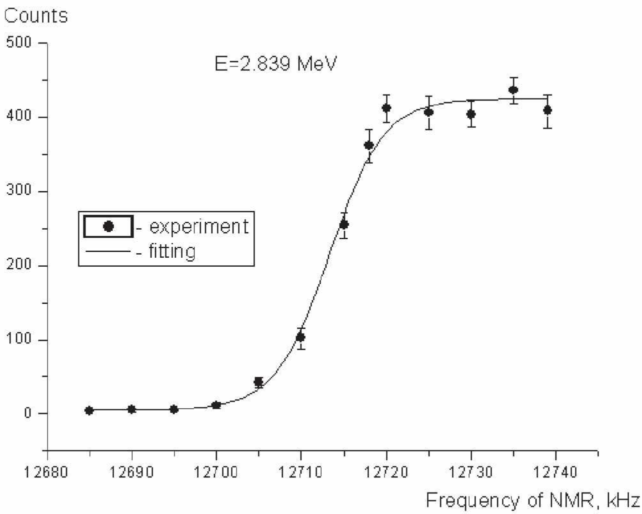

Fig.1. Gamma-quanta dependence on a frequency of NMR detecting element.

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APPLICATION OF VARIATIONS CALCULUS METHODS FOR OPTIMIZATION OF TIME-OF-FLIGHT NEUTRON SPECTROMETER CHARACTERISTICS

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A time spectrum of a neutron flight from chopper to detector contains all physical information. According to variations calculus methods, the time t of neutron flight from chopper to its absorption point inside the detector should be considered as a random variable depending on the specific neutron trajectory. The distribution function of the latter depends on a dozen of factors (shape and sizes of the target and detector, etc.). The most informative are the first two moments M_1 and M_2 of time-of-flight distribution. They correspond to the shift and width of the spectrum line, respectively. In an ideal case for a point target, the detector surface should be located on a specific surface called the time focusing surface (TFS). The presence of a target of the final sizes and deviation of the detector surface from the TFS will generally result not only in change of average time of neutrons arrival on the detector, but also in a nonzero dispersion of their times of arrival. The first and second phenomena lead to the shift of the first moment and to the broadening of the response functions, respectively.

At its simplest, the variational problem is to find a detector surface that would turn into zero the first moment M_1 of the random quantity $\zeta = t - t_0$ (t_0 is the time of neutron arrival on an ideal time focusing surface) during averaging of all factors that determine the distribution of flight times. The minimum of the second moment $M_2(\zeta)$ would be achieved on that surface.

In this case each such trajectory that contributes to M_1 and M_2 should take into account the neutron diffraction on a target. The first condition is followed by turning into zero the corresponding linear functional J_1 built on all possible neutron trajectories. At the same time, the related quadratic functional J_2 that determines the line width or device resolution should reach its minimum on the detector surface.

The solution of the variational problem is equivalent to the solution of the Euler equation (equation for J_2) with imposed Lagrange constraint (equation for J_1). The resulting equation will look like the standard Euler–Lagrange partial differential equation. The Euler–Lagrange equation solution determines the shape of the required detector surface that provides the minimum of the spectrometer resolution and the absence of the systematic drift along its time scale.

The methods of variational calculus together with Monte-Carlo methods have been applied to optimize the design and characteristics of high resolution Fourier diffractometer.

IMPROVEMENT OF DYNAMICAL CHARACTERISTICS OF RHODIUM-BASED SELF- POWERED NEUTRON DETECTOR

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A new solution has been suggested for the problem of improvement of dynamical characteristics of a rhodium-based self-powered neutron detector (SPND), which is the commonly used device for measuring neutron fluxes inside the core of the reactor of VVER type [1]. A quantity to be measured in a new registration scheme is supposed to be not a standard electrical current but the so-called generalized current, which is a linear combination of the standard current and its time derivative [2].

The theory of the response of the standard and modified SPND to fastly changing neutron fields has been developed. The time-dependent SPND response for the standard and generalized currents has been investigated for various variants of fast generation of neutron fields described by the point reactor neutron kinetics equations.

The investigations show that the modified SPND allows not only to measure neutron fluxes under stationary mode of reactor operation but also to react promptly to fast changes of neutron flux (around a second and less). Such fast changes take place not only under normal operation of a nuclear power station at maneuvering of its power, but also at various deviations from normal operation, and also in various emergency situations.

Enhancement of dynamic characteristics of a signal in various conditions of fast introduction of reactance in a reactor is of high importance for signal interpretation of an SPND signal in a working reactor. Using a modified SPND, which measures the generalized current, can provide reliable control of neutron flux inside the core of VVER type reactor in the most problematic and nuclear-dangerous moments of its operation.

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THE RESULTS OF NUMERICAL SIMULATION OF THE DETECTION DEVICE AND MEASUREMENT GEOMETRY FOR DEEP RADIATION MONITORING

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Water and sediment control, contaminated as a result of radiation accidents at nuclear power plants, is one of the tasks of radiation monitoring within to overcome the consequences of such accidents.

Submersible spectrometer AT6104DM designed to provide water and sediment radiation monitoring and represents the probe based on the scintillation detection NaI (Tl) size 63x63 mm inside waterproof stainless steel container and PDA module with applied software. Functions control in situ measuring is realizing by 150 m deep-sea cable.

In the result of theoretical researches have been calculated the response functions in the form of theoretical spectra of monitored radionuclides in definite measuring geometries. The results of mathematical modeling of the gamma emitting transfer process allowed to estimate with an acceptable accuracy the dimensions of the measurement object, in particular the critical radius - radius of contaminated sediments surface which provides 90-95 % of the response function. Theoretical spectra of radionuclides ^{134}Cs and ^{137}Cs for contaminated depths 5, 10, 15 and 20 cm and values of the critical radius allowed to develop an algorithm for monitored radionuclides activity measuring by in situ method without information about radionuclides depth distribution in sediments.

Verification of the developed mathematical models carried out in the Tohoku region, Japan. Experimental studies of the radionuclides activity measuring in sediment carried out in irrigation ponds with known distribution in depth and activity level of Cs-134 and Cs-137. Variations at the level of 20–25% indicated a good degree of correspondence of mathematical models.

GEANT4 MONTE CARLO CALCULATED DOSIMETRY PARAMETERS FOR ^{169}Yb

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Monte Carlo simulation widespread also was included into practice of calculations of dosimetric characteristics of brachytherapy sources. Thus the problems connected with dosimetry in areas with high gradients of a dose, accuracy of positioning of dosimeters and accuracy of definition of their active volume act in film. The considerable quantity of various program codes was applied to tabulation of data according to formalism AAPM TG-43 in the scientific literature, including EGSnrc, GEANT4, PENELOPE, PTRAN and MCNP4C. The purpose of the present work is definition of dosimetric characteristics of a new source on a basis radionuclide ^{169}Yb, developed Open Company «Medical sterilising systems», by means of program code GEANT4.9.6. Verification of the given version of a program code performed by literary data for well-known sources BEBIG Co0.A86 and BEBIG Ir2.A85-2.

Value of a dose-rate constant for source BEBIG Co0.A86, received in the present work, makes 1.102±0.018 cGy/(hU), and for source Ir2.A85-2-1.114±0.019 cGy/(hU). Results of calculations by means of software package GEANT4.0 executed Granero [1, 2] for the same sources make values 1.087±0.011 cGy/(hU) and 1.109±0.013 cGy/(hU). Results coincide within an error, and divergences can be caused difference in spectra of radioisotopes and versions of a program code.

Values of radial dose functions of investigated sources fit a polynom of the third degree for a source ^{60}Co and polynoms of the fifth degree for other sources. Deviations of the points received by modelling, from the values received at calculations on fitting function in all cases do not exceed ±2 %. Angular distribution of studied sources rather similar, in a case ^{169}Yb more strongly pronounced dose recession under corners close to 0° and 180°.

Sources ^{169}Yb are preferable in the event that the basic part of a tumour settles down on removal from a capsule, dose loading thus decreases for fabrics located for a tumour.

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HIGH ENERGY NUCLEI CHANNELING

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Channeling of charged particles in crystals received extensive attention in the interpretation of related nuclear processes, such as the suppression of nuclear reactions (Tulinov effect), resonant excitation of nuclear radiation (Okorokov effect), powerful electromagnetic radiation (Baryshevsky-Kumahov effect), etc. The beam divergence of high energy particles (either from ground based accelerators or galactic rays in space) considerably exceeds, as a rule, the critical angle of channeling when these particles interact with crystals. That requires a simultaneous consideration of a coherent scattering with zero momentum transfer to the lattice [1, 2] and incoherent scattering in vast transition area from the channeling to a random mode of motion with independent collisions with atoms of the crystal. The results of studies of the motion of charged particles with high energy E , taking into account the coherent scattering by atomic chain (using a modified Lindhard continuous potential and assumption of conservation of energy of the transverse motion, $\varepsilon_{\perp}$) and incoherent multiatomic scattering with non-conserved E, $\varepsilon_{\perp}$ (taking into account the correlated vibrations in the atomic chain in the crystal). The model crystal was composed of atomic chains in accordance with the symmetry of a real crystal. It is demonstrated the existence of an extensive angular range, exceeding the range of axial channeling up to two orders of magnitude, where the regime antichanneling (RA) realizes with the level of incoherent scattering exceeding the random scattering by two or more times. Distribution of the particles moments in RA regime is shifted to small values, which requires a consideration of all the above-mentioned nuclear processes. Basing on the results obtained, an interpretation is given for the experimental data of Ref. [3] what has not been done yet. A new scheme of the particle motion regimes, driven by the crystal lattice, is suggested.

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COPPER FRAGMENTATION IN NUCLEAR REACTIONS UNDER IMPACT OF HIGH ENERGY COSMIC PROTONS

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Copper fragmentation in nuclear reactions under impact of cosmic protons is considered. There is a trend of increase of relative copper concentration in modern integrated circuits (IC) with multilayered 3D architecture, where Cu is used as a main material component of inter-element contact paths, contact pads, interlayer contact vias. In contrast to the original space protons, the nuclear reactions fragments suffer much larger ionization losses, therefore can initiate a charge in a sensitive volume of the ICs exceeding the critical charge for generation of a false signal which can lead to malfunction of spacecraft on-board electronics. In the report the results will be presented of calculations, using TALYS code, of elastic and inelastic scattering cross-sections for protons with energies up to 200 MeV, isotopes and isobars yields of fragments, their energy, charge and mass distributions. The results demonstrate that fragmentation of the copper must be taken into account for more accurate prognosis of the possibility of spacecraft on-board electronics upsets.

SECONDARY NEUTRONS GENERATED BY MEDICAL LINEAR ELECTRON ACCELERATOR

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Bremsstrahlung produced by medical linear high-energy electron accelerators, is commonly used instead of gamma-ray radiotherapy facilities in modern radiation therapy. For linear accelerators with electron energies up to 10 MeV incident on the target, secondary neutron radiation is produced in addition to bremsstrahlung.

It is important to know the neutron contribution to the therapeutic beam to assess patient dose, as well as their contribution to the scattered radiation inside and outside the treatment room for dose assessment of personnel and the public due to the high danger of neutron radiation. Neutrons are produced at the materials of the accelerator head, mainly as a result of the interaction of gamma rays with atomic nuclei in the target, beam-line components and shielding. They are produced by the giant dipole resonance (GDR) [1]. GDR neutrons are produced by photons with energies from approximately 6 to 40 MeV. GDR occurs at lower energies of incident radiation for heavy nuclei in comparing to light nuclei. For example, for tungsten-183 and iron-57 which are the basic materials of the accelerator head the (γ, n) reaction threshold amounts 6.19 MeV and 7.65 MeV, respectively [2].

The contribution of secondary neutrons to the therapeutic beam and the scattered radiation field around the head of the medical linear accelerator has been assessed using Monte Carlo simulation of particle transport. The simulation was performed for Clinac - 2300C with an electron energy of 18 MeV using MCNP. A detailed model of the accelerator head was developed for the calculations. The model included a bending magnet, the target holder, the primary collimator, flattering filter, movable collimator, multileaf collimator, engineering materials and shielding.

Calculations show that the neutrons give a negligible contribution to the dose within the field of the therapeutic beam. However, their contribution increases markedly outside the therapeutic field.

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AURUM-DOPED $CdIn_2S_4$ SINGLE CRYSTALS FOR ROENTGEN DETECTION

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One of the most important ideas underlying the occurrence of *X*-ray conductivity is high absorptivity of the semiconductor material in the *X*-ray spectral region. In this regard, of special interest are high-resistance semiconductor materials. These are compounds of $A^{II}B_2^{III}C_4^{VI}$ type (A^{II} = Zn, Cd; B^{III} = Al, Ga, In; C^{VI} = S, Se, Te). Among the representatives of this class of materials are $CdIn_2S_4$ single crystals. Information on luminescence and photoelectric properties of these single crystals can be found in the literature; however there are no data on their *X*-ray conductivity. The objective of this study is the investigation of *X*-ray electric properties of $CdIn_2S_4$ single crystals doped by aurum.

$CdIn_2S_4$<Au> compound was prepared using the method of high-temperature synthesis by alloying high-purity constituents in an evacuated quartz ampoule. $CdIn_2S_4$<Au> single crystals were grown from synthesized pellets by the chemical transport technique with iodine as a carrier gas. Single crystals thus obtained had an octahedral shape with clear-cut faceting and a high optical transparency.

The registered range of the *X*-rays energy was 25 – 50 keV and the range of the measured power was 0.78 – 78.05 R/min. All measurements were carried out at $T = 300$ K. The roentgensensitivity coefficient of the crystals under investigation was calculated by the formula: $K = \Delta I_r/(U \cdot E)$, where ΔI_r is roentgencurrent; U is the applied voltage and E is a dose rate.

The effect of doping $CdIn_2S_4$ single crystals by aurum (3 mol.%) on their roentgenconductivity and *X*-ray dosimetric characteristics is investigated. It is found that the characteristic coefficient of *X*-ray sensitivity of $CdIn_2S_4$<Au> single crystals increases 22.5 times compared with undoped $CdIn_2S_4$ at effective radiation hardness 25-50 keV and dose rate 0.75-78.05 R/min.

Thus, it can be concluded that aurum-doped (3 mol.%) $CdIn_2S_4$ single crystals are highly sensitive to *X*-rays and can be used for designing uncooled *X*-ray detectors.

RADIATION EFFECTS OF NEAR-FIELD IN GAMMA ACTIVATED NANOPARTICLES ZrO_2–CATALYSTES IN METHANOL CONVERSION

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On the example of a model system of methanol the conversion influence of effects of γ-activation of nano ZrO_2- catalysts is investigated on their functional characteristics in the processes of heterogeneous catalysis. Influence of γ–activated nanopowder ZrO_2 on direction and reaction yield was controlled up on the series of experiments at room temperature with ZrO_2 in their initial and the γ-activated state. Activating of samples was carried out by bremsstrahlung on high-current electronic accelerator in NSC KIPT at energy of electrons 22 MeV and a current 500 μA. The features of structural transformations in γ-activated ZrO_2 were researched the method of *X*-ray diffractometry. It was shown that in the structure of ZrO_2 no essential changes and γ-activated particles of oxide keep monophase state and crystallinity of the initial state. Catalytic activity of ZrO_2 before and after their γ-activated was estimated on the absorbency of products of conversion reaction of methanol on the spectrophotometer of SF-46. The found out the sharp increase of activity of ZrO_2-catalystes after their γ-activated is ascribed to *synergy* of factors of ionizing radiation - big ionization losses of Auger electrons near a surface ZrO_2 nanoparticles from ^{89}Zr - and influences of high-reactionary formations of heterogeneous catalysis.

ELEMENT ANALYSIS OF BIOLOGICAL SAMPLES OF CHILDREN WITH DIFFERENT CHRONIC DISEASES BY ACCELERATOR BASE TECHNIQUES

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Nuclear-physical methods (γ-activation analyses, PIXE, RFA) were used for determination of essential elements, toxic elements and isotope ratio $^{44}Ca/^{48}Ca$ in biological samples (hair, blood, serum, plasma, stomach slime).

Clinical course of different chronic diseases of children (9–14 old years) was investigated. Changes of state of mineral component in bone metabolic diseases which accompany chronic gastrointestinal diseases, acute obstructive bronchitis and bronchial asthma, dermal diseases were studied with help of nuclear-physical methods.

The biological samples (weight about 1 g) were irradiated by bremsstrahlung from the high-power electron accelerator (700 μA, E=25 MeV) [1]. Radiation was registered by the Ge(Li)-detector with energy resolution of 2.8 keV for line 1333 keV. The isotopic ratio $^{44}Ca/^{48}Ca$ was determined by means of nuclear reactions $^{48}Ca(\gamma,n)^{47}Ca$, $^{44}Ca(\gamma,n)^{43}K$. The detection limit was ranged from 10^{-5}% mass (for Ca and Pb) to 10^{-7}% mass (for I). The PIXE was used on tandem accelerator with energy 1–3 MeV [2].

The statistical analysis methods (correlation analyses, regression analyses, density function of probability) were used for describing the changes in the biological samples. The high correlation coefficient were between isotope ratio $^{44}Ca/^{48}Ca$, Pb, I, Se, Ca, and clinical data of various chronic diseases. Possible therapeutic correction of trace elements metabolism and improvement are discussed.

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IMPLANTATION OF IONS ^{8}He, Kr AND Xe IN NUCLEAR TRACK EMULSION

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The ACCULINNA fragment separator in the G.N.Flerov Laboratory of Nuclear Reactions was used to irradiate a nuclear track emulsion by a beam of radioactive ^{8}He nuclei of energy of 60 MeV and enrichment of about 80%. Measurements of 278 decays of ^{8}He nuclei stopped in the emulsion allow one to evaluate possibilities of α-spectrometry and to observe a thermal drift of ^{8}He.

At the accelerator complex IC-100 a nuclear track emulsion is exposed to beams of ions ^{86}Kr^{+17} and ^{132}Xe^{+26} with energy of about 1.2 *A* MeV. Measured ranges and scattering angles of Kr and Xe ions are compared with the values calculated in the model SRIM.

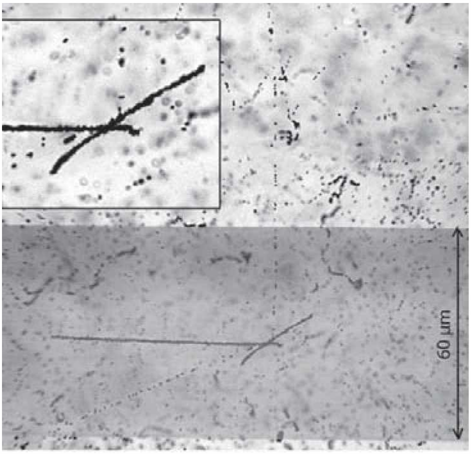

Fig. 1. Mosaic macrophotography of a hammer-like decay of ^{8}He nucleus (horizontal track) stopped in nuclear track emulsion. Pair of electrons (point-like tracks) and pair of α-particles (short opposite tracks). On insertion (top): enlarged decay vertex. To illustrate special resolution the image of the decay is superimposed to macrophotography of a human hair of thickness of 60 μm.

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STUDY OF ELECTRONIC PROPERTIES OF TRANSITION METALS AND ALLOYS BY POSITRON ANNIHILATION SPECTROSCOPY

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We have analyzed a number of data on the electronic properties of the pure metals [1][http://zldm.ru/upload/iblock/53b/20097506027.pdf]. For transition metals there is a clear correlation between the melting point and the number of unpaired *d*-electrons. We think that the unpaired *d*-electrons characterize the tendency of metals to the formation of covalent bonds, which are stronger than metallic bonds. This process of formation of such bonds is likely activation character. These properties and determine the increase of the melting point with increasing the number of unpaired electrons *d*-electrons. These effects may also explain the presence of possible modified ductile-brittle transition - type Ioffe in structural materials (metals and alloys) under irradiation with neutrons at elevated temperatures. The temperature of the brittle-ductile transition Ioffe sensitive to impurity content) and the structure of the material. Especially important is the brittle fracture in those cases when it occurs at sufficiently high temperatures (room temperature and above). Indeed irradiation by neutrons of metals and alloys at temperatures of less than $0.3T_m$, wherein T_m - the melting point, increases its strength due to the formation of radiation damage and defects, which are an obstacle to the movement of dislocations, but in this case the radiation substantially, and in large doses drastically worsens their deformation and plastic properties . This circumstance (radiation embrittlement) limits the service life of many alloys used in nuclear power: with increasing radiation dose sensitivity to impact alloys increases.In our experiments with the reactor steels it has been found that the concentration of electrons in the conduction band decreases with increasing neutron fluence. We have entered value

$$\alpha_k \approx \frac{n(\text{irrad}) - n(\text{rad})}{n(\text{irrad})},$$

characterizing the degree of covalent chemical bonds. Here $n(\text{irrad})$– concentration of electrons in the conduction band in the irradiated metal, and $n(\text{rad})$– concentration of electrons in the conduction band of irradiated metal. Based on the experimental data: $n(\text{irrad})=11.9\cdot10^{22}\,\text{cm}^{-3}$, $n(\text{rad})=9\cdot10^{22}\,\text{cm}^{-3}$. Hence the degree of covalence of the chemical bond is the value of $\alpha_k \approx 0.25$. The research vessel steels used in operating reactors VVER- 440. In the samples studied steels identified vacancy defects, including those caused by neutron irradiation, and are defined by their size.

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$^{44}Ti(^{44}Sc)$ - PAC STUDY IN TiO_2 AND Sc_2O_3

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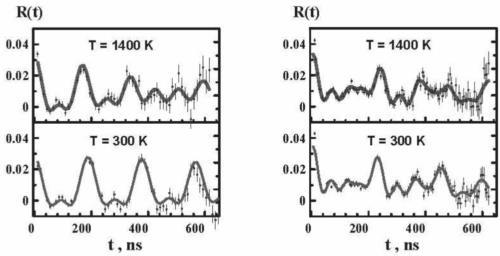
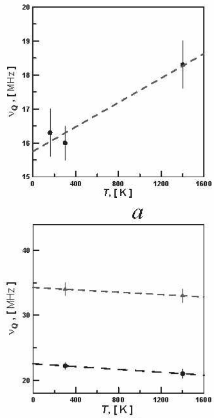
Titanium dioxide (TiO_2) is used like photocatalyst and electronic data storage material. The scandium oxide (Sc_2O_3) is used in high-temperature systems and high frequency electronic ceramics. Authors in works [1, 2] have been carefully studied the TiO_2 and Sc_2O_3, but only at room temperature. We studied the high temperature influence on the electric field gradients (EFG) in sites of Ti and Sc, by method of perturbed angular correlation (PAC) with $^{44}Ti(^{44}Sc)$. Have been used the 4-th detectors spectrometer [3] and NaI crystals with size 50x5 mm. We prepare the sample by method co-precipitation. This gets us the structure without defects, and we have got the intensity of EFG according to the relative abundance of each site in the lattice. In Sc_2O_3 have two nonequivalent sites for the metal cations, without axially symmetry - called C and with axially symmetry - D, both 6-Oxygen coordinated. Their relative abundance in the lattice is $fC / fD = 3$.



a *b*

Fig. 1.



b

Fig. 2. Temperature dependence of ν_Q on ^{44}Sc in: a) TiO_2 ; b) Sc_2O_3.

On Fig. 1 *a* (*b*) the PAC spectra of ^{44}Sc measured at room and high temperature in TiO_2 (Sc_2O_3) are shown. And on Fig. 2 *a*, *b* the dependence of ν_Q versus temperature is shown. We observed that in TiO_2 the quadrupole frequency (ν_Q) increases when the temperature increasing, while in Sc_2O_3 the ν_Q slowly decreases when temperature increases.

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COMPARATOR UNITS FOR METROLOGICAL CERTIFICATION OF WEAK *X*-RAY AND GAMMA RADIATION FIELDS BY DOSE RATE

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Comparator units based on commercially available detection units can be used to certify parameters of weak standard fields of *X* and gamma radiation by method of comparison.

Comparator unit consists of BDKG-05M spectrometric detection unit for gamma radiation, BDKR-01M spectrometric detection unit for *X* radiation, and a PC with dedicated application software.

Spectrometric dosimetry method based on the principle of conversion of measured instrument spectrum is used to build comparator units from BDKR-01M and BDKM-05M detection units. This method of dose rate calculation by "spectrum-dose" transformation operator allows finding the full dose rate value by applying the function $G(E)$ without conversion of spectrum from measured amplitude distribution map of photon radiation [1].

In order to find the conversion function $G(E)$ we calculated instrument functions of detection unit response to parallel monoenergetic gamma radiation flux in 50 keV – 350 keV energy range for BDKR-01M and in 20 keV - 3000 keV for BDKG-05M, as well as other parameters. The calculation was carried out by Monte Carlo method on SNEGMONT software [2].

The results are used as a baseline to assess energy dependence of scintillation detectors' dose sensitivity and determine "spectrum-dose" transformation operators to measure air kerma dose rate, ambient equivalent dose rate and exposure dose rate.

Specially selected detectors with high measuring path stability and low resolution, and application of the above approach allow using detection units in photon radiation metrology to calibrate standard and working measuring instruments with maximum error 3% – 6% by applying weak *X* and gamma radiation fields in the energy range from 5 keV to 3000 keV.

ATOMTEX Scientific and Production enterprise (Minsk, Belarus) and Federal State Unitary Enterprise "D.I.Mendeleyey Institute For Metrology" (St. Petersburg, Russia) are planning to use these comparator units in parallel for metrological purposes.

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MuSun EXPERIMENT: THE CONTROL OF IMPURITIES IN ULTRACLEAN DEUTERIUM GAS

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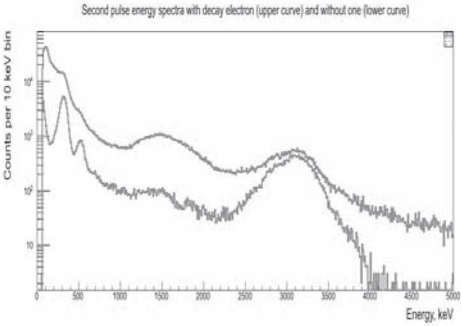
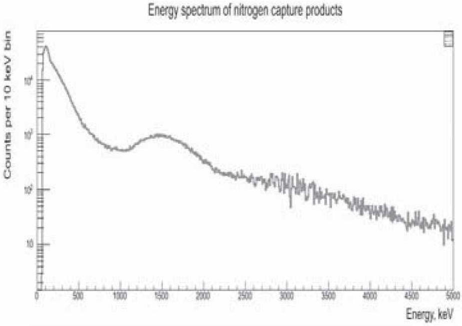
The MuSun experiment is aiming to measure the rate of muon capture by the simplest nucleus, the deuteron. This is the simplest weak interaction process on a nucleus that can both be calculated and measured to a high degree of precision. The capture rate has to be evaluated to better than 1.5% precision by measurement of the difference between the lifetimes of positive and negative muons in deuterium-filled TPC. This method requires reliable registration of muon stops in deuterium gas in TPC. The experiment requires the highest level of deuterium gas purity, considering all admixtures with $Z>1$ on the level of 1 ppb [1], maintained during running periods of several months. This critical and challenging task is achieved by continuous gas purification with the system CHUPS, and the purity must be verified. In the main runs, the TPC will be operated at T=31 K and P=5 bar, corresponding to 0.064 density of LH_2. At such conditions, only nitrogen admixture can remain in deuterium gas at unsuitable level of ~20 ppb. We use two independent methods of measurement of nitrogen concentration in deuterium: 1) chromatographic analysis of deuterium gas;
2) registration of recoiled carbon nuclei after muon capture by nitrogen nuclei in the TPC volume.





This talk reports the recent progress in the second method of evaluation of nitrogen concentration in deuterium gas at the level of 1 ppb and lower. The energy spectra of second pulses observed in the TPC is shown on the upper figure (The 1st pulse is the muon stop signal). The upper curve is the spectrum of 2nd pulses when the signal of decay electron is absent. The lower curve is the same with the muon decay electron present. The difference between them is the spectrum of all the products of muon capture by nitrogen (on the lower figure). The peak of recoiled carbon nuclei is seen at 120 keV energy.

This method makes possible the evaluation of the muon lifetime correction even without precize knowledge of nitrogen concentration.

1. http://muon.npl.washington.edu/exp/MuSun/documents/prop07.pdf.

CRYOGENIC TIME–PROJECTION CHAMBER FOR MEASUREMENT OF MUON CAPTURE RATE ON THE DEUTERON

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The motivation of the MuSun experiment is to measure the rate Λ_d for muon capture on the deuteron to better than 1.5 % precision 0. This process is the simplest weak interaction process on a nucleus that can both be calculated and measured to a high degree of precision. MuSun is the evolution of preceding study of muon capture on the proton, the MuCap experiment 0. The MuSun experiment is carried out at the world's most intense muon source of Paul Sherrer Institute (Switzerland). The central detector of the experiment is the Cryogenic Time Projection Chamber (CryoTPC). CryoTPC is the active target which detects the muon stop event in deuterium and positions its spatial coordinates. CryoTPC is filled with deuterium at the pressure of 5 bar and the temperature of 31 K. These conditions are defined by the demands of the reaction kinematics and provide required gas density. The applied high voltage of 10 kV/cm gives a possibility to identify confidently the muon stops, captures on deuteron or heavy admixtures and fusion events.

The experimental setup includes: *a*) the cooling system on the base of the cryorefrigerator and the neon heat pipe. This system supports the temperature stability of ± 0.05 K in the range of 23-300 K; *b*) the cryogenic purification system 0. The system produces the continuous circulation of deuterium by the cryogenic adsorption compressor with the purification in the cryogenic adsorber. System supports the flux up to 5 standard liters per minute and stabilizes the pressure with the accuracy of 1 mbar at 3-12 bar level. The system supports purity of the working gas at the level of 1 ppb of residual air admixtutes; *c*) the cryogenic distillation system 0 for isotopic purification of deuterium. This system produces deuterium with the protium concentration less than 100 ppb.

Auxilary systems: automatic liquid nitrogen refilling system, high voltage system, readout system with cooled preamplifiers, vacuum system. All parameters of the CryoTPC system are controlled by slow control system and included into the common dataflow of the experiment.

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"IN SITU" MONITORING OF SOIL CONTAMINATION BY MULTIFUNCTIONAL AT6101DR PORTABLE GAMMA SPECTROMETER TAKING INTO ACCOUNT RADIONUCLIDE DEPTH

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Emergencies in nuclear fuel cycle plants result in radioactive contamination of environment. That is why one of radiation monitoring objectives is monitoring of soil contamination level affected by radioactive emissions.

"In situ" method on the basis of AT6101DR portable gamma spectrometer allows soil radiation monitoring and can be particularly used to measure activity of natural (^{40}K, ^{226}Ra,^{232}Th) and industrial (^{134}Cs, ^{137}Cs) radionuclides, as well as to determine the depth of industrial ^{134}Cs and ^{137}Cs radionuclides in the soil without sampling.

AT6101DR portable gamma spectrometer is a multi-function instrument, which consists of BDKG-11 spectrometric scintillation detection unit inside sealed container and a handheld PC with application software. It has measurement range of gamma radiation energy distribution from 50 to 3000keV.

Simulation model of gamma-quanta transfer from soil to detector working medium, simulation model of soil and of spectrometer's detection unit have been developed.

Results of mathematical simulation made it possible to calculate functional dependence between effective radiuses of soil and therefore to determine the spectrometer's sensitivity to monitored radionuclides depending on their depth in the soil. Instrument spectra for industrial ^{134}Cs and ^{137}Cs radionuclides are calculated for different depths (2 cm, 5 cm, 10 cm and 15cm).

The depth of monitored radionuclide in soil is determined by detector response function obtained in the process of mathematical simulation, which reproduces model spectrum to the specified accuracy. Radionuclide depth measurement also allows identification of radionuclides present in the sample.

RESONANT DIFFUSION OF BERYLLIUM MOLECULE

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The report represents the calculation of the probabilities for resonant tunneling [1] of realistic beryllium molecule comprising a continuous spectrum through the potential barriers of the Gaussian type. The parameters of the barrier potential correspond to the potential surface of copper crystal (001) for the hydrogen atom.

Based on the derived probability we calculated the diffusion of beryllium molecule. The quantum coefficient of diffusion in solids can be written in the form $D_{qua} = D_0 F(T)$, and transforms to the coefficient of classical diffusion $D_c = D_0 e^{-E_{\max}/T}$ at high temperature.

Comparison of different types of diffusion is illustrated in Figure 1. The quantum diffusion of the molecule is shown by the solid line. For comparison, we calculated the classical diffusion of the molecule (dot-dashed line), quantum diffusion of the atom (dotted line) and of rigid molecule (dashed line).

It can be seen that at the temperatures below 80 K the molecular diffusion is much higher than atomic. The differences reach 8 orders.

The work is performed within the framework of grant RK MES 0602/GF.

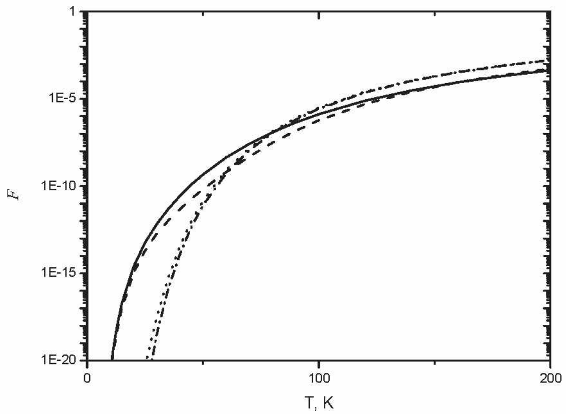

Fig. 1. Comparison of different types of diffusion for beryllium molecule.

1. F.M.Pen'kov. // Phys. Rev. A. 2000. V.62. 044701-1,4.

INFLUENCE OF GAS PRESSURE ON INTENSITY OF THE PYROELECTRIC *X*-RAY SOURCES

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The idea of using pyroelectric crystals for *X*-ray generation was raised by J.D. Brownridge [1]. Changing the temperature of the pyroelectric crystal of about one hundred degrees results in the formation of the uncompensated electrical charges on the surfaces sufficient to generate the electric field with a potential of a few tens of keV. These fields cause ionization of residual gas atoms and create beams of accelerated electrons and ions. The interaction of accelerated electrons with the crystal and the target leads to the generation of *X*-ray bremsstrahlung and *X*-ray characteristic radiation.

The pyroelectric devices can also be used to generate neutrons [2, 3]. Nuclear fusion reaction D + D = He3 + n has been implemented in a device in which pyroelectric crystal of lithium tantalate and deuterated target were placed in a deuterium gas. Currently pyroelectric devices are considered as promising mobile sources of *X*-rays and neutron radiation having small dimensions and low power.

This paper is devoted to the choice of gas and to the study the effect of pressure on the *X*-ray radiation intensity. Experiments were carried out in a vacuum chamber in which a pyroelectric crystal of lithium niobate $NbLiO_3$ and a copper foil as a target (thickness of 15 micrometers) were placed. The crystal temperature was measured by a copper-constantan thermocouple. *X*-ray intensity was measured during heating-cooling cycles in the temperature range 25°C – 125°C – 25°C. The gases air, helium, nitrogen and argon were investigated.

In the report the experimental data on the optimal gas pressure corresponding to the maximum intensity of *X*-rays will be presented. A qualitative model of the processes in pyroelectric sources will be considered.

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2. B.Naranjo *et al.* // Nature. 2005. V.434. P.1115.
3. J.Geuther *et al.* // Phys. Rev. Lett. 2006. V.96. 054803.

SUPERCONDUCTING TUNNEL JUNCTION *X*-RAY DETECTORS: TEMPORARY SHAPE OF THE SIGNALS

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Detectors based on superconducting tunnel junctions (STJ detectors) have an excellent energy resolution and low energy threshold and can be used in the precision *X*-ray, ultraviolet and optical spectroscopy [1]. In *X*-ray range the energy resolution of about 10–20 eV for the 5.9 keV is substantially better than the resolution of 140–150 eV of typical silicon detectors. Unfortunately, the real energy resolution is noticeably worse than the theoretical predictions. The reason of the energy resolution degradation is a complex process of the detector signal formation, which is affected by the electron and phonon subsystems of both electrodes.

In this paper, the temporal shape of the detector signals was calculated for different models of STJ detectors. The results are compared with experimental data obtained for the so-called detectors with killed electrode [2]. These detectors have a multilayer structure of electrodes and described by the following formula Ti/Nb/Al-AlO_x/Al/Nb/NbN where Al/Nb/NbN is the main multilayer electrode and Ti/Nb is the killed electrode.

Shape of the signals was calculated on the basis of 2D-diffusional model of quasiparticle motion in both electrodes of STJ-detector. The model takes into account the qusiparticle tunneling by electron and hole channels, quasiparticle losses in the volume of the electrode and at the electrode boundaries, self-recombination terms and 2Δ-phonon exchange between electrodes. The signals related to the quantum absorption in the main electrode and in the killed electrode were considered.

It is shown that the self-recombination and 2Δ-phonon exchange cause a noticeable changing in the temporal shape of the detector signals. Both mechanisms result in additional broadening of the spectral line. The ways of decreasing of these negative effects are discussed.

1. P.Lerch, A.Zender. Quantum Giaever Detectors in Cryogenic Particle Detectors. Topics in applied physics. Christian Enss, (Editor) Springer. 2005. V.99. P.217.
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PREPARATION FOR EXPERIMENTAL SEARCHING FOR STERILE NEUTRINO

Serebrov A.P.[1], Fomin A.K.[1], Zinov'ev V.G.[1], Loginov Yu.E.[1], Onegin M.S.[1], Gagarskiy A.M.[1], Petrov G.A.[1], Solovei V.A.[1], Chernyi A.V.[1], Zherebtsov O.M.[1], Antonov N.E.[1], Martem'yanov V.P.[2], Tsinoev V.G.[2], Tarasenkov V.G.[2], Aleshin V.I.[2], Petelin A.L.[3], Pavlov S.V.[3], Svyatkin M.N.[3], Izhutov A.L.[3], Sazontov S.A.[3], Ryazanov D.K.[3], Gromov M.O.[3], Khramkov N.S.[3], Rykalin V.I.[4]

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The "Neutrino-4" experiment for the 100-MW SM-3 reactor in Dimitrovgrad has been developed with the aim of testing the reactor antineutrino anomaly [1, 2] and foundation oscillation to sterile state at Petersburg Nuclear Physics Institute. The advantage of this reactor for studying the antineutrino anomaly is a low background level and small volume of the active zone. The model of antineutrino detector was built and the first measurement was carried out at the distance of 6-10 m. from active zone of the reactor.

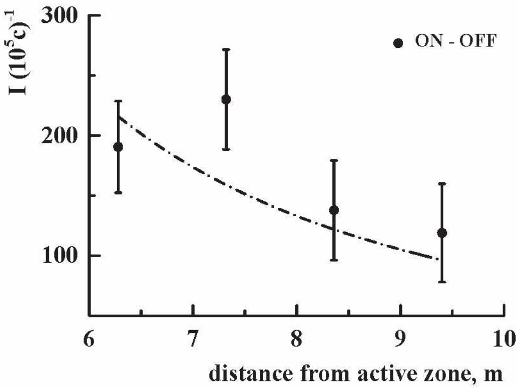

Fig. 1. Verification of $1/r^2$ law by least-squares procedure approximation.

1. G.Mention, M.Fechner, Th.Lasserre *et al.* // Phys. Rev. D. 2011. V.83. 073006.
2. T.Mueller, D.Lhuillier, M.Fallot *et al.* // Phys. Rev. C. 2011. V.83. 054615.

COMPENSATION MECHANISM OF BREMSSTRAHLUNG ANGULAR SPECTRUM DEPENDENCE AT EVALUATION OF EFFECTIVE ATOMIC NUMBER BY DUAL ENERGY ABSORPTION METHOD

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There are measurements results of bremsstrahlung fields of linear electron accelerator UELR-6-1-D-4-01 with 6 / 3.5 MeV energies measured on arc-like detector line with 2112 CWO-scintillator-PIN photodiode sensitive elements on inspection system S*T*-6035 at Pogranichny customs check-point, Primorsky Krai, are shown. Angular dependence of bremsstrahlung effective energy is experimentally measured. Angular drift effect of evaluated atomic number of scanned object material on radioscopic image by dual energy absorption method is measured.

There is mathematical apparatus of analytical calculation of bremsstrahlung spectral and angular distribution generated in combined thick target of linear electron accelerator is proposed and approbated.

Results of angular drift compensation of evaluated effective atomic number by means of proposed mathematical apparatus are given.

THE COMPLEX OF NEUTRON TRANSMUTATION DOPING OF SILICON ON THE BASIN TYPE REACTOR LIKE IRT

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The modern industry is impossible without the use of radiation technology products. Especially, it can be seen when a creating of new power electronics devices that are based on a neutron-doped (NTD) silicon. NTD technology, among all the existing methods for doping silicon, provides the highest uniformity of electrophysical parameters of semiconductors. Therefore NTD silicon is widely used in the world in order to create devices with minimal scatter of electrical resistivity: thyristors, charge coupled devices, VLSI, radiation detectors, photodetectors [1]. The principal difference silicon doped with neutrons from conventional methods is the dopant – phosphorus is not input into the starting material from outside, and it is formed during the irradiation of the atoms directly doped material:

$$^{30}\text{Si}(n,\gamma)^{31}\text{Si} \xrightarrow{\beta^-} {}^{31}\text{P} \qquad (1)$$

With the help of this implantation method, there are opportunities to control the dopant concentration. Moreover, one of the major advantages of this method of phosphorus input in silicon is a good repeatability of doping and obtaining desired materials. [2, 3]

On the reactor IR*T*-T in 1986 the facility for NTD silicon ingots with diameter up to 4 inch with world-class quality was put in place. However, currently a growing demand in the electronics industry on NTD silicon wafers diameter of 5 inches and above. In this regard, researches of the parameters of the neutron fields of HEC-4 of IR*T*-T was conducted in order to clarify the possibility of creating a new facility with a higher productivity for NTD silicon ingots up to 5 inches.

The result of researches is a theoretical model of the silicon ingots motion in the irradiation zone was developed. The implementation of this model was carried out on a horizontal experimental channel HEC -4 IR*T*-T. Automated facility was created for the irradiation of silicon ingots with length up to 700 mm and diameter up to 130 mm. The spatial inhomogeneity of doping does not exceed 5 %. The productivity of the facility for silicon ingots with a diameter of 5 inches and nominal electrical resistivity of 60 ohm·cm is equal 2 kg / h. The quality of NTD silicon is not inferior to the world standards.

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MEASUREMENT OF THE TENSOR ANALYSING POWER COMPONENTS OF THE π^- PHOTOPRODUCTION ON DEUTERONS AT LARGE PROTON MOMENTA

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The simultaneous measurements of three components of tensor analyzing power results are shown for exclusive negative pion photoproduction reaction, provided at the energy range 300–900 MeV. The experiment was performed using internal polarized deuterium target at the VEPP-3 electron storage ring with coincidence proton registration.

From comparisons of obtained dependencies with theoretical predictions made in spectator model and in the impulse approximation with FSI one can consider that for pion photoproduction at large proton momenta, it is required to take into account in addition to πN and NN interactions, more complicated mechanisms of reaction, in particular, ΔN interaction at the intermediate states.

DETERMINATION OF THE NEUTRON / GAMMA SEPARATION THRESHOLD ON SINGLE CRYSTALS OF STILBENE

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To measure the neutrons was used ^{252}Cf with a half – life $T_{1/2} = 2.645$ y., which is the source of neutrons and gamma-rays [1].

In processing the data is very important to discard background - event registration of gamma quanta. Separation of pulses of neutrons from gamma rays was achieved using the pulse shape discrimination. Bringing all the modules to the same species, it will not make any difficulties to allocate necessary amplitudes and define a separation threshold.

From Fig. 1. we see that the the neutron / gamma separation threshold of the first detector is 68 keV and 55 keV for the second detector.

The results obtained are in very good agreement with other experimental data [2,3].

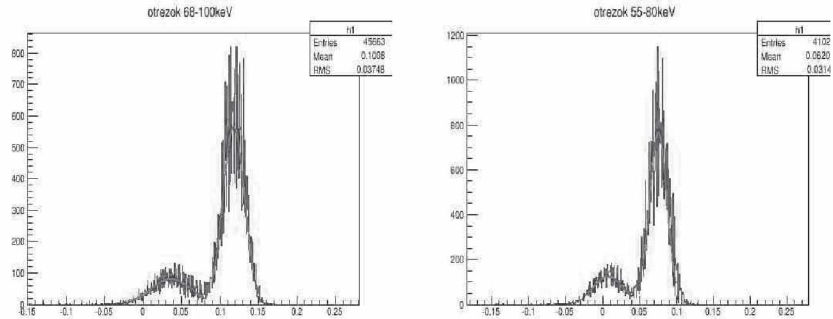

Fig. 1. Threshold of neutron / gamma separation. Left 68-100 keV interval for the first detector and right 55-80 keV interval for the second detector. Left peak for neutrons, the right peak for gamma-ray.

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2. S.D.Ambers, M.Flaska, S.A.Pozzi. // Nuclear Instruments and Methods in Physics Research. A. 2011. V.638. P.116.
3. Neutron-gamma pulse shape discrimination with a NE-213 liquid scintillator by using digital signal processing combined with similarity method. Mardiyanto, 122/Akred-LIPI/P2MBI/06. 2008.

OPTIMIZATION OF THE PARAMETERS OF DETECTORS ARRAY BASED ON CsI (Tl) FOR REGISTRATION OF CHARGED PARTICLES IN EXPERIMENT AIMED TO DETERMINE 2p DECAY OF THE ^{17}Ne

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The nucleus ^{17}Ne could be a possible candidate for simultaneous two-proton decay [1]. The main (and only) well-known branch of the ^{17}Ne collapse from the first excited state (E*=1.288 MeV) is the gamma decay. Coherent emission of two protons, which must at first get a system of ^{16}F+p, then^{16}F broke up to ^{15}O+p, prohibited by the law of energy conservation. It follows that one of the possible experiments is to search for weak branches of a real two-proton decay that state in transfer reactions ^{1}H(^{18}Ne, d)^{17}Ne, with beam energy 25-35 MeV/nucleon of ^{18}Ne. By achieving of a reasonably good energy resolution of about 300 Kev FWHM, it is possible to separate 1.288 MeV resonant state from the background caused by the settlement of resonance states with energies 1.764 and 1.908 MeV.

Such an experiment to detect 2p decay of ^{17}Ne was carried out in the Laboratory of Nuclear Reactions, in Dubna (Russia), on a fragment separator ACCULINNA in April - May 2013. Figure 1 shows the required detection system for experiment of 2p decay of ^{17}Ne consisting of two stranded cameras for tracking particles and also round and square telescopes.

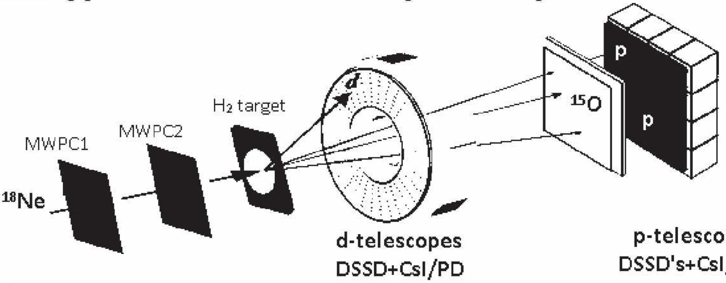

Fig. 1. Scheme of detectors is situated in the chamber of the fragment - separator ACCULINNA.

Several types of scintillators were chosen and investigated for making this array of detectors.

In the framework of this work was designed 16 channel square scintillation detector, which is the part of the square telescope. Square telescope was used to detect particles going from the target at small angles.

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OPERATIONAL EXPERIENCE WITH 55 MeV PULSED RACE-TRACK MICROTRON

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RTM [1, 2] has been built following a classical scheme with two 1 T end magnets and a standing wave linac between them providing 5 MeV energy gain per pass. A 50 keV beam from an electron gun is injected into linac through a 45° magnet and a solenoidal lens. Pulse length is 6 mks, repetition rate is from 6.25 to 50 Hz. The 5 MeV electron beam after the first acceleration is reflected by the end magnet field back to the linac axis and is accelerated up to 10 MeV - the energy sufficient to bypass the linac at the next turn. The 55 MeV beam is extracted from the last orbit with a dipole of 17.5° deflecting angle. Maximum exit pulsed beam current is 3mA. The RF system is based on a 6 MW multibeam klystron KIU-168. A pumping port, a vacuum window, and a circulator are installed between the linac and the klystron. Parameters of the vacuum window and the circulator during commissioning restricted the maximum RF power transported to the linac by 2.5 MW and thus restricted a. To simplify the RF system we use a auto-oscillation mode of klystron operation with accelerating structure in a feed-back loop.

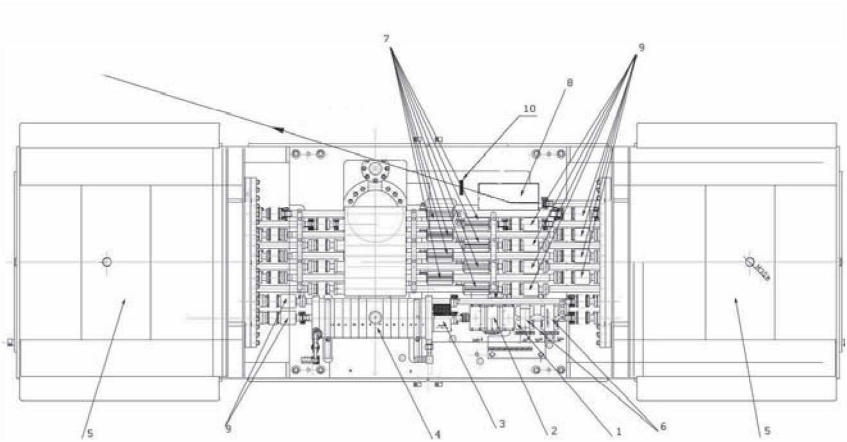

Fig. 1. RTM scheme. 1 – electron gun, 2 – injector magnet, 3 – solenoidal lens, 4 – linac, 5 – end magnet, 6 – quadrupole lens, 7 – steering coils, 8 – extraction magnet, 9 – beam current monitors, 10 – experimental place.

1. A.I.Karev, A.N.Lebedev, V.G.Raevsky, *et al.* // RuPAC. 2010. P.316.
2. V.V.Khankin, N.I.Pakhomov, V.I.Shvedunov, *et al.* // RuPAC. 2012. P.538.

ROLE OF PHOTONUCLEAR REACTIONS PRODUCTS IN THE EQUIVALENT DOSE CALCULATION

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To calculate the equivalent dose that characterizes biological hazards of ionizing radiation special factors called the radiation weighting factor (RWF) are used. The values of these coefficients depend on the type and the energy of radiation [1].

A technique which allows the calculation of the average value of the radiation weighting factor of all types of radiation induced by the passage of photons through thin layers, including photonuclear reactions, is proposed.

RWF is evaluated for thin layers of water and biological tissue considering photoproton and photoneutron nuclear reactions for monochromatic photon radiation in the energy range from 10 to 30 MeV. Using a thin layer of biological material with averaged chemical composition the absorbed energy can be used as a measure of the absorbed dose. The contribution of all types of induced radiation to the absorbed energy is calculated. The relation between the values of all RWF of all types of induced radiation and the photon energy, calculated for biological tissue layers of different thicknesses, is obtained. Despite the low probability of formation, protons and recoil nuclei significantly contribute to the absorbed energy in a thin layer. Their contribution is essentially dependent on the dose and the peak is from 76.0% at a photon energy of 23 MeV for biological tissue layer of 0.1 mm to 8.5% at a photon energy of 24 MeV for a layer of 10 mm. Taking into account the high values of the radiation weighting factor of protons and recoil nuclei the value of RWF of all types of induced radiation reaches 8 for biological tissue thickness of 0.1 mm at a photon energy of 25 MeV. Thus, even when only photoproton and photoneutron reactions are taken into account, RWF of photons can exceed the recommended by the ICRP value of 1 by several times.

1. Conversion Coefficients for Radiological Protection Quantities for External Radiation Exposures. ICRP Publication 116, Ann. ICRP 40(2–5). ICRP, 2010. P.257.

DEVELOPMENT OF THE VERSATILE LEETECH PLATFORM AT THE PHIL PHOTOINJECTOR

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New flexible facility was proposed to be constructed at the photoinjector PHIL at LAL, Orsay. The proposed setup will provide a powerful tool for wide range R&D studies of different detector concepts using "mono-chromatic" samples of low energy electrons with adjustable energy and intensity. The main principle is the selection of the "mono-chromatic" samples from the half-turn of electrons in the magnetic field. Main detector concepts to be studied with the new platform range from large area radiation resistant precision tracking, Micromegas/InGrid concept, and particle identification, to the beam monitoring using bent crystal technique. In the framework of by-product physics studies, *dE/dx* for non-relativistic electrons will be measured using Micromegas/InGrid detector for single primary electron cluster reconstruction. Main characteristics of the setup and simulation results are addressed by this paper. Full GEANT4 simulation of the facility performance was performed to optimize and construct the collimator system, vacuum chamber and related shielding for the experiment.

Control of 3 collimators (with independent moving of four jaws for each collimator) is provided through one master control board and 3 slave boxes. Master board communicates with the outer computer system using Ethernet local network. Interconnection between master and slave boards uses CAN interface protocol. Slave board controls four piezoelectric motors and feedback measurement systems (with precision a few micrometers) – one set for every jaw of collimator.

In addition possibility to obtain quasi monoenergetic positrons using PHIL facility is being studied.

This work was partially supported by PICS and partially funded by grant from State Fund of Ukraine for Fundamental Research (project #F58/04, agreement #F58/380-2013) in the framework of the Key HEP Research Laboratory.

DETERMINATION OF THE CONTRIBUTION OF REACTION $^{158}Gd(n,\gamma)^{159}Gd$ TO THE ABSORBED DOSE IN GdNCT

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Gadolinium neutron capture therapy (GdNCT) is one of the most promising methods of treatment of radioresistant forms of malignant tumors [1]. It uses natural gadolinium-containing preparations. Natural gadolinium consists of the following isotopes: ^{152}Gd (0.205%), ^{154}Gd (2.23%), ^{155}Gd (15.10%), ^{156}Gd (20.60%), ^{157}Gd (15.70%), ^{158}Gd (24.50%), ^{160}Gd (21.60%). From them ^{155}Gd and ^{157}Gd have very large (n,γ) cross sections. There are different estimates of the contribution to the total dose of the secondary particles produced in the nuclear reactions with neutrons in these isotopes of natural gadolinium. Thus the major reactions are neutron capture $^{155}Gd(n,\gamma)^{156}Gd$ and $^{157}Gd(n,\gamma)^{158}Gd$, which together account for > 90 % of the contribution to the absorbed dose [2]. The contribution of other reactions is considered insignificant. Therefore it is interesting to investigate the products of other nuclear reactions with neutrons. One of them is $^{158}Gd(n,\gamma)^{159}Gd$, where an excited nucleus ^{159}Gd becomes β-active. The analysis and evaluation of the contribution of the secondary particles produced in the reaction $^{158}Gd(n,\gamma)^{159}Gd$ to the absorbed dose in GdNCT is implemented.

1. L.S.Yasui *et al.* // Int. Jour. Rad. Biol. 2008. V.84. P.1130.
2. G.A.Kulabdullaev *et al.* // Uzbek physical journal. 2013. V.15. № 4. P.127.

OPTIMAL BREMSSTRAHLUNG ENERGIES TO MEASURE ATOMIC NUMBERS OF OBJECTS

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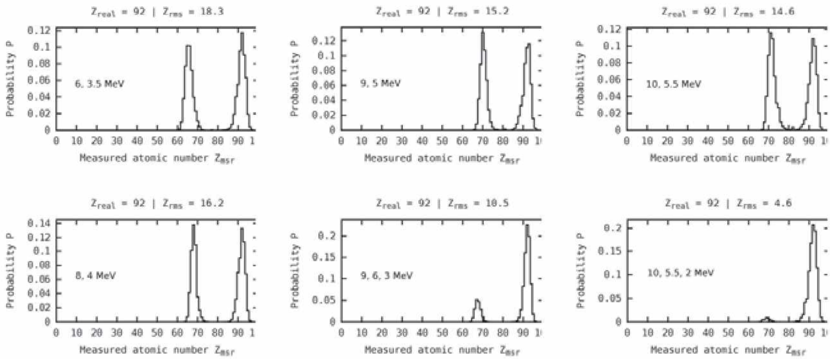
In this work we consider the influence of the bremsstrahlung energies on the accuracy of measurement of the atomic number of unknown objects Z. As a criterion of accuracy the mean deviation Z_{rms} of the measured values from the real atomic number of the object Z_{real} is used. Smaller Z_{rms} are considered to be better for identification. Several previous papers described an introscopic system based on the bremsstrahlung radiation from electron accelerator with tunable energy. A system with 8 and 4 MeV beam energies is described in Ref. [1], in Refs. [2, 3] – 6 and 3.5 MeV, in Ref. [4] – 9 and 5 MeV, and in Ref. [5] – 9, 6 and 3 MeV. In this work we perform optimization of energies for the case of two and three energies. The test object is a uranium cube with an edge length of 10 cm. The average total power of the electron beam is 5 kW. Energy range is from 0.5 to 10 MeV. The following estimates of optimal energy were obtained: 10 and 5.5 MeV for dual energy, and 10, 5.5 and 2 MeV for the triple energy method.



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2. LLC “Scantronic Systems”. References. 2013. http://scantronicsystems.com/en/projects
3. B.S.Ishkhanov, V.I.Shvedunov // Moscow University Physics Bulletin. 2012. V.67. No.6. P.475.
4. P.Bjorkholm // Port Technology International. 2005. V.PT22-6/4. P.1.
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USING OF THE 120-CM CYCLOTRON FOR THE STUDY OF SIMULTANEOUS IONIZING RADIATION AND HYPOMAGNETIC CONDITIONS EFFECTS ON THE SIMPLEST BIOLOGICAL OBJECTS

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Using the 120-cm cyclotron we studied the effect of α-particles under normal conditions and under low geomagnetic field (hypomagnetic conditions) on one of the simplest biological cell organism cyanobacteria *Synechocystis* sp. PCC 6803. The cell suspensions were irradiated in the cuvette with thin mailar walls. The energy of α-particles entering the solution was 24 MeV. The amount of linear energy transfer (LET) of α-particles was close to the LET of relativistic nuclei of the neon-magnesium group in galactic cosmic rays, which allows us to simulate their effect on biological objects.

The hypomagnetic conditions were created using a special three-component Helmholtz coils system, which allowed us to make the geomagnetic field up to 500 times lower.

The experiments showed several stable changes in the irradiated samples under low geomagnetic field compared to the control samples under normal field. It should be noted that the cell adaptation to hypomagnetic conditions (during 24 hours before irradiation) enhances the negative effects of ionizing radiation.

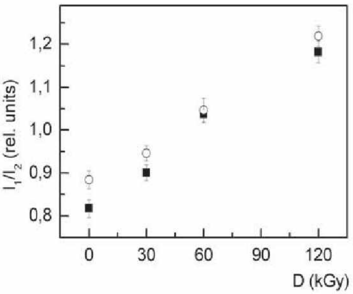

Fig. 1. The dependence of the intensity of the bands 650 nm (I_1) to 685 nm (I_2) (PBS to Chl) in the fluorescence spectra of the cell suspension Synechocystis, adapted to the normal (black squares) and hypomagnetic (open circles) conditions on the value of the absorbed dose D.

The presented method of modeling the galactic cosmic rays effect on biological objects using the 120-cm cyclotron and hypomagnetic conditions proved to be quite effective and reliable.

The work was performed by using equipment purchased by "Program for Development of Moscow University".

THE CODE BARON – THE TOOL FOR MODEL DESCRIPTION OF NUCLEAR ROTATIONAL BANDS

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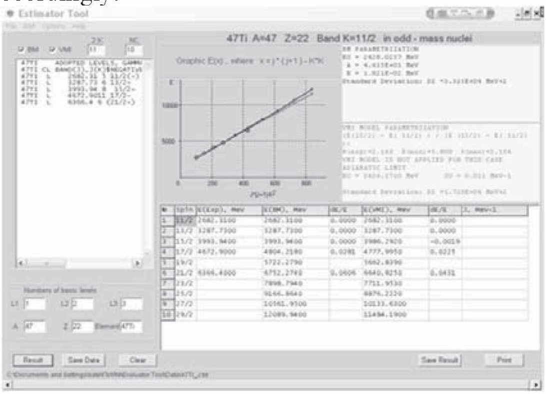
Code BARON (BAnds in ROtating Nuclei) is intended for determination of model parameters of the rotational bands depending on the energies $E(I,K)$ of the band levels by a method of the least squares. We used two the most popular parameterizations: polynomial one

$$E(I,K) = E_0 + A\left[I(I+1) - K^2\right] + B\left[I(I+1) - K^2\right]^2 + \ldots,$$

and the variable moment-of-inertia model

$$E(I,K) = E_0 + \frac{I(I+1) - K^2}{2J(I)} + \frac{C}{2}\left(J(I) - J_0\right)^2, \qquad \frac{\partial E(I,K)}{\partial J(I)} = 0.$$

Both approaches take into account signature corrections for the bands with $K = 1/2$ for odd-A nuclei [1], with K=0 and 1 for odd-odd nuclei [2] and with K=2 for even-even nuclei. Any sequence of levels (not less than three) with the differing values of the spin I and the fixed value of its projection K can be considered to be rotational band. To describe the signature effects in "short" bands with three levels we used the adiabatic approximation, B=0 and $C \to \infty$, accordingly.



The code BARON is supplied by the friendly interface facilitating its use. Initial data can be entered by user from a file or introduced manually. Any updating of the entered values or the extracting of separate levels from the fit procedure is possible. With the values of the parameters found the code BARON calculates a spectrum of the rotational band and builds the graphs for visual comparison and the control.

The code allows to keep results of the calculations in a standard form for the further use.

1. T.V.Alenicheva *et al.* Atlas of rotational bands in odd-A nuclei. PNPI. Saint-Petersburg, 2003. P.164.
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THE CODE ELENA: RADIATION PROPERTIES OF ELEMENTS AND ISOTOPES FOR THE ANALYSIS WITH NEUTRONS

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The code ELENA (ELEment NAvigator) is designed for the information providing of *X*-ray fluorescent, neutron activation and neutron radiation analyses of the elemental and isotopic compound of materials. The actual data are presented in the tables and on the plots placed in windows with corresponding bookmarks, providing search. The bookmark hierarchy reflects the information structure of data and is limited by two levels: properties of an element and properties of an isotope. The follow data are presented for elements

- principal physical and chemical properties;
- energies and intensities of the characteristic *X*-radiation lines;
- isotopic abundance and properties of isotopes known for the element.

With any element selected, the following properties of its isotopes are given

- energies, lifetimes and quantum numbers of low-lying excited states;
- energies and yields of gamma lines in decay of the isotope;
- cross-section in the radiation capture of thermal neutrons and the resonant integral value;
- energies and intensities of the γ-lines from the radiation capture of neutrons.

The code ELENA is written with language C# in the environment MS Visual Studio 10 and works under control of the operation system MS WINDOWS. The package Microsoft.NET Frame Work Version 2.0 or above is necessary to use the code. The library ZedGraph.dll is applied for the graphic presentation of spectra.

The code ELENA is supplied with detailed comments and can be used for training purposes.

1. L.P.Kabina *et al*. PNPI Report 2942, Gatchina, 2014. P.16.
2. L.P.Kabina *et al*. PNPI Report 2897, Gatchina, 2012, P.17.

THE USE OF RITZ COMBINATIONS FOR THE ANALYSIS OF NUCLEAR LEVEL SCHEMES

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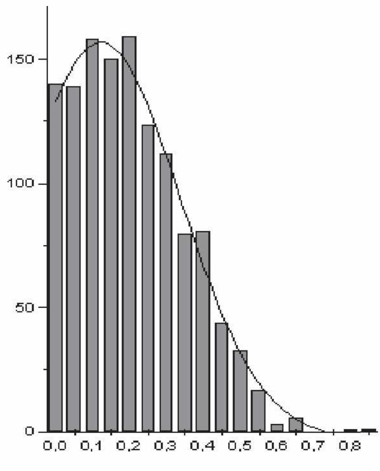
The estimation of quality of placement of transitions in the scheme of nuclear levels was carried out in the standard of ENSDF [1]. The use of criterion χ^2 [2] does not lead to unique conclusions about quality of a scheme since is "model-dependent", leaning on the calculated values of level energies.

For independent quality check of placement of transitions in the level scheme we suggest to use set of the Ritz combinations.

$$\sum_{i=1}^{m} \sigma_i E_i = 0, \qquad (1)$$

where E_i are the transition energies, $\sigma_i = \pm 1$, m is the number of transitions in the combination. The Ritz combination is the closed way in an oriented graph. The construction of the level scheme is the restoration of the graph's knots (level energies) using an available set of edges (transition energies), with the balance of intensities in the knots taken into account. The general way of the decision is search for possible variants with rejection of inadmissible ones. On this way the level scheme of ^{162}Dy [3], for example, and others were successfully constructed.



We have analyzed 1248 nuclear level schemes each with at least 50 transitions. In the figure is shown the distribution of the number of the level schemes depending on a part of "poor" combinations in which the difference of length of the way (1) for $m \leq 4$ from zero exceeds the statistical error connected with experimental errors.

For 88 schemes the "bad" combinations are absent. This means that in the schemes the distances between levels are used instead the experimental values of transition energies.

The advantage of the criterion is its independence on the calculated values of level energies in the scheme. It can be considered as the tool additional to the standard procedure of evaluation.

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AFTERPULSES OF THE H6780 AND R7600U–200 METAL CHANNEL PHOTOMULTIPLIER TUBES

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A possibility of using metal channel PMTs to search for isomeric states in the nano- and microsecond ranges by the autocorrelation method with detection of secondary pulses in addition to the primary ones is studied. It is found out that the time distribution of secondary pulses up to a few microseconds is governed by ion feedback pulses. It is shown that the optimum way to search for nano- and microsecond isomers in low-energy isomeric cascades with metal channel PMTs is to equip an autocorrelation spectrometer with double PMTs for detecting radiation in the coincidence mode. The result of half life determination of 59 keV level in ^{237}Np is presented on Fig.1. In measurements there were used the autocorrelation time spectrometer of the delayed coincidences [1].

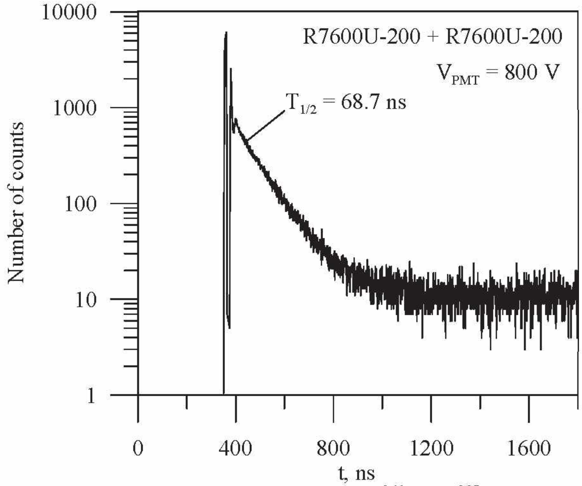

Fig.1.Half life measurement at decay $^{241}Am - ^{237}Np$.

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SOME PROBLEMS OF PRODUCING CONSISTENT VALUES OF THE DECAY CONSTANTS OF RADIOACTIVE NUCLIDES

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The conditions, the calculation schemes, and the results of calculation of time dependences of the activities *A*, of nuclides being the members of the ^{232}Th, ^{235}U, ^{238}U analyzed. In some cases the oscillations of value activities *A* around zero occur and some monotonic negative activities *A* is observed. This is caused by the limited accuracy of calculations using 32-bit computers. Among other possible causes of effects could be the absences of a mutual coordination of the experimental values of all set of the decay constants and branching ratios. These values appear in solutions of system of the differential equations, describing the decay and formation of nuclides.

The accord requirement includes the condition of non-negativity of the activities values (the negativity is admissible formally, but physically prohibited). This requirement is considered as the quite good filter to estimate and to clarify the values of the given constants. It is known that the experimental values of some of them may differ significantly. Therefore it is necessary to consider all spectrum of constant values.

It was expected that the iterative process of refinement of the decay constants values will make it possible of obtaining their mutually coordinated values, which can be considered as physically real. However, in some cases, such coordinated values (the chain ^{232}Th is considered) cannot be obtained. The possible reasons of such results are discussed.

STANDARD SETS OF NUCLIDES BEING THE MEMBERS OF THE ^{232}Th, ^{235}U, ^{238}U SERIES. THEIR IDENTIFICATION AND USE

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In the paper the sets – an ordered sequence of activities genetically-related nuclides being the members of the ^{232}Th (and ^{235}U, ^{238}U series) series is considered. The activities in the samples are determined by gamma-spectrometry.

The ordering activity nuclides being the members of the series is determined by a system of differential Bateman-Rubinson equations, by their solutions and the initial conditions. Among many possible initial conditions for the solution of the system, one can take the following conditions for the activity of the parent N_M and daughter nuclide: $N_M > 0$; $N_D = 0$; at the initial moment of own time $T_E = 0$. For all times $T_E \geq 0$ there are no other sources of the activities of these nuclides. These conditions can be called standard conditions. The set of activities obtained for these conditions will be the standard set of the activities of nuclides. Essencially these conditions coincide with the geochemical conditions of the closed system, which is necessary for correct dating of events.

The calculated time (evolutionar) dependences of nuclides activities will be used as comparison standards. It provides metrology of the experimental standard sets found in the sample.

Occurrence of substance of samples is an occurrence of experimental parent standard sets (nuclides ^{232}Th, ^{235}U, and ^{238}U series). This fact is considered as an event.

During the existence of the sample and its interaction with the environment there can occur a following event – change its nuclide composition violating the parent standard sets. This event is accompanied by the creation of new experimental daughter standard sets.

Detecting these experimental standard sets in the sample and having comparison standards, we can measure them. The duration of existence of this set will be one of results of the measurement.

Some examples of using the offered method for dating of the samples are represented. Also we compare our results with a well known method of nuclear chronometers.

OPTIMIZATION OF PSD METHOD FOR BEGe DETECTORS

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The GERmanium Detector Array (GERDA) experiment [1] at the Gran Sasso Laboratory (Italy) searching for neutrinoless double beta decay of the isotope ^{76}Ge. The background reduction of experiment deals with the pulse shape discrimination (PSD) of the BEGe detectors [2], which will be the most part of next phase of GERDA experiment. This work gives some details of optimization current PSD analysis used in experiment for the exposition Mt = 2.4 kg*yr. In analysis was used power-law energy dependence of acceptance band of A/E parameter. Results obtained indicate that reduction factor can be enlarge on 10-20% depending from confidence level. Such analysis will be useful for Phase II of experiment.

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EVALUATED INTEGRAL CROSS SECTIONS OF $^{9}Be(d,\alpha_{0,1})$ REACTIONS

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The work was carried out within the framework of activity on the development of the Library of Evaluated and Experimental Data on Charged Particle Interaction with Light Nuclei SaBa (Sarov Base) developed in RFNC-VNIIEF [1]. Cubic splines were used as an approximation function.

Search and analysis of existing experimental data on $^{9}Be(d,\alpha_{0,1})$ reactions has been performed. On the basis of data already available in the library and those newly introduced, new evaluations of integral cross section of $^{9}Be(d,\alpha_{0,1})$ reactions were obtained. Evaluated values of astrophysical *S*-factor for $^{9}Be(d,\alpha_{0})$ reaction are presented in Fig.1.

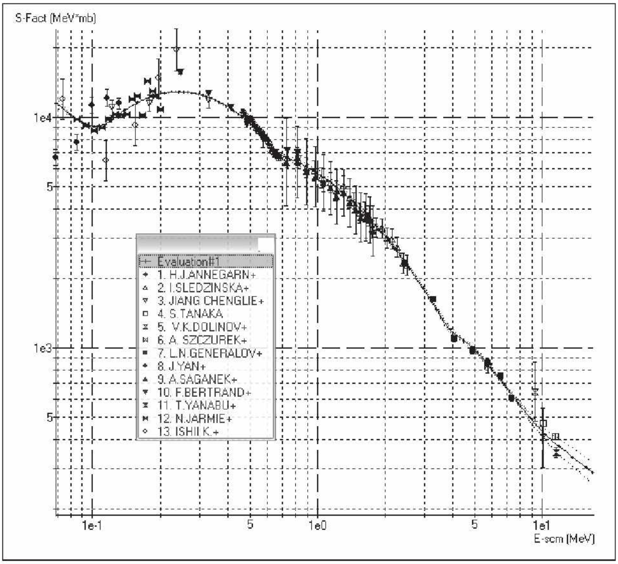

Fig. 1. Evaluated values of astrophysical S-factor for $^{9}Be(d,\alpha_{0})$ reaction.

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BETA-DECAY ELECTRONS AGAINST CANCER

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The oncological formations occurs on the human body surface, the internal organs: lungs, stomach, kidneys, liver, prostate gland and other organs. Standard methods for the treatment of external entities — the surgical removal of the tumor, its electromagnetic radiation and gamma rays, and internal — chemical-therapeutic. Use of protons, alpha particles and heavy ions is possible in major research centers. It is obvious that heavy charged particles have advantages in comparison with electromagnetic oncological diagnostics. In St.Petersburg, freezing the tumor or irradiation with laser beams does not apply. For destruction of outer cancer tumors we applied beta-decay electrons arising from the radioactive decay of ^{137}Cs ($T_{1/2}$ = 30 years, $E_{max} \sim 650$ keV) from the standard set of ESGS (exemplary spectrometric gamma sources) ~ 10^5 Bq activity in combination with alcohol tincture of hemlock [1]. The tompon of hemlock served as a filter for reduce the energy of the electrons up to 50 ~ 100 keV. After unsystematic, irregular using of the hemlock with ^{137}Cs electrons for 2 months the tumor which arose as a result of the injury disappeared completely. Treatment of affected internal organs by electrons in our opinion, is possible by using selective characteristics of organs or tumors to the certain chemical elements, similar concentration of K, Ra, Sr in human bone tissue, Cs – in muscles, Ra – in the thyroid, etc. [2].

Production of a suitable formulation of a specific isotope of an element with a $T_{1/2}$ ~ hours and days and the maximum electron energy from several tens to several hundreds keV and its subsequent introduction into the body.

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MEASUREMENT OF RADIOACTIVE FALLOUT IN LENINGRAD REGION

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Nuclear catastrophes significantly affect the level of the radioactive contamination. The worst accidents occurred at the Chernobyl and the Fukushima nuclear power plants. As the result released radionuclides (more then 10 EBq) from discarded nuclear reactor materials spread around the world.

Soon after the Chernobyl accident the investigation was carried out to notify the pollution of Europe by gamma-spectrometric survey from planes, that showed overall but uncertain picture of the contamination. Thus, according to research in the Leningrad region was found ^{137}Cs from Chernobyl in Kingisepp and Lomonosov districts with an estimated activity 1–5 Ci/km^2 [1].

In order to obtain more accurate picture of the influence of accidents on radioactivity of the Leningrad region, investigations were carry out using another method that consists in measuring environmental objects by semiconductor HPGe gamma-spectrometer.

According this method samples of topsoils from Vyborg, Priozersk, Vsevolozhsk, Gatchina, Kingisepp, Lomonosov and Luga districts and St.Petersburg were measured. Analysis of the sample of topsoil of different areas of Leningrad region showed a significant expansion of the border of radioactive zones, since the activity of ^{137}Cs of the samples from places outside this zones according [1] is sometimes higher then in polluted area. For instance, the activity of ^{137}Cs is approximately 200 Bq/kg in Kotelski village (the contaminated area) and in Luga district was found ^{137}Cs with activity more than 350 Bq/kg. The radioactivity of ^{134}Cs with $T_{1/2}$=2 years, which can identify the Fukushima trace, doesn't exceed 0.3 Bq/kg. This data is consistent with previous investigations in Leningrad region [2].

1. Leningrad region. The map of the radioactive pollution of the area (by Cs-137). 1992.
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COMPACT GAMMA-RAY LASERS AND GAMMA-RAY HOLOGRAMS

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The results of experimental investigations of strongly directed short wave gamma-ray laser generation from micro craters of compact solid-state targets after laser nuclear activation [1] as well as from laser-produced micro jets of tantalum-181 plasma [2]. In difference from [2], when laser radiation was on the wavelength ≈2 A, in last experiments we can obtain coherent gamma-ray radiation on the wavelengths $\lambda \approx 0.1$-0.05 A. To verify this we created the gamma-ray holograms of DNA-molecules, atoms in graphene and separated atoms.

1. N.I.Vogel, V.A.Skvortsov. LXII International conference “Nucleus 2012”. Book of Abstracts. June 25-30, 2012. Voronezh, Russia. 2012. P.86, 241.
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THE MATERIAL PROCESSING BY USING AN EXOTIC QUASIPARTICLES

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A diamond synthesis [1] and diamond bundles production [2] as well as other difficult material processing by using an exotic quasiparticles [3], which in turn had been generated in result of influence an intense picosecond Nd YAG-laser beams on metallic target in vacuum and gases, are considered in present work.

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ANALYSIS OF MULTISPECTRAL RADIOSCOPIC IMAGES USING THE SEGMENTATION DATA ALGORITHM

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The segmentation data algorithm for the radioscopic images analysis is suggested and simulating calculations results are presented.

The algorithm is based on Hotelling's statistics and k-means algorithm [1].

An algorithm for the analysis of data segmentation of multispectral images radioscopic imaging and tomography. The results of applying the algorithm to model problems and the advantages of the proposed method in comparison with per-pixel image processing.

To evaluate the application of the proposed segmentation algorithm was formed test (multispectral) image [2].

After applying the segmentation algorithm to test images with a minimum threshold footprint 9 pixels were identified all segments having a shape matching with a given test image.

The results indicate that the proposed algorithm is effective for data segmentation radioscopic image multispectral analysis. In the absence of information about the research use of this algorithm makes it possible to identify and correctly determine the parameters of significant areas of the image for further analysis. Also, using an algorithm to reduce the time required for processing one image decreases significantly as the number of processed objects compared to the pixel-processing.

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ESTIMATION OF MODEL APPLICABILITY LINEAR CURRENT IN A GAS ENVIRONMENT

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Model of the linear current [1] is used in studies of spatial - temporal structure of emitters, moving at the speed of light.

The GEAN*T*-package assisted method of an electrodynamic problem's foreign source calculation, together with the cumulative field of individual electrons production technology [2] have been used in this work.

The current pulse used in the model of a linear current is formed via the irradiation of the environment by a collimated bunch of hard radiation, and the vector of current density is defined using coordinates and velocities of the electrons, produced in the environment.

The approximation of the shape of the pulses generated in the process of the interaction of hard radiation with a substance (of environment) obtained in [3], has also been used in this work.

The comparison of amplitudes and durations of the B_φ - components of the produced (by the primary irradiation) electromagnetic fields that have been calculated using the current pulse moving along the line's model, on one hand and those, obtained by summing the fields generated by individual electrons - on the other, showed a qualitative similarity of results at small angles .

1. V.V.Borisov. The electromagnetic field of the transient currents. St-Petersbug: St-Petersbug State University Press, 1996.
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APPLICATION OF MONTE CARLO METHOD TO THE DOSIMETRY *X*-RAY EXAMINATIONS

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Application of Monte Carlo method in ionizing radiation dosimetry allows to carry out a virtual experiment to evaluate the absorbed dose distribution in the human body exposed to external irradiation.

The MCNP code was used to implement the Monte Carlo method [1]. The package is designed to simulate transport of neutron, gamma and electron radiation through matter using Monte Carlo methods.

Simulation of *X*-ray examination of the human body consists of several tasks: modeling of *X*-ray source, simulation *X*-ray radiation transport and modeling of anatomy of the human body. The semi-empirical model TASMIP for the *X*-ray tube radiation source is used as the *X*-ray source [2]. This model is most suitable for the calculation of radiation doses for typical *X*-ray diagnostic procedures.

Voxel phantom of the human body was created by using computer tomograms of an Alderson-Rando-like physical anthropomorphic phantom of an adult. The phantom consists of three types of tissue (lung, soft, bone) [3]. A special technique to accelerate the MCNP calculations is used to calculate the spatial distribution of the absorbed dose [4].

The absorbed dose distributions for different age groups were calculated for different exposure conditions. A comparison between the calculated and experimental distributions of the absorbed dose was carried out in an Alderson-Rando-like physical phantom. The experiment was performed by use of thermoluminescent detectors. Irradiation of different parts of phantom was carried out for different modes of *X*-ray operations. Calculated and measured data matched well.

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HEAVY ION IRRADIATION INFLUENCE ON THE THERMODYNAMIC PROPERTIES OF SALINE SOLUTION

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Because of the great success of proton therapy new approaches are presently studied in order to further increase the efficiency of radiotherapy. One of the ways for significant improvement: is to use heavy ions to improve the dose distribution and to produce an increased biological efficiency in the tumor only. Heavy-ion therapy is the use of particles more massive than protons or neutrons, such as carbon, neon, argon ions. Compared to protons, ions have an advantage: due to the higher density of ionisation at the end of their range, correlated damages of the DNA structure within one cell occur more often so that it becomes more difficult for the cancerous cell to repair the damage. Compared to protons, ions have the disadvantage that beyond the Bragg peak, the dose does not decrease to zero, since nuclear reactions between the ions and the atoms of the tissue lead to production of lighter ions which have a higher range. Therefore, some damage occurs also beyond the Bragg peak. In order to minimize the possibility of such a situation it is important to understand the changes made to the thermodynamic properties of the intercellular liquids by the irradiation. Therefore, in this work we try to develop the theory describing the changes of the thermodynamic properties of liquids under the irradiation and the results are compared with the model intercellular liquid that was set to be the NaCl solution (saline solution).

Based on the fundamental chain of Bogoliubov equations the method to calculate the "effective" temperature of the system in the case of its irradiation by the charged particles of constant intensity is suggested. Introducing such "effective" temperature allows for describing thermodynamic properties of biological liquids in the nonequilibrium stationary state employing the formalism of the equilibrium thermodynamics. In that case their structural properties are defined by the "effective" temperature that is characteristic to the equilibrium system with the thermodynamic properties similar to those observed in the nonequilibrium system. Existence of that temperature different from the real measured temperature is explained by the deviation of the momentum distribution function from the equilibrium Maxwell distribution. To confirm the theoretical predictions the molecular dynamics simulations in the DL_POLY package were done to study the local structure of the NaCl solutions under the irradiation. Analysis of the results shows that under the irradiation the local structures are formed both with destroying the hydrogen bonds and without it. Therefore, it is shown that the structure of the solution is being changed that within the suggested theory indicates the presence of the "effective" temperature characterizing thermodynamic properties of the system.

MULTI-PURPOSE DETECTOR SYSTEM FOR INVESTIGATIONS OF MULTINUCLEON TRANSFER REACTIONS

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The multinucleon transfer reaction is the perspective method for the investigation and production of the extreme neutron-rich heavy nuclei. The new setup is intended as a multi-purpose detector system optimized to study multinucleon transfer reactions and fission of neutron-rich excited heavy and super-heavy nuclei. The detector system is designed to provide multiparameter correlation measurements of the heavy fission fragments, prompt neutrons, and charge particles in quasi-fission and transfer reactions.

The Multi-Purpose Detector system consists of 12 neutron detectors and a Time-of-flight spectrometer for the fission fragments registration. The time-of-flight spectrometer includes micro channel plates (MCP) as start and stop detectors and assemblies of position-sensitive semiconductor (PIN) as E detectors. The “START” detector detects electrons knocked out by fission fragments passing through the Al oxide foil (60 $\mu g/cm^2$) located at a distance of 1 cm from the target, and the “STOP” detector detects electrons from PIN at the end of the fragment path. The TOF-E spectrometer allows the identification of the primary masses of the fission fragments and the full reconstruction of the kinematics of the sequential fission decay mode. The time resolution of whole spectrometer is 80 – 100 ps and energy resolution better than 40 keV. Thereby, we can measure masses of fission fragments with resolution about 1 a.m.u. The assemblies of position-sensitive semiconductor detectors are new multi-detector modules. They consist of 8 planar position-sensitive detectors on the basis of silicon. The position resolution of the detectors is 0.1mm x 3mm. The neutrons are measured in the energy range 0.5 – 20 MeV by the time-of-flight technique. Detectors are positioned in-plane and out-of-plane of the reaction at the various angles to the detected fragments. Energy resolution at neutron energy E_n = 2 MeV is about 4%. Stilbene is used as the active element of the neutron detectors. In addition to the stilbene neutron detectors we are using a new concept of a detector consisting of a bundle of scintillator bars (size 5x5x400 mm^3; 64 bars per detector). At each end of the bundle the scintillator elements is vied by segmented MCP-PMT tubes. The main advantages of these detectors are: high geometrical flexibility, fine granularity, fast response, position-sensitivity along all the 3 axes (5 x 5 x 5 mm^3) and time resolution of 100 ps. The same sensors will be used by NIKA in Dubna, PANDA at GSI and FIT detector at ALICE in CERN.

EPR DOSIMETRY STUDY OF THE RESIDENTS IN THE VICINITY OF THE SEMIPALATINSK NUCLEAR TEST SITE

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A tooth enamel electron paramagnetic resonance (EPR) dosimetry study was carried out with the purpose of obtaining the individual absorbed radiation doses of population from settlements in the Semipalatinsk region of Kazakhstan, which was exposed to radioactive fallout traces from nuclear explosions in the Semipalatinsk Nuclear Test Site and Lop Nor test base, China. Most of the settlements are located near the central axis of radioactive fallout trace from the most contaminating surface nuclear test, which was conducted on 29 August 1949, with the maximum detected excess dose being 430±93 mGy. A maximum dose of 268 ± 79 mGy was determined from the settlements located close to radioactive fallout trace resulting from surface nuclear tests on 24 August 1956 (Ust-Kamenogorsk, Znamenka, Shemonaikha, Glubokoe, Tavriya and Gagarino). An accidental dose of 56 ± 42 mGy was found in Kurchatov city residents located close to fallout trace after the nuclear test on 7 August 1962. This method was applied to human tooth enamel to obtain individual absorbed doses of residents of the Makanchi, Urdzhar and Taskesken settlements located near the Kazakhstan–Chinese border due to the influence of nuclear tests (1964–1981) at Lop Nor. The highest dose was 123 ± 32 mGy.

OPTIMIZATION OF A PHOTONEUTRON W-Be-SOURCE OF THERMAL NEUTRONS

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The design of a photoneutron source based on the 8 MeV electron linac LUE-8 of INR RAS is considered. The source consists of tungsten bremsstrahlung converter, beryllium neutron-producing target, polyethylene neutron moderator and radiation shielding.

A computer model of the source was built. The optimization of the source construction and its parameters was performed by means of the MCNP5 (Monte-Carlo-N-Particle) code which simulates the processes of interaction of electrons, photons and neutrons with structural elements of the source.

The optimal parameters of tungsten converter and a beryllium target were chosen. The values of the flux of thermal and fast neutrons and gamma rays inside and outside the source were obtained at various dimensions of the moderator and the radiation shielding. The obtained results indicate the possibility to achieve the thermal neutron flux density of ~ 10^8 n/cm^2/sec in the irradiation cavity of the source.

METHOD FOR CALCULATION CAPTURING ENERGY REACTIONS CONTRIBUTION TO TOTAL ENERGY RELEASE IN NUCLEAR REACTORS

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The basic features of energy release in nuclear reactors and its components have been examined. The method for calculation fraction of capturing reactions – reactions with neutron disappearance (reaction channels (n,γ), (n,α), (n,p), etc.) – in total energy release in nuclear reactors has been developed. Using this method, characteristics of three models of WWER-1000 have been calculated. It is shown, that capturing reaction contribution depends not only on the type of a nuclear reactor and fuel assemblies, but also on fuel enrichment. The total energy per fission released in WWER-1000 has been calculated, its value is 200.1 MeV for fuel assembly model (type 13ZS) and 201.0 MeV for fuel assembly with gadolinium model (type 30ZSV) [1]. The fraction of capturing energy in total energy release for two models is 3.18% and 3.64% correspondingly.

The results show that depending on fuel assembly's type the total energy release could grow by 0.5%. At present, the majority of calculating programs use the value of capturing energy obtained for fuel assemblies of the second generation with low uranium enrichment, and without burnable absorbers. Using this data for fuel assemblies with gadolinium would create an error in total energy release at the level of 0.5%.

The developed method enables to obtain more precise value of the total energy release for different reactor types, and to estimate its dependency on fuel enrichment, burnable absorbers content, fuel burn-up and other characteristics of fuel core.

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THE CHALLENGES OF CREATING SUBCRITICAL RESEARCH INSTALLATIONS DRIVEN BY EXTERNAL NEUTRON SOURCES

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The world faces today the problem of growing energy demands for the society. Nuclear energy seems to play an important role in developed countries as a reliable energy source.

For a long time, successful development of nuclear power based on the critical reactors using fissile nuclides ^{235}U, ^{233}U, ^{239}Pu satisfied the needs of civil nuclear power and nuclear weapon complex.

However, future nuclear power industry must be somewhat different, addressing increased safety consciousness and technological development, for example, by using closed nuclear fuel cycle, decreased volumes of radioactive waste, and other improvements.

Such factors led to extensive investigation and development of fast reactors and subcritical nuclear installations driven by external neutron sources known as GENERATION IV.

In particular, nuclear installations using powerful proton acceleratos as external neutron source are called Accelerator Driven Systems (ADS).

The main idea of using high energy accelearors is large-scale application of high energy spallation reactions to produce neutrons in the targets having atomic mass more than 150 (Pb, Bi, W, U, Pb-Bi) with its subsequent multiplication in a subcritical blanket ($k_{eff} \sim 0.9 - 0.98$).

This paper analyzes the challenges of creating ADS.

BIRTH-DEATH MODEL ADAPTATION FOR DESCRIPTION OF TIME EVOLUTION OF THE NEUTRON + SUBCRITICAL MULTIPLYING MEDIUM SYSTEM

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Valuation of averages of random valuables and their dispersions is determined by choice of appropriate probability process for many processes known in science and engineering. The so called instant driving rates are simulated then. In such a case expected values of random valuables and their dispersions may often be presented precisely or approximately in the form of analytical functions of transient rates.

It is a rather general method. That is why it is evident that this method may be used when describing the processes taking place at interacting of a neutron with multiplying medium in nuclear power facilities of various types as well. This is the task to be solved in the work for subcritical multiplying medium.

MEASUREMENT OF THE REACTION RATES IN ^{232}Th SAMPLES IRRADIATED BY 4 GeV DEUTERONS AND SECONDARY NEUTRONS

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The experiment was performed at the "QUINTA" [1] (uranium target assembly, weight of 500 kg, consisting of 5 separate sections) on the deuteron beam (4 GeV) of the Nuclotron accelerator VBLHEP JINR. The total flux of deuterons on the target was $1.41 \cdot 10^{+13}$ particles during 1157 min. irradiation. The sample of ^{232}Th was placed inside the uranium assembly at the deuteron-beam axis in one of the six special gaps between sections 1 and 2. The weight of ^{232}Th (foil 150 microns) was 0.1303 grams and a diameter 0.98 cm. After irradiation, the sample was taken to the spectrometric complex YASNAPP-2 [2] in the JINR LNP, where the spectra of γ-radiation were measured using HPGe-detectors. Measurements of the sample were performed repeatedly over various time intervals (from 10 minutes to several days). Spectra were processed using the DEIMOS32 code [3]. Identification of the nuclei formed by reactions of deuterons and secondary neutrons with ^{232}Th was carried out using the data published in [4] and software package [5]. The reaction rates for more than 100 products were obtained. Some of the results are presented in the table.

Isotope	Reaction	Reaction rate
Pa-233	(n,γ),(d,n)	4.69(82)E–26
Th-231	(d,t),(d,nd),(d,2np),(n,2n)	2.35(63)E–26
Kr-88	(n,f),(d,spallation)	1.22(46)E–27
Sr-91	—//—	1.83(14)E–27
Mo-99	—//—	1.61(60)E–27
Rh-105	—//—	1.37(93)E–27
Ru-105	—//—	1.03(53)E–27
In-110	—//—	2.03(33)E–28
I-135	—//—	1.07(10)E–27
Ce-143	—//—	1.22(51)E–27

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INVESTIGATION OF THE EFFECTIVE NEUTRON ENERGY AT THE MASSIVE SPALLATION URANIUM TARGET QUINTA

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Uranium samples have been irradiated in the secondary neutron field generated at the massive natural uranium spallation target *QUINTA* [1]. The target assembly is composed of five hexagonal sections filled with uranium cylinders of the total mass of about 500 kg. The target was irradiated with the deuteron beams of energies 2 *A* GeV and 4 *A* GeV, of the total beam intensities $2.25(3)\times10^{13}$ and $6.13(6)\times10^{12}$ deuterons, respectively, at the JINR Nuclotron in December 2013. The samples of natural and enriched uranium (m ≈ 1 g, diam. = 8 mm) were situated in different positions along the target axis (*z* = 254; 385; 516; 647 mm) and target radius (*r* = 0; 40; 80; 120 mm).

After the irradiation, the samples were measured with the well-calibrated HPGe detectors of 20% and 30% relative efficiency. Each sample has been measured at least six times in order to reach the results for isotopes of different half-lives $T_{1/2}$. The reaction rates (*R*, number of produced residual nuclei per one deuteron and one atom of the sample) for ^{238}U isotope were deduced from reaction rates of both natural and enriched uranium samples of different ^{235}U abundance. The reaction rates were calculated for the following fission products: ^{91}Sr, ^{97}Zr, ^{112}Ag, ^{115}Cd, ^{131}I, ^{133}I, ^{135}I, and ^{143}Ce.

Since the ^{112}Ag and ^{115}Cd isotopes lie in the valley of the typical double-hump fission fragment mass distribution and the other mentioned isotopes in the peak region, it was possible to calculate the inverse peak-to-valley (iPV) ratios. In general, the iPV should grow with an increase in the incident neutron energy. Indeed, a decrease in neutron energy as a function of target radius was confirmed, since the experimental ^{112}Ag / ^{97}Zr iPV^r (here *r* is the target radius at *z* = 254 mm; 2 *A* GeV run) are the following: iPV^0 = 0.49(3), iPV^{40} = 0.36(2), iPV^{80} = 0.24(1), iPV^{120} = 0.21(2). Other iPVs have similar trend.

Moreover, the ^{238}U fission fragment mass distributions for different incident neutron energies have been calculated with the nuclear reaction program TALYS-1.6 [2] using the optical model. An effective energy of the neutron field in some positions of the samples was estimated as a result of a comparison between the calculated values and experimental data.

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STRUCTURE OF MATERIAL OF REACTOR VESSEL FOR NUCLEAR POWER PLANTS: NEUTRON SMALL-ANGLE SCATTERING DATA

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In recent neutron scattering experiments the volume of metal of reactor vessel (anti-corrosive covering) has been scanned by a thin neutron beam (fragment of welded joint) to check a quality of welded joint and base metal. As it was found, the base metal contains mainly linear defects (dislocations). Meanwhile, the welded metal possesses very different defects' morphology.

The developed internal surface in metal specimen was observed by small-angle neutron scattering. The total area of the borders of submicron-size inclusions, $S_T \sim 10^4$ cm^2 (per cm^3), was estimated. In steels well deformed there was first observed a phenomenon of smoothing of internal surface nearby material breaking. This can be used to develop new effective criteria for the diagnostics using neutron scattering data to detect fine structural precursors of material crash. Neutron scattering data presented illustrate a feasibility of neutron methods for nanostructures' examination in metals. The following analysis of the relationship between the parameters of nanostructures and macroscopic strength characteristics should bring a firm base for the applications of neutron scattering methods for examination of materials and reliable prognosis of safety.

STUDY OF INTERACTION OF DEUTERIUM PLASMA WITH THE FIRST WALL IN GLOBUS-M TOKAMAK BY NUCLEAR MICROANALYSIS TECHNIQUES

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Globus-M is the first Russian spherical tokamak built at A.F. Ioffe Physico-Technical Institute in 1999. It can operate with high deuterium plasma density up to 10^{20} m^{-3} and high specific power deposition in to the plasma volume up to a few MW/m^3 [1]. The analysis of wall material (steel and graphite tiles RGTi-91) to hold (collect) deuterium was made (Fig.). The element composition of the films deposited on the inner surface of vacuum chamber was studied by Rutherford back scattering technique and by nuclear reaction analysis.

The migration of the deuterium inside the steels and graphite tiles was studied. Results are presented in Table. Thickness and composition of the deposited layers are depended on the evolved power in different places of chamber.

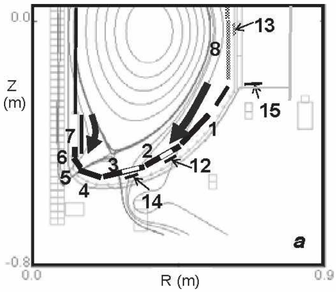

Fig. Cross section of the Globus–M lower part with deuterium plasma configuration. Number of investigation samples: 1-8 – graphite tiles; 12, 14 and 15 – steel samples.

Table. Partial thicknesses of deposits on the different samples (10^{16} at./cm^2) (*T*-total thickness, one Ti and C, at/cm^2)

Samples	D	B	C	Si	Cr	Fe	Ni	Cu	W	*T*
1	36	83		6	17	44	5	1	4	$160 \cdot 10^{16}$
2	56	63		1	30	75	9	3	6	$187 \cdot 10^{16}$
3	79	660		0	45	112	13	3	7	$926 \cdot 10^{16}$
4	82	650		2	53	139	18	7	6	$875 \cdot 10^{16}$
5	100	200		8	39	102	13	4	2	$368 \cdot 10^{16}$
6	120	94		0	45	120	15	5	7	$286 \cdot 10^{16}$
7	~0.01	1		4	4	14	2	1	0	$26 \cdot 10^{16}$
8	~0.01	0		2	2	7	0,3	0	0	$11 \cdot 10^{16}$
12	32	5.4	90	—	—	—	—	—	—	—
14	31	15	80	—	—	—	—	—	—	—
15	19	16	28	—	—	—	—	—	—	—

1. V.K.Gusev *et al.* // Nuclear Fusion. 2009. V.49. № 10. 104021.

RELEASE ASSESSMENT OF TRITIUM IN LIQUID EFFLUENTS OF BUSHEHR NUCLEAR POWER PLANT (BNPP) IN 2013

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Tritium is a radioisotope produced as a by-product in various nuclear reactor systems. Owing to its natural specifications, it is necessary to control the production and release of tritium in nuclear facilities. The amount of tritium in released waste waters generated by the nuclear industry varies as a function of parameters such as reactor type and the plant operation [1]. In order to prevent or minimize the destructive effects of radiation exposure and intake of radioactive materials on workers, public and the environment, it is necessary to use several control systems. BBNPP which is a WWER-1000 reactor type located 17 kilometers southeast the city of Bushehr, beside the Persian Gulf and it is operating from 2011. The Persian Gulf water is being used in condenser coolant system and it is being released into the Persian Gulf (1200 meters away from the Bushehr shoreline) through undersea ZN34 channel. Before release, whole waste waters from reactor building and the auxiliary building passes through an anionic and cationic filter and then is gathered in a reservoir. Release of tritium is done according to the requirements of Iranian Nuclear Regulatory Authority (INRA) which guaranties that the release of tritium, in any form like gaseous or liquid, not to exceed the national standards levels.

Waste water from reactor building and auxiliary buildings, after passing through the treatment system; have been decanted to ZN2 channel which is being mixed with condenser water of turbine and finally will be released to Persian Gulf through ZN34 channel. In this channel volume activity of water is being measured online. Before releasing of gathered water in the tank, a one-liter- sample of the water is being sent to the laboratory. At first, samples are being poured in special geometry glasses. In order to determine the volume activity of gamma emitter radionuclides in samples, it is being put in a gamma spectrometer (HPGe Type) instrument in a determined time, so the activity is being measured. Tritium is a weak beta emitter, so we used a Liquid Scintillation Counter (LSC) in order to counting tritium activity in samples, according to verified procedures. The final spectrum of each sample will be analyzed by spectroscopy expert. If the results of spectroscopy could fulfill the specific requirements, then the whole water of the tank will be released into the environment, otherwise, purification processes will be carried out. During the first and second quarter of 2013, totally 418 and 616 samples have been analyzed and reported, respectively [2].

The annual discharges limit for tritium and other radionuclides including Cr-51, Mn-54, Ci-58, Co-60, Zn-65, Sr-89, Sr-90, Ru-106, Cs-134, Cs-137, Ce-144 in liquid and gaseous effluents from nuclear power plants, mainly pressurized water reactor (PWR) plants, specified by the national regulatory and IAEA standard series is equivalent to 1.5×10^{14}Bq (4.0×10^{3}Ci) and 7.5×10^{11}Bq (2.0×10^{1}Ci), respectively[3]. The results of analyzes shows that total release of tritium in the first half of 2013 is equivalent to 6.24×10^{11}Bq. By assuming that the amount of tritium activity released from Bushehr nuclear power plant in first and second half of 2013 year is equal, total release in one year is equivalent to 1.248×10^{12}Bq. Comparison between this result and the annual limits of tritium discharges shows that the ratio of released tritium to the annual limit is less than 0.01. So, it is clear that the tritium release from Bushehr Nuclear Power Plant waste water is under the specified standard limits. However, it is possible to optimize the results through amendment procedures.

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2. Radiation analyzes of BNPP, identification code: 51.BU.10.00.AB.WI.ATEX.016. BNPP, Bushehr, 2012.
3. Technical specification of safe operation of nuclear power plants and the Standards of Radiation Safety, NRB-96, Russia, 1996.

RESEARCH OF EVOLUTION OF AN ATOMIC ORDER AND VALENCE STATE OF RARE-EARTH ATOMS AND URANIUM IN A NEW METALCARBON COMPOSITE PYROLYZATE OF BIS-PHTHALOCYANINE $C_{64}H_{32}N_{16}Me$ (Me = Y, La, Ce, Eu AND U)

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The bis-phthalocyanine molecule represents two flat C-H-N-complex between which there is an atom of metal. At pyrolysis in the range of T_{ann} =550 - 800°C there is a destruction of the molecules to almost total loss of hydrogen, part of nitrogen and carbon, and due to the released bonds extreme atoms of carbon connect, forming the closed carbon structure in which there is an atom (atoms) of metal. Such metalcarbon composites may be of interest, in particular, to creation thermally, chemically and a radiation resistant metalcarbon matrix for storage and a transmutation of radioactive waste of the spented nuclear fuel of the nuclear power plant.

Pyrolyzates of bis-phthalocyanine of two-, three- and tetravalent rare earths, and also uranium were investigated in the range of pyrolysis temperatures T_{ann}= 800-1700°C. At this general case three types of crystal phases are revealed.

The first phase belongs to carbon component of system and answers the most part of mass of a sample (up to 90%). In process of increase in temperature of pyrolysis (T_{ann}=800-1700°C) crystallographic perfection of the phase gradually grows and in a limit becomes same, as at graphite.

The second phase is a high-temperature phase of crystallized nitrides and carbides, and is observed at T>1100°C. At that a weight share of a crystallized phase and the size of crystallites (in range of 6-90 nanometers) grow with a temperature and annealing time.

The third phase – actually amorphous that testifies to an initial stage of its formation, else at level of a near order. It is possible to assume that, generally in this phase atoms of metal are contained in the cells formed at destruction of bis-phthalocyanine molecules.

In this (amorphous) phase basic elements of pyrolyzates Me are in chemically connected state, but their effective electronic configurations aren't stable and depend on temperature and annealing time. At the same time in case of europium electronic configurations which weren't observed earlier are realized that can testify to specifics of a chemical bond in such systems.

Proceeding from our researches, the amorphous phase with a pyrolysis temperature in T_{ann}=800-1100°C range for practical purposes is represented to more perspective.

POLYMERIC COMPOSITIONS FOR "DRY" DECONTAMINATION OF NPP EQUIPMENT AND PREMISES

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Despite the widespread application of chemical decontamination of surfaces based on the use of solutions, they have significant drawbacks, especially in the case of large surfaces decontamination.

In order to optimize the technology of decontamination "dry" surface decontamination methods and technologies based on the use of decontaminating coatings and pastes become widely used. Application of "dry" decontamination methods leads to significant reduce of solid radioactive wastes quantities, and thus, cost of their recycling and disposal become less.

In JIPNR – "Sosny" NASB developed decontaminating polymeric compositions based on binder - polyvinyl alcohol solution with active additives such as nitric and borohydrofluoric acids, 1-hydroxyethylidenediphosphonic acid and its salts, detergents and fillers - natural tripoli; tripoli modified by ferrocyanides of nickel and copper; pulverized dolomite modified by manganese oxides, ferrocyanides of nickel and copper; clinoptilolite modified by iron chlorides (III) and calcium sodium phosphate and potassium ferrocyanide; hydrolytic lignin.

It is shown that the developed decontaminating polymeric compositions (pastes) possess high decontaminating capacity (FD $10^2 – 10^3$) and low adhesion to the surfaces of stainless and carbon steels, including painted, plastic, self-leveling floors, Teflon- surface.

Prolonged leaching method according to GOST 29114-91 allowed determine the chemical resistance of "dry" decontamination wastes, strength of ^{137}Cs and ^{60}Co fixation in wastes obtained in result of using new decontamination pastes.

It has been demonstrated that the use of natural and the modified fillers (tripoli, clinoptilolite, and dolomite) in decontaminating pastes reduces the rate of radionuclides leaching. The cesium and cobalt radionuclides were most firmly fixed by pastes containing natural and modified clinoptilolite and tripoli as fillers.

Effectiveness and relevance of the results is contained in ensuring the reliability, efficiency and safety of "dry" decontamination radioactive wastes storage obtained after external surfaces equipment and facilities decontamination with the use of new pastes.

Production of these pastes can be organized directly at the place of carrying out of decontamination works, such as chemical department of nuclear power plants.

DIFFUSION OF CESIUM, STRONTIUM AND ALKALINE IN MAGNESIUM PHOSPHATES SYSTEM

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Safety requirement for the storage and disposal of radioactive waste have advanced substantially over the past years. Especially these achievements are important for the nuclear industry of Ukraine. For this purpose the stable ceramic matrices for immobilization of such waste (for example, ^{137}Cs) were created. Crystalline magnesium potassium phosphates are analogs to natural phosphate minerals and have great physicochemical stability in geological medium and good isolating properties [1].

Special attention was given to the study of stability of the matrices under high temperatures and the influence of effect of electrons and gamma radiation on magnesium phosphates system.

Samples of ceramicrete with 10% of $CaSO_4$, with elements analogues of radioactive isotopes of the Hanford K-East and K-West Basins, with cesium and strontium were investigated. Diffusion in initial and irradiated of samples of ceramicrete has been studied. The irradiation of samples was carried out by electrons and γ–radiation to dose 10^8 and 10^6 Gy, accordingly.

Nuclear reactions $^{133}Cs(\gamma,n)^{132}Cs$, $^{96}Sr(\gamma,n)^{95}Sr$ and $^{23}Na(n,\gamma)^{24}Na$ have been used. Irradiation of these systems were realized by bremsstrahlung on high-current electron accelerator at energy of electrons 23 MeV and current 500 μA. Higher factors of diffusion of cesium and sodium in comparison with strontium are found out.

1. A.S.Wagh, S.Y.Jeong // J. Am. Ceram. Soc. 2003. V.86[11]. P.1838.

NUCLEAR MATERIALS PROTECTION AND NATIONAL SECURITY

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Since 2002 the states had more attention to threat transfer of nuclear weapons and transferring information related to weapons production. However, in the third Millennium there was a huge threat of nuclear terrorism. The starts of creation nuclear security Fund in NSS 2014, slogan, which was a progress in preventing nuclear terrorism.

Currently nuclear terrorism targets include: nuclear power, research reactors and uranium concentrate production, processing enterprises, storage and reprocessing facilities for spent fuel. Another scenario is radiological terrorism which contains capturing the vehicle carrying nuclear fuel or waste with high level of radiation.

Sabotage upon nuclear facility does not require such a deep scientific and technical knowledge even to manufacture a nuclear bomb. Sufficient penetration is enough to an object group of insurgents with small arms and explosives. The cooling system also can become a target for sabotage also if they destroy the probability of radioactive emission.

Terrorists may try to destroy maintain systems of the reactor, systems of water supply, control and protection in order to cause a thermal explosion of the reactor. Even if attackers do not achieve the explosion of reactor and just stop it, anyhow it has large-scale economic and socio-political consequences.

The research analyzes show the significant part of nuclear materials poorly protected and is vulnerable to abduction or sale on the black market. The international atomic energy Agency (IAEA) has a documentary evidence of more than hundred cases of theft or loss of highly enriched uranium and plutonium.

The analysis of the publication of the report «Index NTI» in January 2014 provoked a lively discussion about priority measures of ensuring nuclear security. For example, the Republic of Belarus took the 9th position at total scores, Kazakhstan 15th place and RF-18, however, the criteria of «the provision of security measures and control» Belarus is on 4th place, after the United States, Canada and Britain, Kazakhstan and Russia are on the 9th rating.

The issue of control and physical protection of nuclear materials to reach consensus on effective Global system is one of the most important discussions in 21 century.

1. NTI Nuclear Materials Security Index, second edition, January 2014.
2. The U.S.-Russia Initiative to Prevent Nuclear Terrorism Newsletter: December 2013 - February 2014. Harvard University, March 13, 2014.

IMAGING OF NUCLEAR INTERACTIONS IN NUCLEAR TRACK EMULSION

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Currently, the BECQUEREL Project at the JINR Nuclotron is devoted systematic exploration of clustering features of light stable and radioactive nuclei. A nuclear track emulsion (NTE) is used to explore the fragmentation of the relativistic nuclei down to the most peripheral interactions - nuclear “white” stars. This technique provides a record spatial resolution and allows one to observe the 3D images of peripheral collisions. The analysis of the relativistic fragmentation of neutron-deficient isotopes has particular advantages owing to a larger fraction of observable nucleons. The collection of videos and images reflecting cluster degrees of freedom is gathered at the Web site http://becquerel.jinr.ru/.

Due to the successes of computerized microscopy particular perspective is the application of NTE to RI beams. Samples of NTE have been exposed in JINR to ^{8}He nuclei, thermal and fast neutrons and ions Kr and Xe (example in Fig. 1). The images of the investigated events complemented the nuclear photo collection. In terms of applications the received material will be valuable for the development of systems of automatic search for nuclear interactions, as well as for university education.

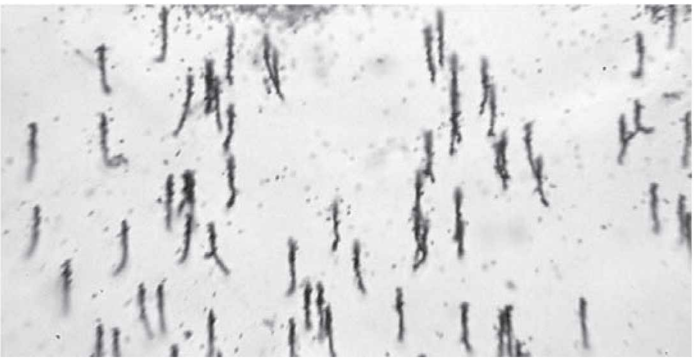

Fig. 1. Macrophotography of NTE exposed to 1.2 A MeV Xe ions.

CLASSIFICATION AND SYSTEMATIZATION OF STRUCTURE OF BELARUSIAN EDUCATIONAL AND RESEARCH PORTAL OF NUCLEAR KNOWLEDGE

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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) [1]. Nuclear knowledge (NK) base stems from both research and development as well as industrial applications of nuclear technologies and includes energy and nonenergy applications. Knowledge management (KM) is an integrated, systematic approach to identifying, acquiring, transforming, developing, disseminating, using, sharing, and preserving knowledge, relevant to achieving specified objectives. Approximate percentage of NK subject area by the IAEA is the next: nuclear physics 11%, nuclear materials 9%, engineering and instrumentation 9%, elementary particle physics 16%, atomic, molecular and condensed matter physics 10%, life sciences 18%, chemistry 4%, nuclear power and safety 6%, nuclear fuel cycle and radioactive waste 3%, fusion research and technology 7%, environmental and earth sciences 3%, isotopes 1%, non-nuclear energy 1%, economic, legal and social 2%.

The strategy of the IAEA in NKM is the following. It is extremely important that the educational process involves the enterprises of nuclear industry. Great attention is paid to creation and development of educational networks and portals, both national and regional, providing platforms for education and training, transfer of skills and experience, exchange of best practice across companies, development of nuclear technology etc.

Belarus now joins the club of countries that have or are building nuclear power plant. Our country has a large scientific potential in the field of atomic and nuclear physics. There are several websites of selected organizations and institutions in Belarus that are not related to the united portal, providing separate information on the subject that is far from completeness. It is obvious the necessity of creation of portal of nuclear knowledge. The purpose of its creation is the accumulation and development of knowledge in the nuclear field as well as popularization of nuclear knowledge for the general public. Creating of a full-fledged portal of nuclear knowledge is the multi-stage process. As the first step it is proposed to create educational and research portal of nuclear knowledge.

In this report, classification and systematization of structure of educational and research portal of nuclear knowledge are presented and discussed.

1. International Atomic Energy Agency. Knowledge Management for Nuclear Industry Operating rganizations, IAEA-TECDOC-1510. 2006. P.185.

AUTHOR INDEX

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N

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T

U

V

W

Y

Z

LXIV INTERNATIONAL CONFERENCE «NUCLEUS 2014» FUNDAMENTAL PROBLEMS OF NUCLEAR PHYSICS, ATOMIC POWER ENGINEERING AND NUCLEAR TECHNOLOGIES (LXIV MEETING ON NUCLEAR SPECTROSCOPY AND NUCLEAR STRUCTURE)

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