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National Academy of Sciences of Ukraine

National Science Center
«Kharkov Institute of Physics and Technology»

Institute of High-Energy Physics and Nuclear Physics

ABSTRACTS OF REPORTS XXI CONFERENCE OF HIGH ENERGY PHYSICS AND NUCLEAR PHYSICS

Kharkiv
2023

Content

Section 1. Nuclear physics and elementary particles

STUDY OF THE $^{12}C(\gamma, P)^{11}B$ REACTION WITH POLARIZED PHOTONS AT ENERGIES 40-65 MeV AT MAX-LAB

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In the laboratory MAX-lab (Lund, Sweden), two experiments on measurements of the cross sections asymmetry for carbon photodisintegration reactions $^{12}C(\vec{\gamma},p_{01})^{11}B$, $^{12}C(\vec{\gamma},p_{2-6})^{11}B$, $^{12}C(\vec{\gamma},p_0)^{11}B$ and $^{12}C(\vec{\gamma},p_1)^{11}B$ have been performed. The measurements were performed using a beam of tagged linearly polarized photons generated by electrons with an energy of 192.7 MeV in a diamond crystal. Preliminary results of the first experiment have been presented in [1]. The effective angle of protons registration was 85^0. The $^{12}C(\vec{\gamma},p_0)^{11}B$ reaction makes the main contribution to the $^{12}C(\vec{\gamma},p_{01})^{11}B$ reaction and is determined by a single-particle mechanism. Therefore, the asymmetry for both reactions practically coincides and is very large, $\Sigma = 0.8 - 0.9$. Main contribution to the $^{12}C(\vec{\gamma},p_{2-6})^{11}B$ reaction comes from the states $3/2^+$(5.02 MeV) and $7/2^-$(6.74 MeV). Its asymmetry is $\Sigma \sim 0.6$, as well as the reactions $^{12}C(\vec{\gamma},p_1)^{11}B$, and is close to the asymmetry of the reaction $d(\vec{\gamma},p)n$ that may indicate a significant contribution of the two-particle mechanism to these reactions.

1. D. Burdeinyi, J. Brudvik, K. Fissum, V. Ganenko et al., Cross Section Asymmetry of two-body Carbon Disintegration $^{12}C(\gamma,p)^{11}B$ with Polarized Photons at Energy 40-50MeV. Nuclear Physics A957(2017)p.321-331

STATUS OF PARTICIPATION OF THE NSC KIPT IN THE CMS EXPERIMENT

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In the summer of 2022, after a long (more than 3.5 years) break, the Large Hadron Collider (LHC) resumed operation with the new (record for an accelerator) value of energy of proton-proton collision energy of 13.6 TeV. Despite some complications, in general, the start of LHC Run 3 turned out to be successful. On the other hand, processing of the large array of experimental information accumulated in the CMS experiment during LHC Run 2 (2016-2018) is still under way. In addition to studies of the Higgs boson properties, a number of new important results have been obtained over the past year, related to both studying the Standard Model (SM) processes and searches for signals of "new physics" beyond the SM. A wide range of activities within participation in the CMS experiment was continued at the NSC KIPT. In particular, operation of the specialised computing facility for processing data from the LHC – the only Ukrainian Tier-2 (T2) centre of the CMS grid infrastructure, T2_UA_KIPT, – was provided. The T2_UA_KIPT operation quality determined by the degree of readiness for the distributed CMS data processing, for the time period from the beginning of 2022 up to 02/24/2022 was 100%. Then, a list of necessary changes in the T2_UA_KIPT configuration, which are required to be implemented after the forced shutdown of the facility on 24.02.2022, was compiled and analysed, with the aim of resuming facility's operation immediately as soon as the appropriate conditions are restored. Also, the physics analysis of the UltraLegacy CMS data was carried out aimed at the search for a SUSY signal, *viz.*, the direct chargino pair production in the proton-proton collisions at 13 TeV. The selected events are those that have two reconstructed oppositely charged leptons (an electron-positron or muon pair, or an electron/positron accompanied by a muon) with high transverse momenta and a great total transverse momentum imbalance in the event. The 2016 dataset composed of two event subsamples matching the total integral luminosity of L_{int} = 36.3 fb^{-1} has been processed. Because of the forced shutdown of the T2_UA_KIPT CMS Tier-2 centre and temporary impossibility of its use (in particular, due to the lack of access to previously developed analysis tools), the LatinoAnalysis "universal" CMS analysis package has been studied and tested remotely. As an example, event distributions were obtained with this package for the top quark production control regions on the 2016 "postVFP-era" event subsample, which corresponds to L_{int} =16.81 fb^{-1}. Then, the work is also in progress within the program of the endcap hadron calorimetry upgrades. A study was carried out on the impact of the dose rate on the radiation resistance of the SCSN-81 (which currently constitutes the calorimeter active elements) and EJ-260 (which is being considered for possible use in the future) plastic scintillators, when irradiated with bremsstrahlung photons at the NSC KIPT electron accelerator. The method of varying the dose rate with lead shielding plates was applied. The developed and manufactured experimental setup for irradiation of scintillator samples with bremsstrahlung photons has proved to provide five dose rate

values ranging from 7.5 to 162 krad/hr. The obtained results are in good agreement both with our earlier results obtained in other experimental conditions and with the data by other authors obtained in the 1990s.

The work was supported in part by a grant from the NAS of Ukraine within the Targeted research program “Collaboration in advanced international projects on high-energy and nuclear physics“.

PROCESSING OF DATA OBTAINED IN THE CMS EXPERIMENT USING THE LATINOANALYSIS PACKAGE

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Results of processing and analysis of data accumulated in the CMS experiment at the Large Hadron Collider in 2016 (samples of 13 TeV proton-proton collisions) are presented. The analysis was carried out using the LatinoAnalysis package, which is a multifunctional analysis tool specially designed to search for "new physics" signals beyond the Standard Model (SM) over events with detected leptons. The structure of the package and its capabilities are demonstrated by the example of searching for the direct chargino pair production (with the subsequent $\widetilde{\chi_1^{\pm}} \to \tilde{l}^{\pm}\nu_l(l^{\pm}\tilde{\nu_l}) \to l^{\pm}\nu_l\widetilde{\chi_1^0}$ chargino decay) predicted within the supersymmetric extension of the SM. At the first stage (the so-called "skimming"), the events with at least one charged lepton (electron/positron or muon) satisfying very weak identification criteria were preliminarily selected and recorded in the nanoAOD format on the disk storage of the CERN computing complex. At the second processing stage, various weights, efficiencies, scale factors, etc., were built into the Monte Carlo (MC) event samples resulted from the "skimming", in order to improve the adequacy of reproduction by the MC simulation of the real experimental conditions. Also, the 4-momenta of reconstructed physics objects are modified at this stage based on updated calibrations. The third stage is the actual physics analysis. After determining the signal and control regions for the quantities of interest, ROOT histograms are filled in with visualization of various spectra in the form of graphs, and the data cards are generated for the statistical analysis. As a result, for the signal being searched for, the CL=95% exclusion contours for possible chargino and neutralino masses were built. When the final result was obtained, the JetSmearing procedure was applied, which brings the energy resolution of the MC-generated hadron jets in line with the one that is experimentally observed, and a number of other recommendations were implemented to improve the quality of reproduction of the CMS experiment by the MC simulation.

GEOMETRICAL OPTICS METHOD IN THE THEORY OF SCATTERING OF CHARGED PARTICLES IN EXTERNAL FIELD

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The geometrical optics method is widely used in wave mechanics for description of distribution of electromagnetic waves in heterogeneous media [1, 2]. The present work is devoted to study of the possibilities of application of this method in high energy physics for finding the solution of the Dirac equation for the wave function of a charged particle in external potential field. Within this method, the main characteristics of the particle wave function (its phase and pre-exponential factor) are determined via characteristics of the family of particle trajectories in the external field. This gives us an opportunity to use the effective numerical methods for description of interaction of particles with the field of complex configuration, such as the field of crystal lattice. It is shown that a possibility of description of various interference phenomena at interaction of particles with an external field is conserved within this method. Basing upon it, the process of scattering of fast charged particles in a crystal within the transitional region of thicknesses – up to those at which the channeling process begins to reveal itself, is considered. A study of such a process was performed by the example of interaction of a particle with the continuous potential of crystal atomic planes. In this case, differential scattering sections are obtained.

1. Arnold V. Mathematical Methods in Classical Mechanics, Springer-Verlag, NY, 1989.

2. Kravtsov Y., Orlov Y. Geometrical Optics of Inhomogeneous Media, Springer-Verlag, Berlin, 2011.

HIGH ENERGY PARTICLES SCATTERING ON CHARGED RELATIVISTIC PARTICLES BEAMS WITH AN ELLIPTICAL CROSS SECTION

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The problem of high-energy particles scattering on relativistic beams with an elliptical cross-section was considered. On the basis of previously developed methods [1], a differential scattering cross section was obtained for this case in the eikonal approximation of quantum electrodynamics. Such methods make it possible to examine the scattering on complex structure targets in a relatively simple way. In addition, optimizations were implemented that simplified the calculations for this particular case. The application conditions of this approximation within the given problem were also clarified.

It is shown that in the considered case there is a range of impact parameters for which the scattering problem is reduced to a one-dimensional one. Signs of the rainbow scattering effect were found. The presence of this effect displays quantum effects in the scattering of fast charged particles on relativistic beams.

1. Shul'ga N.F., Koriukina V.D. The Eikonal Approximation of the Scattering Theory for Fast Charged Particles in a Thin Layer of Crystalline and Amorphous Media. Nucl. Instr. Meth B. 2021. Vol. 487. P. 25-29

THE DIFFERENTIAL DISTRIBUTIONS OVER INVARIANT VARIABLES IN REACTIONS $e^+e^- \to p\bar{n}\pi^-$ AND $e^+e^- \to \bar{p}n\pi^+$

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The contribution of the nonresonant mechanism (NRM) to the differential cross section of the reactions $e^+e^- \to p\bar{n}\pi^-$ and $e^+e^- \to \bar{p}n\pi^+$ is studied. As distinct from the processes with neutral pion $e^+e^- \to N\bar{N}\pi^0$, N=p, n investigated earlier in our works, the NRM includes additional Feynman diagram with the virtual pion pole which is proportional to the pion electromagnetic form factor (PEF). In this case problem arises with reconstruction of the gauge invariance and to solve it we use two different approaches. In the first approach the PEF is defined as a difference the proton and neutron Dirac electromagnetic form factors. In the second one all these formfactors are supposed independent, and the gauge invariance is ensured by some modification of the underlying Feynman diagrams. This allows us to apply the well developed formalism of the invariant amplitudes to describe the full differential cross section. The used parametrization of the PEF in the time-like region is based on the VDM model and describe cross section for the ISR process $e^+ e^- \to \pi^+ \pi^-(\gamma)$ by Babar, CDM-2 and BESIII Collaborations. For the nucleon electromagnetic form factors we employ two different parameterizations used early for description of the processes with neutral pion.

Using the final particles phase in terms of the invariant variables and the limits of their variations we calculate different double and single differential distributions that are in principle accessible at BESIII.

EFFECTS OF SCALAR BOSON IN ELASTIC DEUTERON-ELECTRON SCATTERING

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The differential cross section for the elastic scattering of unpolarized deuterons on unpolarized electrons at rest, de → de, is calculated taking into account two mechanisms: one-photon and scalar-boson exchange. The following polarization observables were calculated: 1- the analyzing powers (asymmetries) due to the tensor polarization of the deuteron beam, 2 - the coefficients of the polarization transfer from the arbitrarily polarized target electron to the recoil electrons. The differential cross section and polarization observables have been expressed in terms of the deuteron electromagnetic form factors: GC (charge monopole), GM (magnetic dipole) and GS (charge quadrupole). Some peculiarities of the inverse kinematics (the mass of the colliding particle is larger than mass of the target particle) have been discussed.

SYSTEMATIC STUDY OF REFRACTIVE EFFECTS IN THE α-^{208}Pb ELASTIC SCATTERING IN THE S-MATRIX MODEL

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For many years, much attention has been paid to the study of refraction effects (nuclear rainbow, Airy structures, Fraunhofer crossovers) in the scattering of light ions on nuclei, since their analysis allows one to probe the inner region of interaction of nuclei. Most often, an optical model is used to analyze such data, in particular, based on phenomenological optical potentials. Previously, the authors developed an original S-matrix model, which makes it possible to describe various refractive patterns in wide scattering angle ranges; this can be a useful alternative approach complementing the optical model. Recently, this model was used for analyzing the refractive patterns in α-12C and α-24Mg scattering to examine the energy dependences of the model parameters and some scattering characteristics, which gave encouraging results [1, 2]. The present work is devoted to the systematic analysis of data on the elastic scattering of α-particles on heavy 208Pb nuclei using this S-matrix model in a wide energy range, namely: at 104, 139, 166, 172, 240, 288, 340, 386, 480, and 699 MeV, and the diffraction and refractive patterns of scattering have been investigated. The energy behavior of the found model parameters, as well as of the total reaction cross-section, the angles of Fraunhofer crossover of the near and far scattering components, and the nuclear rainbow angles have been studied, a comparison has been made with the differential cross sections calculated by the optical model.

1. Yu.A. Berezhnoy, G.M. Onyshchenko, V.V. Pilipenko, Int. J. Mod. Phys. E 26 (2017) 1750027.

2. Yu.A. Berezhnoy et al, Int. J. Mod. Phys. E 27 (2018) 1850061.

ABOUT MAGNETIC PROPERTIES OF SUPERFLUID NEUTRON MATTER WITH SPIN-TRIPLET ANISOTROPIC *p*-WAVE PAIRING IN SUPERSTRONG MAGNETIC FIELDS AND AT SUPRANUCLEAR DENSITIES

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Magnetic properties of a dense superfluid neutron matter (relevant to the physics in cores of magnetars — the strongly magnetized neutron stars) at supranuclear densi-ties $n>n_0$ (where n_0=0,17 fm^{-3} is the saturation nuclear density) with generalized Skyrme effective forces (with three density dependent terms) and with spin – triplet anisotropic p – wave pairing (similar to ^{3}He−A in magnetic fields, i.e. with spin S=1 and orbital moment L=1 of anisotropic Cooper pairs of neutrons) in the presence of a superstrong magnetic field (exceeding the 10^{17} G) are studied within the framework of the non-relativistic generalized Fermi-liquid theory at zero temperature. The upper limit for the density range of a neutron matter is restricted by the magnitude $3\cdot n_0$ in order to avoid the account of relativistic corrections growing with density. The appro-ximate general formula (valid for any parametrization of the Skyrme forces) is deri-ved here analytically for the magnetic susceptibility (which contains additional cor-rection depending nonlinearly on superstrong magnetic field H and on the density n) of a superfluid neutron matter in the limit of zero temperature. The obtained general formula for magnetic susceptibility is specified for the generalized BSk21 parametri-zation of the Skyrme forces and figures for corresponding values are plotted on the interval $1{,}5\cdot n_0 \leq n \leq 3\cdot n_0$ and for superstrong magnetic fields $2\cdot 10^{17}\,\mathrm{G} \leq H \leq 2\cdot 10^{18}\,\mathrm{G}$. It is established that the high-density ferromagnetic instability is removed in neutron matter with the generalized Skyrme forces (and, in particular, with the generalized BSk21 parametrization) not only in normal, but also in superfluid neutron matter with spin – triplet anisotropic p – wave pairing at supranuclear densities and in superstrong magnetic fields.

INVESTIGATION OF THE INFLUENCE OF THE NUCLEON PAIRING FORCE ON THE OCTUPOLE DEFORMATION OF URANIUM ISOTOPES IN THE MEAN-FIELD APPROXIMATION

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Properties of the uranium isotopes with $A = 220 – 232$ are calculated in the Hartree-Fock-Bogolyubov approximation and the axial symmetry of nuclei with SkM* Skyrme forces. This work is continuation of our previous study of the properties of radium isotopes [1]. In our calculations we used the computer code HFBTHO v2.00d [2]. Pairing of nucleons in nuclei is described by zero-range pairing forces of mixed type with different sets of pairing force constants. In the calculations we used constrained conditions on the parameters of the quadrupole β_2 and octupole β_3 deformations of the nuclei. In the vicinity of the minimum of the dependence $E(\beta_2, \beta_3)$, to refine the minimum value of the total energy of the nucleus E , the calculations were carried out without constrained conditions on β_2 and β_3 . It is shown that for the considered uranium isotopes as well as for radium isotopes [1] the deformation of nuclei β_3 strongly depends on the choice of parameters of the nucleon pairing force. Overestimated values of the pairing force constants lead to decrease or complete disappearance of the deformation in the considered uranium isotopes.

1. V.I. Kuprikov, V.N. Tarasov // Phys. At. Nucl., 2021, **84**, No.6, pp. 796–803.
2. M.V. Stoitsov et al. // Comput. Phys. Commun. 2013, **184**, 1592.

STUDYING THE RESONANCE PRODUCTION CROSS-SECTION OF THE HEAVY VECTORS WITHIN HEAVY VECTOR TRIPLET MODEL

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In the context of TeV-scale extensions of the Standard Model both the experimental searches [1, 2] and the construction of phenomenological models [3] for the new heavy bosons searches are used by us. Heavy particles predicted by a the Simplified Model constructed to describe only the on-shell resonance, have to be compared with LHC data. Heavy bosons V', $pp \rightarrow V' \rightarrow Vh$ (V=W, Z), have certain properties that can be calculated within the Heavy Vector Triplet model using the MadGraph computer program. We have calculated the production cross sections of heavy particles V' using the experimental constraints in the parameter space (c_H,c_F) imposed on the benchmark scenario. The nature of the functional dependence of the cross section at the basic parameters of the model on the mass of the new boson, as well as the mechanism for the heavy particle production is studied.

1. ATLAS Collaboration, G. Aad et al. Search for WZ resonances in the fully leptonic channel using pp collisions at s = 8 TeV with the ATLAS detector, arXiv:1406.4456.

2. The ATLAS Collaboration. Search for heavy resonances decaying into a W boson and a Higgs boson in final states with√leptons and b-jets in 139 fb^{-1} of pp collisions at s = 13 TeV with the ATLAS detector, ATLAS-CONF-2021-026.

3. Duccio Pappadopulo, Andrea Thamm, Riccardo Torre, Andrea Wulzer. Heavy Vector Triplets: Bridging Theory and Data, arXiv:1402.4431 [hep-ph].

ANALYTICAL METHOD FOR CALCULATING THE PROBABILITIES OF 2nd-ORDER PROCESSES IN THE FINE STRUCTURE CONSTANT OCCURRING IN THE FIELD OF A PLANE ELECTROMAGNETIC WAVE

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A new method of obtaining analytical expressions for the probabilities of 2nd-order processes in a constant thin structure with a photon intermediate state, which are described by two Feyman diagrams, is proposed. Parts of the probability corresponding to the contribution of each of the diagrams separately were written down through the probabilities of the 1st-order subprocesses describing the polarization effects of the intermediate photon. The calculation of the part of the probability corresponding to the interference of the amplitudes is particularly difficult. An analytical method which allows to determine the phase in the amplitude of the process is proposed to solve this problem.

CURVATURE OF THE DIFFRACTION CONE OF PROTON-PROTON ELASTIC SCATTERING AT COLLIDER ENERGIES IN MAXIMAL POMERON AND ODDERON MODEL

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The behavior of the curvature parameter was studied within the framework of the maximal Pomeron and Odderon model at all available energies within the diffraction cone. These models naturally consider the curvature as the manifestation of the threshold structure of the scattering amplitude required by t-channel unitarity. The two-component scattering amplitude with spin flip and without spin flip, taking into account the maximum Pomeron and Odderon, as well as the standard Reggeon contributions, is able to describe a wide range of experimental data in the available range of energies and momentum transfer. In this case it is more convenient consider the curvature parameter averaged in some interval of momentum transfer. The curvature parameter as a derivative of nuclear slope is reconstructed from the experimental differential cross-section in *pp* elastic scattering for high energies in the small-|*t*| region where the non-exponential behavior of the diffraction cone, i.e. the "curvature" phenomenon is clearly visible. The model predict the decreasing of curvature parameter which decreases with energy and changes sign at energy far from available maximal ones.

NUCLEOSYNTHESIS OF NUCLEAR MATTER: ENTROPY EFFECTS

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There are well-known directions of the theory of nucleosynthesis, which consider the formation of nuclear matter as a collection of atomic nuclei of free mass (A) and charge (Z) as a result of cascades of r- and s- processes responsible for the formation of light and heavy chemical elements. Another direction of nucleosynthesis proposed in previous works, see [1], comes from the conditions of dissipation of a hypothetical nuclear substance with significant values ($>10^{30} - 10^{40}$) of atomic masses and charges.

This work shows that the conditions for the formation of channels for the decay of nuclear matter in the range of about 10^3 - 10^4 of their atomic masses/charges must take into account entropy effects, i.e. the degeneration of the states of the synthesized nuclei when taking into account different schemes of their implementation. The color statistics of nuclear matter and a 2-urn model of the formation of fission fragments were used for the study. The results were obtained by applying mass formulas and known systems for estimating the binding energies of the formed nuclear complexes.

It is shown that this approach can be useful for explaining the dominant number of actinide nuclei during the decay of nuclear matter, the fission fragments of which form the isotopic and chemical composition of celestial bodies.

1. V.T. Maslyuk, E.O. Skakun, M.I. Romanyuk Nucleosynthesis on the contrary: from nuclear matter to atomic nuclei // International conference "Uzhgorod School of Atomic Physics and Quantum Electronics" to the 100th anniversary of the birthday of Professor Ivan Prokhorovich Zapisochny. Uzhgorod, May 26-27, 2022. ISBN 978-617-7798-90-2. С. 343-347.

CORRELATION OF THE BOTTOM QUARKS IN ELECTRON-POSITRON ANNIHILATION AND SEARCH FOR CP-VIOLATION

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The purpose of the work is to study the effects of CP-violation in the process of e^+e^- annihilation with a focus on the future electron-positron collider CLIC (380 GeV). It is based on the study of electron-positron annihilation into a pair of top quarks which due to their properties decay into bottom quarks and W-bosons. In order to take into account CP-violation, the interaction Lagrangian of the top quarks with photon and Z-boson is modified by including terms proportional to the electric dipole moment and weak electric dipole moment, respectively.

Cross section for this process is obtained as a function of several variables: energies of the bottom quarks and electron, polarization of the initial electron, scalar and pseudo-scalar constants that determine the CP-violation. The energy asymmetries of the bottom quarks are analyzed for various polarizations of the initial electron.

Section 2. Fundamental research at intermediate and high energies

PHOTONEUTRON ACTIVATION YIELDS ON THE ^{118}Sn AND ^{124}Sn TIN ISOTOPE NUCLEI AT THE NEAR-THRESHOLD ENERGY RANGE

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Photon-induced nuclear reaction research is important for the nuclear structure and interaction comprehension, that is for basic nuclear physics, and experimental data on photonuclear reactions have a wide region of practical applications and contribute to related science development. In particular, integral yields and/or cross sections of photonuclear reactions are required for modeling nucleosynthesis processes in the Universe. Photonuclear reactions play a decisive role in the stellar nucleosynthesis of the so-called *p-nuclei* [1] – 35 observed in nature stable isotopes which, due to the peculiarities of some isobaric chains of the nuclide valley of stability, could not be formed in slow or fast neutron capture reactions (s- and r -processes) [2,3] as a result of which the majority of atomic nuclei of medium and heavy weights were arised.

The presented work reports the results of the experimental measurements and theoretical calculations within the Hauser-Feshbach statistical model of the photonuclear reactions ^{118}Sn(γ,n)^{117m}Sn and ^{124}Sn(γ,n)^{123m}Sn integral yields in the photon energy range related to the stellar nucleosynthesis. The photoactivation technique of measurements was applied at the experimental studies. Irradiations of the targets were carried out with the bremsstrahlung photon flux of the LPE-300 electron linear accelerator of the NSC KIPT (Kharkiv) while the measurement and analysis of the nascent activities by high resolution off-line γ-spectrometry.

A feature of the studied reactions is the production of residual nuclei in the isomeric states, which increases the possibilities of further improvement of statistical theory parameterization, in particular the nuclear level density and its spin dependence.

Theoretical calculations were performed using the well-known computer code TALYS [4] with different models of the nuclear level density and the radiation strength function. The back-shifted Fermi gas model [5] for the nuclear level density and Kopecky-Uhl generalized Lorentzian [6] for the radiation strength function can be considered as the best combination for an adequate prediction the experimental results.

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INFLUENCE OF CASCADE TRANSITIONS ON DETERMINATION OF A SAMPLE RADIOACTIVITY BY THE GAMMA-SPECTROMETRY METHOD

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Currently high-resolution semiconductor gamma-spectrometry is widely used to determine the intensities of γ-ray emissions following both nuclear reactions and long-lived radioactive nuclei decays. Analyzing measured γ-ray energy spectra, investigators usually determine areas of the total photon absorption peaks each of which corresponds to a certain transition connecting two levels of the same nucleus. Providing an experimenter aims high measurement accuracy, the instrumental effect of summing γ-ray intensities of prompt radiative transitions in the same nucleus should be taken into account and the appropriate corrections should be determined and introduced. The corrections can be of two types: 1) on random coincidences and 2) on coincidences caused by cascade photon summing.

In the first case, at a low intensity of gamma radiation, the correction on random coincidences is rather small and can be easily taken into account using existing formulas.

In the second case, two types of summing effects can take place: 1) a photon with energy E_0 is registered together with other photons during the resolution time of the spectrometer and drops out of the total absorption peak, and 2) two cascade photons with energies E_1 and E_2 ($E_1+E_2=E_0$) are totaly absorbed in the detector cristal. This second event is registered as one photon with energy E_0. The intensity of the total absorption peak under study is decreased due to the type 1 effect and is increased due to the type 2 effect. This correction does not depend on the intensity accumulation rate. Probability of such summation effects increases with decreasing distance between the source and the detector. So it is better to carry out measurements at the such source-detector distance at which there is no need to take into account the influence of this effect.

In this work we experimentally studied the corrections for the summing effects determining the yields of the $^{112}Sn(\gamma,n)^{111}Sn$ reaction in the giant resonance region. The activity of the irradiated with a bremsstrahlung beam tin-112 sample was measured using an HPGe γ-ray spectrometer at two source-detector distances: the first distance was large enough to ignore the correction for the summing effect and the second one was equal to zero. The ratio of the intensities at these distances makes it possible to determine the correction for the summng effect for each γ-line. The corrections determined in this way were used in further work.

MEASURING DIFFERENTIAL CROSS-SECTIONS REACTIONS OF RADIATIVE PROTON CAPTURE BY NUCLEI OF CHROMIUM ISOTOPES IN THE PROTON ENERGY REGION 1.2-2.8 MeV

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Experimental studies were carried out to measure the differential cross sections for the reaction of radiative capture of protons by nuclei of chromium isotopes in the proton energy range of 1.2-2.8 MeV at the operating electrostatic accelerator ESA-5 of the NSC KIPT.

Based on the analysis of the spectra of radiative capture of protons by ^{52}Cr isotope nuclei, gamma transitions from adjacent low-lying states to the ground state of the ^{53}Mn daughter nucleus were identified, with energies of 378 keV, 1290 keV and 1441 keV. The processing of gamma spectra was carried out using different gamma spectral analysis programs to obtain the most reliable data. The calculated yields of the ^{52}Cr(p,γ)^{53}Mn reaction were used in the formulas for calculating the cross sections for the reaction of radiative proton capture, and the obtained data were sent to the international nuclear database IBANDL containing data for elemental analysis. Subsequent processing of the spectra obtained from the 1290 keV and 1441 keV gamma lines will provide information on the partial cross sections of the ^{52}Cr(p,γ)^{53}Mn reaction and calculate the radiative strength functions in the ^{53}Mn nucleus, which is necessary to fill the NNDC nuclear database.

From the evaluation of the reaction cross sections (p,γ) for the ^{50}Cr, ^{53}Cr, and ^{54}Cr isotopes, it was concluded that additional experimental studies should be carried out on enriched targets in order to significantly improve the accuracy of the results.

MAGNETIC DIPOLE RESONANCE IN THE NUCLEI OF THE sd-SHELL

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A review of experimental research carried out at the NSC KIPT related to the study of the properties of magnetic dipole resonance (MDR) in the nuclei of the sd—shell is presented. By studying the decay of resonance-like structures (RLS) observed in the reaction of radiative capture of protons by sd-shell nuclei, we discovered a new experimental fact related to the existence of triplet pairing between odd neutrons and protons located on the same orbit. This manifests itself in the fact that the position of the center of gravity (CG) of magnetic dipole resonance (MDR) in odd-odd 4N+np nuclei is 3 MeV lower in excitation energy than in pair-even 4N nuclei and is practically independent of A (it is generally accepted) consider that the dependence should be of type E = 40A-1/3). To explain this phenomenon, a model was proposed, from which it follows that the odd nuclei of the sd-shell can be divided into two groups depending on the state of the odd particle in the d5/2 or d3/2 subshell. In the first case, the position of the MDR CG will be in the region of the excitation energy of 5–6 MeV, since it will be determined only by the spinorbital splitting energy. In the second case, it will be in the region of the excitation energy of 8-10 MeV, since in this case nn- or pp-pairs from the d5/2-subshell will participate in the formation of the MDR. This conclusion is confirmed for sd-shell nuclei. The experimental behavior of the total MDR force in the odd nuclei of the sd-shell corresponds to that obtained from the analysis of the Kurat sum rule (within the framework of the single-particle shell model).

NUMERICAL CALCULATIONS OF RFF IN NEUTRON-EXCESS NUCLEI pf-SHELLS

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In recent years, interest in studying the energy dependence of radiative strength functions (RFFs) in medium and heavy nuclei has increased significantly. These functions are necessary for the development of theoretical models that describe the structure, shape change, and deformation of nuclei, determination of the energies and amplitudes of collective excitations, partial and total reaction cross sections, and others. The absence of experimental data on excess neutron nuclei hinders the development of theoretical models.

The RFF(p,γ)-reaction calculations were performed using the TEPEL computer code developed at NSC KIPT. Approbation of this computer code in calculations of the RFF of a large array of medium nuclei shows an adequate description of the experimental data in the entire studied proton energy range.

Estimated calculations of the energy dependence of the RFF in more than ten excess neutron pf-shell nuclei, for example, ^{62}Cr, ^{68}Fe, ^{75}Cu, ^{78}Zn, and others, have been performed.

DIGITAL STUDY OF THE $^{14}N(\gamma,2\alpha)^{6}Li$ REACTION

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A systematic study of the $^{14}N(\gamma,2\alpha^{6}Li)$ reaction was performed. The graphical application with the ability to automatically measure the coordinates of points along tracks on digital photographs [1] was created in the Python programming language to obtain the physical parameters of events. The main procedure is to analyze the intensity of pixels in the area of tracks along a circular trajectory of a certain radius.

The excitation energy of the 2α-particle system is determined and a structure with two maxima is detected. It was suggested that the structure is formed either as a result of the decay of the intermediate excited state of the ^{8}Be nucleus or is simulated by one of the background pairs during the decay of the intermediate excited state of the ^{10}B nucleus.

A kinematic scheme for calculating the physical parameters of the reaction has been developed in the assumption of a two-particle decay mode with the formation of an intermediate excited state. A comparison of experimental data and kinematic calculation was performed. It was determined that the decay process with the formation of an intermediate excited ^{8}Be nucleus in the ground and 1^{st} excited states is carried out with high reliability.

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THE HOYLE STATE OF ^{12}C NUCLEUS IN THE ^{14}N(γ,np)3α REACTION

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Using the track 4π-detector method (a diffusion chamber arranged in a magnetic field on the way of a beam of bremsstrahlung photons with the final energy E_γ^{max} = 150 MeV), the reaction ^{14}N(γ,np)3α has been studied. The distributions of events over the excitation energy of 2^x and 3^x α-particles were analyzed. For the 2α-particle distribution, a channel of the formation of ^{8}Be nucleus in the ground state is revealed and resolved. For the events corresponding to this channel, the distribution of events over the excitation energy of three α-particles is plotted. A peak is detected in the near-threshold 3α-particle region, which can correspond to the Hoyle state of ^{12}C nucleus.

Thus, a partial channel of the reaction ^{14}N(γ,np)^{12}C* with the subsequent two-particle decay of ^{12}C* into α_1 + $^8Be_0$ is distinguished. The energy and angular distributions of α-particles at various formation stages are analyzed. The angular distributions in the center of ^{12}C nucleus mass coordinate frame are found to be isotropic, which allowed a conclusion to be drawn that the quantum characteristics of ^{12}C nucleus are $J^\pi = 0^+$. It is also shown that the energy of the α-particle accompanying the formation of ^{8}Be nucleus in the ground state is maximum.

The channel of the ^{12}C nucleus formation in the Hoyle state has not been identified earlier in photonuclear reactions.

CROSS-SECTIONS FOR PHOTOPROTON AND PHOTONEUTRON REACTIONS ON TANTALUM AT ENERGY UP TO 100 MeV

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The photoproduction of the metastable hafnium isotope in the ^{181}Ta(γ,p)^{180m}Hf reaction was studied at end-point bremsstrahlung energy $E_{\gamma max}$ up to 100 MeV. The experiment was performed with the beam from the electron linear accelerator LUE-40 the RDC "Accelerator" NSC KIPT with the use of the gamma-activation and off-line γ-ray spectrometric technique. The experimental values of the flux-average cross-sections $\langle\sigma(E_{\gamma max})\rangle_m$ for the ^{181}Ta(γ,p)^{180m}Hf reaction were determined by the γ-lines with energies E_γ = 443.09 and 500.64 keV. The bremsstrahlung flux that fell on target was calculated for real experimental conditions using the GEANT4.9.2 code, and additionally monitored by the yield of the ^{100}Mo(γ,n)^{99}Mo reaction.

The obtained cross-sections $\langle\sigma(E_{\gamma max})\rangle_m$ were compared with the literature data [1], and it was shown satisfactorily agreement. At the same time, experimental results significantly exceed theoretical flux-average cross-sections $\langle\sigma(E_{\gamma max})\rangle_{th}$, which were calculated using the cross-section $\sigma(E)$ values from the TALYS1.95 code for six different level density models *LD*.

The values of the experimental flux-average cross-sections $\langle\sigma(E_{\gamma max})\rangle_m$ for the ^{181}Ta(γ,p)^{180m}Hf reaction at $E_{\gamma max}$ above 55 MeV were obtained for the first time.

A comparative analysis of the calculated total cross-sections for the reactions ^{181}Ta(γ,p)^{180}Hf and ^{181}Ta(γ,n)^{180}Ta [2] was performed. For this purpose the isospin selection rules [3] and obtained experimental flux-averaged cross-section for the ^{181}Ta(γ,p)^{180m}Hf reaction were used. It is shown that the photoproton (γ,p) to photoneutron (γ,n) strength ratio is consistent with the expected estimate according to the isospin selection rules and the data obtained from the (e, $e'p$) experiment [4].

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ISOMERIC PAIR ^{95g}Nb AND ^{95m}Nb IN PHOTONUCLEAR REACTIONS ON NATURAL MOLYBDENUM AT ENERGY OF 35-95 MeV

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The production of the ^{95g}Nb and ^{95m}Nb isomeric pair in photonuclear reactions on natural molybdenum were studied at end-point bremsstrahlung energy $E_{\gamma max}$ = 35–95 MeV. The experiment was performed at the electron linear accelerator LUE-40 the RDC "Accelerator" NSC KIPT with the use of the activation and off-line γ-ray spectrometric technique. The experimental values of the isomeric ratio $d(E_{\gamma max})$ of the ^{95g}Nb and ^{95m}Nb product nuclei were obtained by using the formulas from [1,2], which make it possible to take into account the accumulation of ^{95g}Nb nuclei due to the internal transition from the isomeric to the ground state. The flux-average cross-sections $\langle\sigma(E_{\gamma max})\rangle_m$ for the production of the ^{95m}Nb nucleus in the isomeric state were determined. This made it possible to estimate the total experimental cross-sections $\langle\sigma(E_{\gamma max})\rangle$ for the ^{nat}Mo(γ,*p*x*n*)^{95}Nb reaction.

Theoretical values of $d(E_{\gamma max})$ and $\langle\sigma(E_{\gamma max})\rangle$ were calculated using the cross-sections $\sigma(E)$ for monochromatic photons from the TALYS1.95 code. The flux of bremsstrahlung gamma quanta that fell on target was calculated for real conditions in the experiment using the GEANT4.9.2 code, and additionally monitored by the yield of the ^{100}Mo(γ,*n*)^{99}Mo reaction.

The obtained values of $d(E_{\gamma max})$ for the nuclei-products from the ^{nat}Mo(γ,*p*x*n*)^{95g,m}Nb reaction are compared with the available data in the literature [3] and the results of calculation using the TALYS1.95 code. The calculated contribution of the ^{96}Mo(γ,*p*) reaction to the ^{95g,m}Nb nuclei photoproduction on natural molybdenum was determined.

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PHOTONUCLEAR RESEARCH AT ENERGY 35-100 MeV IN RDC "ACCELERATOR" NSC KIPT

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The researches into multiparticle photonuclear reactions are being actively performed on electron linear accelerator LUE-40 in the RDC "Accelerator" NSC KIPT for nuclei with an atomic weight of $25 < A < 190$ at the end-point bremsstrahlung energy $E_{\gamma max}$ up to 100 MeV. To obtain experimental data on the cross-sections used activation and off-line γ-ray spectrometric technique. The modeling of bremsstrahlung flux that fell on target was performed using the GEANT4.9.2 code with taking into account the actual geometry of the experiment and the energy distribution in the electron beam.

The report presents experimental results for bremsstrahlung flux-averaged cross-sections $\langle\sigma(E_{\gamma max})\rangle$ and isomeric ratios $d(E_{\gamma max})$ nuclei-products of the photonuclear reactions on the ^{nat}Mo, ^{nat}Ni, ^{181}Ta, ^{93}Nb, ^{nat}Cu, and ^{27}Al nuclei. The results of a comparison with known data from the literature and calculated values using the cross-sections $\sigma(E)$ from TALYS1.95 code for six level density models [1] are presented.

Two different experimental setups were used in the experiments. In one of them, an aluminum electron absorber was used to clean the bremsstrahlung γ-flux from electrons, in the other, a deflecting magnet was [2]. A comparison of the flux-average cross-sections $\langle\sigma(E_{\gamma max})\rangle$ measured for two experimental setups was performed [3], and good agreement between the results was shown.

The possibility of using the reactions ^{100}Mo(γ,n)^{99}Mo, ^{27}Al(γ,*x*)^{24}Na, ^{93}Nb(γ,n)^{92m}Nb, ^{93}Nb(γ,3n)^{90}Nb, and ^{181}Ta(γ,n)^{180g}Ta as monitors of the bremsstrahlung γ-flux was investigated. The advantages and disadvantages of applying these monitor reactions were studied for the energy range 30 – 100 MeV.

The results of these experiments were presented in the international database EXFOR [4].

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COBALT ISOTOPES PRODUCTION IN PHOTONUCLEAR REACTIONS $^{nat}Ni(\gamma,pxn)^{55,56,57,58}Co$

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Interest in studies of photonuclear reactions with nickel isotopes is due to several reasons. Nickel is an important structural and surface coating material, used in accelerator nuclear technology and accelerator driven sub-critical system [1]. Nickel is also used as a target material for the medical isotopes production or radio-pharmaceuticals, and radioactive sources. The radionuclides ^{56}Co, ^{57}Co and ^{58}Co are useful for the synthesis of radio-pharmaceuticals, research purposes and for radiotherapy applications.

The calculation of the flux-average cross-sections $\langle\sigma(E_{\gamma max})\rangle$ of photonuclear reactions $^{nat}Ni(\gamma,pxn)^{55,56,57,58}Co$ was performed for all stable isotopes of nickel using the cross-sections $\sigma(E)$ from the TALYS1.95 code for different level density models *LD* 1–6. The flux of bremsstrahlung gamma quanta that fell on the target was calculated using the GEANT4.9.2 code for real conditions of experiment on the electron linear accelerator LUE-40 RDC "Accelerator" NSC KIPT [2].

Preliminary values of experimental flux-average cross-sections for photoproduction of cobalt isotopes on natural nickel were obtained at end-point bremsstrahlung energy $E_{\gamma max}$ up to 100 MeV. The results of calculations and experiment are compared with data from [3].

The yields of the $^{55,56,57,58}Co$ nuclei in the photonuclear reactions on all stable nickel isotopes was calculated and the dominant reaction channels were determined in the range of studied energies.

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ISOMERIC PAIRS IN PHOTONUCLEAR REACTIONS ON In AND Rh NUCLEI

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Nuclei with isomeric (*m*) and unstable ground states (*g*) are of particular interest, since they allow to study of the metastable state population of this nucleus relative to its ground state, i.e. obtain the isomeric ratio of the reaction products. Data on isomeric ratios of reaction products make it possible to investigate issues related to nuclear reactions and nuclear structure, such as the spin dependence of the nuclear level density, angular momentum transfer, nucleon pairing, shell effects, refine the theory of gamma transitions, and test theoretical models of the nucleus. The study of isomeric ratios using photonuclear reactions has an advantage since the γ-quantum introduces a small angular momentum and does not change the nucleon composition of the compound nucleus.

In the case of using bremsstrahlung flux, the value of the isomeric ratio $d(E_{\gamma max})$ is measured as the ratio of the flux-average cross-sections formation of end-nucleus reaction products in isomeric and ground states: $d(E_{\gamma max}) = \langle\sigma(E_{\gamma max})\rangle_m / \langle\sigma(E_{\gamma max})\rangle_g$.

In this work, we consider isomeric pairs of nuclei that are products of photonuclear reactions on indium and rhodium nuclei. The calculation of isomeric ratios $d(E_{\gamma max})$ was performed using the cross-sections $\sigma(E)$ from the TALYS1.95 code. The flux-averaged cross-section $\langle\sigma(E_{\gamma max})\rangle$ were estimated using the bremsstrahlung flux obtained by modeling in the GEANT4.9.2 code. The contribution of competing reactions on different In isotopes to the total yield of the studied reactions was estimated.

The calculated values of $d(E_{\gamma max})$ were compared with the data from the EXFOR database.

DEFORMATION OF ODD NUCLEI ^{23}Na, ^{25}Mg AND ^{25}Al IN SINGLE-PARTICLE STATES

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Using the evolutionary approach recently developed by us /1,2/, the shapes of odd 2s1d-shell ^{23}Na, ^{25}Mg and ^{25}Al nuclei in the ground and single-particle excited states have been extracted from the experimental data on the energies, spins, and parities of these states, as well as the measured probabilities of electromagnetic transitions between them. It is shown that the studied nuclei are differently deformed in their single-particle states and the contribution of the hexadecapole deformation is not small compared to the contribution of the quadrupole deformation. The single states and the continuous sets of states with abnormally weak deformation are found in the single-particle spectra of the nuclei studied. This indicates the existence of the shape phase transitions from the spherical state of the nucleus into a deformed state.

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ANALYSIS OF ELASTIC α-^{58}NI SCATTERING IN THE ENERGY REGION FROM 100-699 MeV BY THE S-MATRIX MODEL

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Elastic scattering of α-particles on ^{58}Ni nuclei is analyzed for energies from 26 to 174 MeV/nucleon using original 6-parameter S-matrix model [1] accounting Coulomb interaction and effects of strong nuclear absorption and reflection of scattered waves. The experimental data processing is provided for the following α-particle energies: 104, 139, 172.5, 240, 288, 340, 386, 480, and 699 MeV. Separation of the scattering amplitude for the "near" and "far" components [2] has allowed to investigate the diffraction pattern of the scattering as a consequence of the interference of these sub-amplitudes. Energy dependence of model parameters, differential and total reaction cross-section, intersection angles of the "near" and "far" components of scattering amplitude ("Fraunhofer crossover") and nuclear rainbow angles are presented.

It is shown that the linear size of strong absorption region and the region of nuclear refraction $L_{0,1}/k$, their diffuseness parameters $\Delta_{0,1}/k$ and the transparency coefficient of the nuclear matter ε are following linear trend on the energy which is in accordance with the results from other nuclei [3,4]. Exponential behavior of the nuclear diffraction parameter δ_1, nuclear rainbow angle θ_r and of Fraunhofer crossover θ_{cr} is obtained. The dependence of quantum deflection function and the S-matrix modulus from quasi-classical impact parameter for all investigated energies is presented as well. The results are compared to the similar ones obtained from the optical model.

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ALPHA DECAY OF NEODYMIUM ISOTOPES

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Five of seven naturally occurring neodymium isotopes are potentially alpha unstable. The theoretical estimations of their half-lives range from 2.3×10^{15} y for α decay of ^{144}Nd to the ground state of the daughter [1] to 9.5×10^{121} y for α decay of this nuclide to the first excited state of ^{140}Ce. Gamma-ray spectroscopy of a Nd_2O_3 sample with a mass of 2.381 kg was realized using a four-HPGe-detectors low-background set-up at the Gran Sasso underground laboratory (Italy). Data analysis of 51237 h measurements allowed the improvement of the current limits for α decays of ^{143}Nd, ^{145}Nd and ^{146}Nd by 2-3 orders of magnitude, while the investigation of the α decay of ^{148}Nd was performed for the first time. In addition, a first limit on double α decay of ^{148}Nd was set.

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NUCLEAR YIELD AND CROSS SECTION OF THE PHOTONEUTRON REACTION ON TELLURIUM-120

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Nuclei, which are usually called p-nuclei, are produced through a chain of photonuclear reactions (γ, n), (γ, p), (γ, α). The light isotope Te^{120} also belongs to p-nuclei. We have studied the yield and cross-section of the $^{120}Te(\gamma, n)119Te$ reaction in the range of maximum bremsstrahlung gamma beam energies $E\gamma max=10\div18$ MeV.

The measurement was carried out on the bremsstrahlung gamma beam of the M-30 microtron of the Department of Photonuclear Processes of the Institute of Electronic Physics of the National Academy of Sciences of Ukraine. Irradiation of prototypes was carried out with a step of 0.5 MeV. The energy spread of the electron beam did not exceed 30–50 keV. The average current of the accelerator was 5 μA.

An activation technique was used for the research. The studied targets were made in the form of discs of vitreous tellurium oxide TeO, 25 mm in diameter and 2 mm thick, with a purity of 99.99%. The miscalculations of the recording equipment were less than 5%.

In parallel with the measurement of gamma lines from the decay of ^{119}Te, the measurement of gamma lines from the decay of ^{129}Te obtained in the reaction of $^{130}Te(\gamma,n)^{129m,g}Te$ was carried out, which were used to normalize and calibrate the outputs of the $^{120}Te(\gamma,n)^{119}Te$ reactions. As a result, we obtained the ratio of the excitation yield of the ground state of the isotope ^{119}Te (Y_1) to the yield of excitation of the ground state of the isotope ^{129}Te (Y_2): $\eta_1=Y_1/Y_2$. For all isotopes of tellurium, the ground and isomeric states were populated in the (γ,n) reactions. At the same time, the total output (γ,n) of the Y_n reaction is related to the excitation outputs of the basic Y_g and the isomeric state Y_m as follows: $Y_n = Y_g + Y_m$.

Thus, by measuring the ratio of the population yields in the reaction (□,n) of the ground states of tellurium isotopes, we determined the ratio of the total yields of the (γ,n) reaction on the ^{120}Te isotope to the total yield of the $^{130}Te(\gamma, n)^{129}Te$ reaction, i.e., Y_n^{120}/Y_n^{130}, which made it possible to calculate the reaction cross sections of $^{120}Te(\gamma, n)^{119}Te$ using the cross-section of the $^{130}Te(\gamma, n)^{129}Te$ reaction (measured earlier in [1]). The calculation was carried out by the inverse matrix method with a step of 1 MeV. The cross-sections have a single-hump shape with a maximum energy of ~15.4 MeV.

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STRUCTURE OF MASS DISTRIBUTIONS OF ^{238}U PHOTOFISSION PRODUCT YIELDS AT 17.5 MeV BREMSSTRAHLUNG PHOTONS ENERGY

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The results of experimental studies of mass distributions of 30 products of ^{238}U photofission at the maximum bremsstrahlung energy of 17.5 MeV are presented. Stimulation of the ^{238}U photofission reaction was carried out on the M-30 microtron of the IEPh of the National Academy of Sciences of Ukraine. The GEANT4 toolkit was used to calculate the spectra of photons, residual electrons, and secondary photoneutrons that interacted with the ^{238}U target. The obtained experimental results indicate the presence of a fine structure in the obtained mass distribution of yields of photofission products of ^{238}U, which is manifested in increased yields of products localized in the area of masses 133-134, 139-140 and 143-144. This is consistent with the existing experimental data at close excitation energies and is related to the influence of such a nuclear structure as the proximity of closed nuclear shells and the even-odd effect. To describe the structure of the mass distribution, a parametric formula of the sum of three gaussians is proposed, the centers of gravity of which are localized in the maxima of product yields. In addition, a comparison of the obtained experimental results of the photofission product yields of ^{238}U with the results of modeling with the GEF-2021.1.1 and Talys1.96 software codes was carried out. It should be noted that the theoretical values of the outputs generally describe and predict the fine structure of the mass distribution.

Section 3. Fundamental research of ultra-relativistic particle interaction with single crystals and matter

GAMMA-RADIATION BY 200 MeV ELECTRONS IN A DIAMOND CRYSTAL AT PLANE ORIENTATION

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On the MAX-lab experimental facility, gamma radiation by electrons with an energy of about 200 MeV in a diamond crystal with a thickness of 100 μm has been measured. The electrons were incident on the crystal along the (110) plane at small angles to the <100> axis. The measurements have shown that with increasing of the angle of incidence, the mode of electron motion changes from above-barrier chaotic to above-barrier regular type, which leads to a change in the mechanisms by electron radiation and, as a consequence, to a change in the spectra of emitted photons. Theoretical calculations based on the quasi-classical QED approximation are in good agreement with the experimental data.

LOW-ENERGY SPECTRA OF SECONDARY ELECTRON EMISSION DURING THE PASSAGE OF RELATIVISTIC ELECTRONS THROUGH MATTER

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When metallic surfaces are bombarded by relativistic electrons, secondary electron emission occurs, the spectra of which have some features common to all substances. In particular, the energy spectra of secondary electron emission for relativistic initial energies in the low energy region have a maximum in the range up to 20 eV. This maximum characterizes a group of electrons called true secondary.

This report presents the measured spectra of low-energy electrons that appear when bombarded by relativistic electrons with energies in the range of 10-30 MeV in an aluminum target 50 μm thick.

The measurements showed that the shape of the low-energy spectra weakly depends on the initial energy. The mechanism of excitation and exit of secondary low-energy electrons is approximately the same in the specified range of initial energies. Comparison with the same spectra obtained at much lower energies of primary particles showed that as the initial energy increases, the full width at half maximum (FWHM) of the spectrum decreases, while the position of the energy maximum remains practically unchanged.

The yield of low-energy electrons from the first target surface is higher than from the second one. The position of the maxima in the spectra of low-energy electrons is in the range of 1.2-1.45 eV, and the full width of the spectra at half-maximum lies in the range of 3-3.6 eV for the initial energies of relativistic electrons of 10-30 MeV.

STUDY OF THE ANOMALOUS DIFFUSION PHENOMENON IN THE FAST CHARGED PARTICLES SCATTERING IN THE PERIODIC FIELD OF CRYSTALLOGRAPHIC ATOMIC PLANES

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In work [1] it was shown that at fast charged particles motion in the field of crystal atomic strings the phenomenon of anomalous diffusion is possible in which the thickness dependence of the average value of the square of the particles displacement in the plane that is orthogonal to the axis of atomic strings is significantly different from the linear one. In this work we show that a similar phenomenon is possible in the high-energy particles scattering during their motion in the crystal at small angles to the crystal atomic plane of the order of the critical angle for planar channeling. The consideration was carried out on the basis of numerical simulation of the particle scattering process with taking into account incoherent scattering effects on the atoms thermal oscillations in the crystalline lattice.

It is shown that in this case the phenomenon of particles subdiffusion in the crystal is possible at which the process of their multiple incoherent scattering is weakening. This effect occurs for both positively and negatively charged particles. When the angle of particle incidence on the crystal atomic planes increases beginning from the two values of the critical angle of planar channeling the particle diffusion index during scattering approaches the corresponding value of the diffusion index in an amorphous medium.

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COMPARATIVE ANALYSIS OF THE DEFLECTION EFFICIENCY OF ANTIPROTONS WITH ENERGY 1–14 GeV WITH PLANAR CHANNELING IN A BENT CRYSTAL AND WITH STOCHASTIC DEFLECTION

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As part of the FAIR project, it is planned to create a High Energy Storage Ring (HESR) at the GSI Helmholtz Center for Heavy Ion Research to store antiprotons in the range of kinetic energies from ≈1 to 14 GeV. These antiprotons will be used for the next generation of strong interaction experiments. However, if it is possible to extract part of the beam halo from the storage ring, it will allow to carry out a number of experiments in the parasitic mode in parallel with the main experiment, using antiprotons extracted from the accelerator ring into separate experimental channels. The use of bent crystals to deflect antiprotons may allow this extraction of particles because there are several mechanisms for deflecting charged particles using bent crystals, and among them are those that are effective at deflecting not only positively charged particles but also negatively charged ones. The report is devoted to the results of the study of the efficiency of deflection of the specified particles using a stochastic deflection mechanism and planar channeling in a bent crystal [1].

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DISTRIBUTION FUNCTION OF AN ULTRARELATIVISTIC ELECTRON-POSITRON PAIR IONIZATION ENERGY LOSS IN A THIN TARGET UNDER THE CONDITION OF CHUDAKOV EFFECT

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The value of ionization energy loss of a particle in a thin target is stochastic and is distributed according to a certain law known as the Landau distribution. The maximum of this distribution (spectrum) corresponds to the most probable value of ionization loss E_{MP}, which may noticeably differ from the average value E_{AV} of the particle ionization loss in the target. Previously, the ionization loss spectra were comprehensively studied for the case when the particles of the beam traverse the target one at a time. In the present work we investigate the ionization loss spectra of electron-positron pairs in thin targets under the condition of manifestation of the Chudakov effect. This effect is the reduction of the pair ionization loss, compared to the sum of independent electron and positron losses, due to destructive interference (mutual screening) of the Coulomb fields of the particles forming the pair. Previously, this effect was studied only for the average value E_{AV} of the pair ionization loss. In the present work the distribution function for the pair ionization loss, as well as the expression for the most probable value of its loss E_{MP}, are obtained. It is shown that the Chudakov effect for the quantity E_{MP} can be noticeably stronger than for the quantity E_{AV}. The obtained results are presented in the paper [1]. The developed theory could be applied for a more consistent analysis of the results of the experiment [2].

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POSITRON LIFETIME IN RADIATION DEFECTS IN THE SPHERICALLY SYMMETRICAL APPROACHING

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The positron lifetime spectroscopy method provides unique opportunities for studying irradiated material and determining the concentration of point defects. Analytical approaches have been developed for calculating the positron lifetime in a material, taking into account local changes in the electron density produced by its defective structure. The Tao-Eldrup model, which allows to analytically calculate the lifetime of a positron in a spherically symmetric potential, has been modified in the case of finite height of potential well. Thus, the annihilation rate is determined by the overlap of the positron and electron density due to tunneling through the boundaries of the potential well into the main material and inside the well. It is shown that the value of the lifetime rather quickly grows with the increasing of potential well height, and can significantly exceed the positron lifetime in the main material structure. The developed model provides important information for the analysis of positron lifetime spectra in irradiated materials and data for verification of quantitative calculation results for positron lifetime by density functional methods, which are widely used for such tasks.

Section 4. Physics and technology of radiation detectors

DEVELOPMENT OF A MICROPROCESSOR MEASURING AND CONTROL CHANNEL OF A MAGNETIC SPECTROMETER OF AN ELECTRON ACCELERATOR LU-30

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To upgrade the existing magnetic spectrometer, a measuring and control channel based on the Atmega328 microprocessor was developed. The use of microprocessor control makes it possible to improve the accuracy of measuring the beam energy spectrum and facilitates further modernization of the spectrometer.

DEVELOPMENT OF A SOFTWARE AND HARDWARE COMPLEX FOR BUILDING A TWO-CHANNEL GAMMA-RAY SPECTROMETER

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A small-sized spectrometric path has been developed for operation as part of a two-channel X-ray and gamma-ray spectrometer in a wide energy range. The path is designed to work with uncooled silicon planar detectors, but can be used with other types of detectors. The software allows processing information from each spectrometric channel and presenting information in the form of a single spectrum.

STUDY OF DOSE RATE EFFECT ON RADIATION RESISTANCE OF SCSN-81 AND EJ-260 SCINTILLATORS UNDER IRRADIATION BY BREMSSTRAHLUNG PHOTONS

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The influence of the dose rate of irradiation with bremsstrahlung photons on the degree of damage to samples of plastic scintillators SCSN-81 and EJ-260 at the LU-10 electron linac was studied. The dose rate was varied due to the use of a set of shielding lead screens. To do this, a layout was set up with a set of four 10.1 mm thick lead plates and two 1 mm thick aluminum plates separated by 20 mm. To eliminate the influence of the environment radiation background in the accelerator experimental hall of the on the irradiation dose rate, this construction was placed in a protective box of lead bricks. The box was additionally covered with NEUTROSTOP C0 polyethylene blocks and installed along the accelerator beamline. The values of the radiation dose rate in the compartments of the structure were as follows: 161.86 krad/hr in front of the screens (h = 0); 34.48 krad/hr after the first screen (total thickness of h=10.1 mm); 18.62 krad/hr after the second screen (h=20.2 mm); 11.9 krad/hr after the third screen (h=30.3 mm) and 7.5 krad/hr after the fourth screen (h = 40.4 mm). Samples of SCSN-81 and EJ-260 scintillators were placed in compartments between the plates and irradiated to the integral dose of 5±5% Mrad. The change in the technical light output was determined by the ratio of the α-peak (from the ^{239}Pu source) position after irradiation to that before the irradiation. The decrease in the technical light yield of the scintillator samples with a change in the radiation dose rate from 162 krad/hr down to 7.5 krad/hr turned out to be 28% and 29% for the SCSN-81 and EJ-260 scintillator, respectively. The results of our measurements with such an irradiation layout of the light yield degradation for the SCSN-81 and EJ-260 scintillators, in depends on the dose rate of irradiation with bremsstrahlung photons, are in fair agreement with the data given in paper [1].

The work was supported in part by a grant from the NAS of Ukraine within the Targeted research program “Collaboration in advanced international projects on high-energy and nuclear physics“.

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CREATION OF COMPOSITE SCINTILLATORS WITH A SHORT DECAY TIME

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To date, LuAG:Ce crystals are one of the most common scintillators, since they have been known for a long time and there are technologies for mass production of large-volume crystals. However, the scintillation properties of such crystals can be improved by creating mixed crystals with the replacement of some ions by others.

In this work, composite scintillators based on the grown LuYAG:Ce inorganic crystals were produced. For the obtained samples, studies of optical transmission, luminescence, light output, and decay time were carried out. The optimal conditions and sizes of crystalline grains for the creation of composite scintillators have been determined.

Studies of the radiation resistance of these scintillators under electron irradiation have shown that its radiation resistance more than 50 Mrad.

MECHANICAL FEATURE OF COMPOSITE SCINTILATORS IN THE ELECTRON ACCELERATOR IRRADIATION ZONE

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In previous works, it was shown that, upon irradiation of composite scintillators based on grains of inorganic single crystals, after obtaining significant doses (more than 100 Mrad), cracks began to appear.

The process of the irradiation of composite scintillators occurs in the surrounding atmosphere. Irradiation was at low (0.2 ± 0.01 Mrad/h) or high (1500 ± 5 Mrad/h) dose rates. In the first case, it was predominantly of bremsstrahlung photons. In the second case, the surface of the samples was irradiated directly with electrons. Despite on the rate of irradiation, cracking was observed in both cases. The main difference was only the radiation dose at which such the effect began to be observed.

In this work, two main factors of cracking of composite scintillators under irradiation are analysed. In addition to the ionizing radiation itself, cracking can be influenced by both "temperature" and "radiation-chemical" factors. The analysis is based on experimental data obtained by irradiating scintillators and the results of model chemical and temperature experiments.

DEVELOPMENT OF HIGH-QUALITY $ZnWO_4$ SCINTILLATING DETECTORS TO SEARCH FOR DARK MATTER AND DOUBLE-BETA DECAY

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Optical, luminescence and scintillation properties have been measured with several ZnWO4 crystal scintillators grown by the low-thermal gradient Czochralski technique after an extended R&D that included variation of the compound stoichiometry, using of WO3 of different producers, utilization of re-crystallization and annealing of the grown boules. The best optical and scintillation properties have been obtained with the crystal samples produced by single crystallization with the stoichiometric composition of the ZnWO4 compound prepared from deeply purified WO3, and annealed in air atmosphere. No clear correlation was observed between the scintillation and luminescence relative intensities, which indicates that the material quality can be improved further. The energy resolution (full weight at half maximum, FWHM) has been measured with a ∅30×31 mm sample as 9.6% for 661.7 keV γ quanta of 137Cs, and 6.4% at 1332.5 keV (60Co). The measurements with two highest quality crystal samples are in progress at the Gran Sasso underground laboratory to estimate the radiopurity level of the samples.

EMPIRICAL FORMULA OF THE DEPENDENCE OF HPGe- DETECTOR EFFICIENCY ON ENERGY AND DISTANCE FOR SHIELDED GAMMA RADIATION SOURCES

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When determining the qualitative (isotopic) and quantitative composition of nuclear materials, which are in hermetic containers made of stainless steel, a passive method of analysis - semiconductor gamma spectrometry - is widely used. The accuracy of the analysis method depends on the accuracy of the calibration of the detectors in terms of absolute efficiency, which in turn depends on the physical and geometric characteristics of the detectors, screens and samples and the geometry of the measurements (their relative location).

The paper presents the results of experimental research on the dependence of the absolute efficiency of the HPGe detector [1] on the energy of gamma quanta (50 ÷ 3000 keV) and the distance between the detector and the source (50; 100 mm) with a stainless steel screen (brand: 12X18H10T [2]) with a thickness of 9.5 mm. Based on our previous work [1], a formula was obtained for describing the dependence of the efficiency of the HPGe detector on energy and distance for shielded standard point sources of gamma quanta, which allows to increase the accuracy of determining the activity of nuclear materials during passive analysis.

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Section 5. Research and development of charged particle accelerators

MAGNETO-OPTICAL STRUCTURE OF THE MULTIFUNCTIONAL ACCELERATOR COMPLEX NSC KIPT

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Electron accelerators are one of the most effective tools in studying the structure of the atomic nucleus and the nature of nuclear forces. According to the European Strategy for Particle Physics - Accelerator R&D Roadmap [1] published in 2022, the latest electron accelerators will also find wide application as intense sources of radiation in the terahertz, infrared, vacuum ultraviolet and X-ray spectrum regions.

In work [2], on the basis of the latest achievements, a search was made for the main technological and circuit solutions for the creation of a multifunctional accelerator complex (Multifunctional Accelerator Complex - MAC) with a continuous beam for research in high-energy physics, nuclear physics, neutron physics, physics of free electron lasers and its use for the implementation of radiation technologies in industry, energy, medicine, biology and other fields of science and technology.

In our work, the magneto-optical structure of the complex is considered in more detail, the focusing functions of the recirculator and the parameters of the beams at the beginning of the main output channels to the experimental installations are given.

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ELABORATION OF THE PLASMA-DIELECTRIC WAKEFIELD ACCELERATOR WITH A PROFILED SEQUENCE OF DRIVER ELECTRON BUNCHES (THEORY AND EXPERIMENT)

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A theoretical and experimental study of wakefield excitation by a profiled sequence of relativistic electron bunches in the plasma-dielectric structure, the parameters of which provide the conditions for the excitation of a small decelerating field for all driver bunches with simultaneous growth with the number of bunches of the accelerating total wakefield was carried out. Theoretically, the transformation coefficient was found for the parameters of the experiment as the ratio of the total wakefield of the sequence to the field that decelerates driver bunches. In the performed experiments, the total wakefield was measured by the microwave probe. The magnitude of the decelerating field is determined by the shift of the maximum of the spectrum measured by the magnetic analyzer before and after wakefield excitation in the structure. The obtained transformation coefficient satisfactorily corresponds to the theoretical one, increases with the number of bunches in the sequence and significantly exceeds this one for an unprofiled sequence.

This work was supported by NAS of Ukraine Program "Plasma physics and plasma electronics: basic researches and applications", Project П4/60-2022.

LOW INTENSITY ELECTRON AND POSITRON BEAMS IN THE ENERGY RANGE UP TO 100 MeV AT IHEPNP NNC KIPT FACILITY

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In work [1], the possibility of creating at the IHEPNP NNC KIPT an experimental facility for research in the field of interaction of radiation with amorphous substances and crystals, nuclear and applied physics has been discussed. The facility is planned to be built using the existing experimental infrastructure and a linear electron accelerator with an energy up to 100 MeV, and it should include two beam lines [1]: one (line-1) will be used for experiments with high-intensity electron and photon beams, the other (line-2) for experiments with low-intensity beams of electrons and positrons, ~ $1\text{-}10^3$ particles per pulse of the accelerator. For study of the possibilities of forming the required parameters of the beams and evaluating their characteristics, using a GEANT-4 package, a simulation of the production of electrons and positrons in the tungsten converter with thickness of ~2X0, and their passage through the beam line-2 has been performed. Preliminary results of the simulation show that using the electron beam with energy of 100 MeV and elements of the beam line-2, it is possible to obtain the positron (electron) beams with energy 20-80 MeV, the energy spread less 2 MeV and required intensity.

1. V.B. Ganenko, V.I. Kasilov, G.D. Kovalenko, N.I. Maslov, I.L. Semisalov. *Experimental facility IHEPNP for fundamental and applied researches in energy range up to 100 MeV.* // Problems of atomic science and technology, 2020, № 5(155). Series: Nuclear Physics Investigations (67), p.1-4

FOCUSING OF ELECTRON BUNCHES AT WAKEFIELD EXCITATION IN PLASMA

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The emergency and evolution of focusing force acting on electron bunches are investigated at plasma wakefield excitation by a sequence of bunches depending on the bunch length and distance between bunches for various charge profiles of the bunch. Before in numerous publications in the field of high energy physics the focusing process is interpreted as the action of a plasma lens, in which the essential role of plasma is concluded to the compensation of the bunch space charge. This presentation reveals that the spatio-temporal dynamics of the charge compensation process is fully the process of wakefield excitation. When an electron bunch moves in a plasma, its electrons are affected by the focusing forces of its own magnetic field and the excited radial wake field, as well as the force of defocusing by the space charge of the bunch. The ratio between them determines the dynamics of the focusing effect. In the relativistic case, the focusing of the magnetic field almost completely compensates for the defocusing by the space charge of the bunch. Therefore, the wakefield focusing plays the main role in the dynamics of the resulting focusing. The study of the considered process is important especially for a bunch of finite length, a bunch of non-uniform charge profile and for a sequence of bunches with any distance between bunches. The spatio-temporal dynamics of the focusing force in all considered cases is completely determined only by the wakefield, excited by the sequence and repeats its behavior.

PROBE FOR MEASURING THE LONGITUDINAL COMPONENT OF THE ELECTRIC FIELD IN A DIELECTRIC WAKEFIELD ACCELERATOR

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To conduct experiments to determine the amplitude of the electric field and the transformation ratio in the wake field accelerator based on dielectric structures excited by electron bunches of the Almaz-2 electron accelerator, a probe was developed and manufactured. The probe consists of a ¼ wavelength antenna (27 mm) and a detection circuit based on a 2A201A microwave diode.

To calibrate the probe, a measuring stand was assembled, consisting of a microwave generator and a horn emitter. A SPEKTRAN spectrum analyzer (Germany) was used as a microwave power meter, and a digital oscilloscope was used as a meter of the detected signal from the probe.

The results of measurements made on the stand show that at a microwave radiation power of 26 mW/m^2 and an electric microwave field strength of 2.6 V/m at the measurement point, the output signal from the probe is 1 mV.

EFFECT OF DELAY TIME BETWEEN DISCHARGES OF PLASMA CANNONS AND MAIN HYS ON CURRENT SWITCHING IN ACCELERATORS WITH INDUCTIVE ENERGY ACCUMULATOR AND PLASMA CURRENT SWITCH

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Accelerators with inductive energy storage and plasma current commutator are compact and capable of obtaining the power of electron beam current pulses up to 10^9-10^{10} W with a duration in the range of 20-100 ns. Their output parameters, namely: the current and energy of the electron beam, the characteristics of X-ray and electromagnetic radiation, depend on the parameters of the primary circuit, the voltage of the main pulse current generator (PCG), the voltage applied to the plasma guns and the delay time between the activation of the plasma guns (PG) and the main PCG, which supplies voltage to the central electrode of the accelerator [1-5].

The delay time, in turn, depends on the sum of several parameters. This is the synchronization time from the pulse generator, as well as the switching time of the PG and PCG launch blocks. The switching time is a parasitic value that depends on the relevant parameters of the RLC circuit and the parameters of the PG and PCG arresters. Adjustment of the delay time is possible only due to the generator of synchronization pulses. In [6], the influence of the delay time on current switching and electron beam parameters in the range from 6 to 15 μs for the DI-2 accelerator is given. In this work, similar studies out for the DIN-2K accelerator were carried. The commutation current parameters were compared. The dependences of the commutation currents and the output beam of electrons on the delay time are plotted. The optimal value of the delay time at which the current interruption is maximal is found.

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VOLTAGE SOURCE UP TO 30 kV WITH PULSATION NOT MORE THAN 0.1%

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ADC source with a voltage of 30 kV with a ripple of less than 0.1% has been developed and manufactured for accelerating and focusing electrons in a dielectric laser accelerator on a chip structure. The source, which has a smooth voltage change limit from 10 to 30 kV, with a ripple of 0.1% over the entire voltage range in the specified range, is made on the basis of a 3-phase network. Such voltage stability is necessary for the correct recording of the energy of electrons accelerated by a laser pulse.

GENERAL SOLUTION OF THE EXCITATION PROBLEM OF A SYMMETRIC FLAT DIELECTRIC STRUCTURE BY PLANE ELECTROMAGNETIC WAVES

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Flat dielectric structures irradiated with laser pulses can be used for high- gradient acceleration of subrelativistic electron bunches. But in the region of ultrarelativistic energies, the acceleration rate drops sharply [1]. To overcome this limitation, a symmetrical geometry was proposed [2], consisting of two dielectric prisms separated by a vacuum channel for electron acceleration (so called “sandwich”), each prism can be irradiated with a separate laser pulse. In the case of bilateral irradiation of dielectric prisms, only a symmetric solution is given in [2], which describes the distribution of the accelerating field in the vacuum channel, which is symmetric with respect to the channel axis. In this work, we present a general solution for different laser field amplitudes and laser electric field directions, and determine the condition when a symmetric or asymmetric solution is realized. In the case of a general solution, the effect of the asymmetric part on the total amplitude of the accelerating and defocusing fields is also analyzed.

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PROJECT OF A DIFFRACTION STRUCTURE FOR ACCELERATING AN ELECTRON BEAM BY A LASER PULSE

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Calculations of the accelerator layout based on the double-row diffraction structure (gratings) excited by a laser pulse were carried out using the method of numerical modeling. The first row is formed from reflector strips (width $a=\lambda/2$) of the electromagnetic wave and gaps (width $b=\lambda/2$), the second row - reflectors ($a=\lambda/2$) and absorbers ($b=\lambda/2$). Reflectors of the second row (a distance from the first row is $L_1=2n\lambda$, $n=3, 4, 5\ldots$) are located against the gaps of the first row. The gaps of the first row are made for the passage of part of the wave to the second row. A flat electromagnetic wave ($\lambda=0.8$ μm) with an intensity of $E=10^9$ eV/m falls in the first row perpendicular to grating surface. The electron beam moves at a distance from the first row ($L_2>L_1$) above the first row. It is shown that in the proposed structure it is possible to accelerate electrons with an initial energy of 5 MeV/m with an acceleration rate of about 50 MeV/m. Optimization of structure parameters was carried out for the purpose of experimental implementation of the layout.

ACCELERATION OF A HIGH-CURRENT ION BEAM COMPENSATED BY AN ELECTRON BEAM USING THE CUSP MAGNETIC FIELD FOR THE ISOLATION OF ELECTRONS IN THE ACCELERATING GAP

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The process of magnetic isolation of electrons and acceleration of ions during the injection of a high-current ion beam compensated by an electron beam into a magnetic cusp with an accelerating gap and further re-compensation by an electron beam for the transportation in a drift region with a uniform magnetic field was studied by 2.5D numerical simulation. The dependence of the output characteristics of the ion beam acquired energy gain in the accelerating gap and compensated in the drift region on the set of initial parameters of the ion and electron beams and the magnitudes of the magnetic and electric fields is considered. It is shown that for all considered cases a monoenergetic high-current ion beam injected into magnetic cusp with an accelerating gap, is accelerated and changes its trajectory in such a way that in the drift region it, drifts in the crossed electric field of the space charge of the electron and ion beams and the external magnetic field, inevitably making periodic changes its transverse dimensions in space and losing monoenergeticity. Using such ion beam for injection into the next similar section becomes problematic and requires an especial study.

IDENTICAL DECELERATING WAKEFIELDS FOR DRIVER-BUNCHES AND IDENTICAL ACCELERATING WAKEFIELDS FOR WITNESS-BUNCHES FOR THEIR PERIODIC SEQUENCE

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Acceleration by the wakefield in the plasma can provide compact sources of relativistic electron beams of high brightness. Free electron lasers and particle colliders, using plasma wakefield accelerators, require high efficiency and beams with low energy dispersion. Achieving both conditions can be ensured by the formation of identical fields for all accelerating bunches and identical fields for all decelerating bunches by controlled selection of bunch currents and their spatial distribution for a given plasma wave [1-4]. We demonstrate such optimal bunch currents and their spatial distribution in the linear regime in a plasma accelerator with wakefield excited by electron bunches injected from the RF accelerator with high quality.

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UNIVERSAL ION INJECTOR FOR ION-BEAM TECHNOLOGICAL INSTALLATIONS

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The Institute of Applied Physics of the National Academy of Sciences of Ukraine has developed and researched an ion injector for use in technological installations and ion-beam devices. The injector includes a Penning-type sputtering source with a cold hollow cathode and an ion optical system, and can generate gas and metal ions in a wide mass spectrum. The necessary concentration of the metal component of the working medium in the discharge cell of the source is formed by spraying with argon ions the material of the sputtering inserts in the cathode and anti-cathode electrodes. Discharge plasma sputtering, as a mechanism for creating an atomic working environment from a wide range of different metals, is the most universal and reliable, as it is the result of atomic collisions in the surface layers of a solid body without establishing thermal equilibrium with it. Fast electrons oscillating in a longitudinal magnetic field carry out ionization of sputtered atoms. Extraction and formation of a beam containing plasma-forming gas and metal ions is carried out through the emission hole in the anticathode. A study of the working characteristics of the injector on the IPF implanter of the National Academy of Sciences of Ukraine was conducted. The experiments were carried out in the continuous mode of operation of the ion source. The total ion current reaches 160 mkA at a discharge current of 400 mA. The resource of the spraying inserts was ~14 hours. The partial ratio of argon/metal ions in the formed beam is in the range of 3 ÷ 20. The developed injector has a high stability of the ion current, is easy to maintain, can generate ions from any solid conductive body and does not require the use of high-temperature heating elements.

BREAKDOWN RESISTANCE ON THE SURFACE OF COPPER SAMPLES WITH IRRADIATED WITH METAL AND GAS IONS

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The IPF of the National Academy of Sciences of Ukraine is conducting joint research with CERN electrical breakdowns and increasing the stability of structural materials of accelerating structures to high vacuum breakdowns. It is known that change of the structural-phase state and physical properties of solids is possible at the influence of high-energy particles and radiation. The effectiveness of these processes depends on the irradiation conditions and the nature of the material. In this work, the effect of the development of radiation-induced defects is investigated and implantation of impurity ions in the surface layers of structural materials (copper) accelerator structures for resistance to vacuum breakdowns. In experiments on the irradiation of copper samples with accelerated ions metals/gases (in the energy range of 100 – 300 keV) and experimental study of the influence of radiation-induced defects on the front of the punch current and for the appearance of vacuum breakdowns, equipment created in

IPF of the National Academy of Sciences of Ukraine [1]. The work shows the possibility of improving stability of copper samples to high vacuum breakdowns when their surface is irradiated metal and gas ions.

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Section 6. Computer technologies for physical research

MODELING OF THIN FILM HEATING DURING HIGH ENERGY ELECTRON BEAM PASSING

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The preliminary results of modeling the heating of thin films of 50 μm titanium, 50 μm aluminum and 125 μm Kapton® under the passage of high-energy electrons with an energy of 15 MeV through them are presented. A calculation methodology has been developed, which consists in automating the finite difference method using Python programming language tools to solve the problem of heat propagation in the film, taking into account the ionization losses of the primary electron beam and the radiation of a completely black body. The data on the surface temperature distribution of the samples were obtained and the time for establishing thermal equilibrium was determined taking into account the distribution of the electron beam current density. It is shown that optimization of the main parameters of the high-energy electron beam, namely, the current density of the electron beam, makes it possible to neglect the thermal loads on the prototypes of these films, which was confirmed during bench tests at 30 MeV Electron Linac IHEPNP NSC KIPT.

DEVELOPMENT AND TESTING OF A COMPUTER MODEL OF A SYSTEM FOR FORMING NEUTRON FLUXES ON A LINEAR ELECTRON ACCELERATOR

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To conduct experiments on the interaction of neutron fluxes with various materials, as well as to create a compact source of thermal and epithermal neutrons based on the linear electron accelerator LUE-30, a neutron flux formation system was developed and partially manufactured.

In the work a computer model of the system for generating neutron fluxes at the output of a linear electron accelerator was developed in the Geant4 environment, which includes a target made of tungsten plates that generates neutron fluxes, a graphite reflector with a hemispherical dome, with a radius of 5 cm, a lead box 5 cm thick, polyethylene box 5 cm thick, neutron detector with an area of 1 cm^2.

Using the model, a virtual experiment was carried out for 10^8 primary neutrons, which showed that when using a graphite reflector, the number of neutrons at the detector location increases by 16.9%, which is in good agreement with the results of a real experiment conducted earlier.

Also in the work, the energy spectrum of neutrons falling on the detector was obtained, the optimal radius of curvature of the hemispherical dome of the reflector and the position of the neutron source relative to the center of the sphere on the axis of symmetry of the dome were determined. Additionally, computer experiments were carried out to evaluate the effectiveness of other forms of the reflective surface.

COMPUTER MODEL OF THE FORMER OF INTENSE FLOW OF MODULATED NEUTRONS

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In the work, a computer model of a system for generating streams of therapeutic beams of delayed late neutrons for neutron capture therapy of cancer was developed in the Geant4 environment. The formation system includes a cube-shaped polyethylene heater, the face size of which varies from 4 to 8 cm, a neutron absorber made of borated polyethylene 10x10x10 cm in size with a conical collimator with an inlet radius of 0.6 cm, an outlet of 0.5 cm, a neutron detector with an area of 1 cm^2. A virtual experiment was carried out for 10^8 primary neutrons.

The results of the model experiment showed that the majority of neutrons are reflected from the heater and absorber, and a small fraction (0,5%) passes through the boron polyethylene. The number of neutrons passing through the collimator is reduced by 5 orders of magnitude compared to the initial number.

The energy of the vast majority of these neutrons (2/3 of the total number) decreases to values below 1 keV. When the size of the heater changes from 4 to 8 cm, the number of particles passing through the collimator does not change, but only their energy changes.

COMPUTER SIMULATION OF THE THERMAL REGIME OF THE SUBSTRATE DURING THE DEPOSITION OF DIAMOND COATINGS BY THE GAS PLASMA METHOD

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The efficiency of the diamond coating synthesis is determined by the parameters of the plasma flow and the thermal regime of the substrate on which the coating is deposited. The optimal conditions are the temperature of the surface of the substrate in the range of 800÷900°C, while the uniformity of the thickness of the coating depends on the uniformity of the temperature distribution over the surface of the substrate. With a given thermal power of the plasma flow, the optimal thermal regime of the substrate can be ensured by selecting the parameters of the cooling system. To solve the problem in the SolidWorks environment, a simplified geometric model of the cooling system of the molybdenum substrate in the installation for the deposition of diamond coatings by the gas plasma method was developed. Computer simulation was carried out using the FlowSimulation module of the SolidWorks license package. Varying the parameters of the cooling system showed that the best temperature uniformity is achieved with a water consumption of 0.012 l/s; copper water cooling collector; the thickness of the molybdenum substrate is 0.1 mm. At the same time, the inhomogeneity of the temperature distribution along the radius is $\Delta T/T=0.06$. The obtained results are of practical importance for the creation of highly efficient technologies for the synthesis of diamond coatings.

VERIFICATION OF THE SIMULATION TIME REDUCTION TECHNIQUE OF THE RADIOISOTOPE PRODUCTION FOR MEDICINE

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The simulation time reduction technique (STR) [1] when calculating the yield of photonuclear reactions in linac based plants was verified. To use such STR techniques additional restrictions and/or conditions are added to the computer model to exclude the idle running. At the same time the final result is not distorted. The discrepancy between the obtained simulation results of the Mo100(□, n)Mo99 reaction yield and the experimental data did not exceed the experimental measurement errors for published results of two independent experiments. The verified STR technology provided a simulation time reduction at least 1000 times as compared to the standard photonuclear reaction algorithm used in Geant4. The using of the considered STR technology can significantly reduce the time for optimizing the components of plants for the production of short-lived radioisotopes by the method of photonuclear reactions.

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MODELING OF RADIOGRAPHIC COMPLEX FOR NON-DESTRUCTIVE CONTROL OF SOLID FUEL BOOSTERS WITH EXPIRED LIVETIME

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During long-term storage of solid fuel boosters due to chemical processes in them and temperature fluctuations, stratification of solid fuel and the formation of voids are possible. When launching a jet product, the presence of voids in the solid fuel will lead to the spread of the combustion process in these voids, which can lead to either an accident at the launcher or a change in the flight path of the device.

Using mathematical modeling methods, a conceptual model of the radiographic complex (RGC) was developed for its use as a method of nondestructive control at the end of the lifetime period or during the manufacture of the jet product. The RGC model was developed based on the MIB-7.5 small-sized pulsed betatron. The possibility of determining the monolithic nature of the solid fuel charge is shown, specifically: the detection of internal defects and their depth of occurrence. The possibility of detecting defects in the form of air bubbles with a diameter of 3 mm or more and cracks, as well as foreign particle with a density > 2.5 g/cm^3 is given.

In the conditions of martial law, the main objects of the RGC can be Soviet-made rockets for anti-aircraft missiles, rockets for air defense systems, booster units of tactical missiles, as well as other types of products based on solid fuel. We believe that the development of the RGC complex for detecting defects by a non-destructive method for products listed above is a priority task for ensuring the effective operation of the Ukraine Armed Forces and ensuring the safety of the civilian population.

MATHEMATICAL MODELING OF NEUTRON RADIOGRAPHY PROCESSES

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The practical implementation of the neutron radiography method will allow us to create a new tool for non-destructive analysis in the nuclear industry in Ukraine. The introduction of radiography, and then tomography, in neutron beams will provide a new toolkit for inspection of a wide range of products containing both light and heavy elements and their isotopes. The features of the main systems of neutronographic equipment on electron accelerators are considered. The main systems (elements) of the facility include: a radiation source - a source of accelerated electrons that generate neutrons as a result of interaction with the target material, a neutron-generating target, a system for forming the neutron flow and a position-sensitive detector of neutron imaging. This presentation of the neutronographic installation allows you to present its structural scheme in the form of a set of subsystems or aggregates and the relationships between them.

MATHEMATICAL MODELING OF THE URANIUM NEUTRON-PRODUCING TARGET OF SUBCRITICAL ASSEMBLY NSC KIPT

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In the NSC KIPT nuclear research facility "Neutron source based on a subcritical assembly controlled by an electron accelerator", the highest neutron flux can be obtained using a uranium neutron-producing target. To determine the irradiation dose (in displacements per atom) accumulated in a thick uranium target during operation under irradiation of high-energy electrons, the MCNPX program was used, which allows the Monte Carlo method to perform a complete mathematical modeling of all nuclear-physical processes in the target taking into account its specific geometry. The contribution of elastic and inelastic processes to defect formation was estimated: scattering and nuclear reactions involving electrons, neutrons and gamma rays. The analysis showed that U-238 photofission fragments make the greatest contribution to the rate of damage formation in the uranium target of a neutron source when irradiated with high-energy electrons with an energy of 100 MeV (100 mA), and the maximum defect creation rate is about 100 dpa/year. The contribution of other processes is no more than a few percent.

THE R-FUNCTIONS METHOD IN MATHEMATICAL MODELING OF FUEL CARTRIDGE FOR MULTI-ZONE FUEL RODS WITH PLATES, HEXAGONAL ARRAYS OF FUEL RODS AND PHYSICAL PROCESSES IN THEM

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Nowadays it is very difficult to predict accurately the further development of the Ukrainian energy base, however, a particular issue in mathematical modeling of physical processes in fuel cartridges of fuel rods still does not lose its relevance [1-2]. Applying the theory of R-functions [3-5], it was possible to construct a number of mathematical models of multi-zone fuel rods with longitudinal ribbing and screw-shaped plates, and in this work, for the first time, multi-parameter equations of hexagonal arrays of fuel rods were constructed, which allowed to obtain their compressed and expanded packings. Moreover, applying the theory of R-functions to mathematical and computer modeling of the heat transfer during liquid flow for a fuel rod with an analytical representation of the designed surface allows to use geometric letter parameters and complex superpositions of functions, which, in turn, allows to quickly change their structural elements. Mathematical modeling and the associated computer experiment are indispensable in cases where a full-scale experiment is impossible or difficult for some reason. The reliability of the calculation methods, results and conclusions is confirmed by the analysis of the numerical convergence of the solutions and the calculation of the residual.

MULTILEVEL COMPUTER DESIGN of NANOCLUSTERS FOR CARBON-FREE POWER

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In nuclear energy, to predict the safe operation of reactor vessels, multilevel computer simulation is implemented in the PERFORM 60 project. For hydrogen energy, a similar approach can be adopted in the problem of choosing the optimal nanocatalyst for certain stages – hydrogen production, storage and utility. Scheme consisting of several successive steps is proposed. At the first step, the number and type of atoms that make up the nanocluster, its size and shape, the temperature of the medium, and the boundary conditions that simulate the interaction of the cluster with the substrate are specified. At the second step, the dynamic evolution of the atomic system forming cluster is modeled using "first-principle molecular dynamics", and then the particles are fixed. At the third step, based on the method of identification and analysis of compact atomic formations surface the shape of the cluster is measured. This method was proposed by author earlier .The latter characterizes its properties as a whole. The successive application of steps 2 – 3 determines the dynamic evolution of the cluster and its collective modes. At the forth step, using wavelet analysis, based on the temporal evolution of the shape vector descriptor, local features of the dynamic modes of the cluster and its energy as a whole are identified. At step 5, we purposely change all the initial characteristics of the cluster, set at step 1, and return to step 2. The proposed scheme is sequential, selfconsistent and multilevel (as in PERFORM 60), but the number of levels in it is significantly less and equal to three. Since dislocations are absent in nanoclusters, and higher levels of simulation become unnecessary.

Section 7. Nuclear-physical methods applications (Nuclear energy, industry and medicine. Physical and environmental problems of nuclear-physical facilities exploitation and modernization).

ANALYSIS OF STRUCTURAL AND ELEMENTAL TRANSFORMATIONS IN NATURAL QUARTZITES BY ELECTRON AND GAMMA QUANTUM IRRADIATION

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The purpose of this study is to substantiate the reliability of the results of the elemental and structural-phase composition results of the original quartzite from the Ovruch deposit which is promising for radioactive waste disposal. Model experiments were carried out on the irradiation of quartzite samples with high-energy electrons ($D_{abs}=10^6$-10^8 Gy) and convertible gamma quanta ($D_{abs}=10^6$ — 3.5 10^7 Gy).

It was determined that for both types of irradiation, regardless of the dose accumulation velocity, the elemental composition (Si, Al, Fe, Mn, Ca, Ni, Mg) remains unchanged, the initial structure of crystalline quartz which is part of quartzites is improved as a result of radiation annealing defects and impurities, while in the amorphous the successive structural transformations largely depend on the type of bombarding particles. The end result of these transformations in the amorphous phase under the action of both types of irradiation is its crystallization with the formation of polycrystalline quartz.

CRYSTALOGRAPHIC ORGANIZATION AND STATE OF LATTICE VIBRATIONS OF NANOCRYSTALLINE AND MONO-PHASE MAGNETITE BEFORE AND AFTER GAMMA ACTIVATION

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Magnetite nanoparticles are of significant technological interest due to their magnetic and catalytic properties. Radiation modification of magnetite nanoparticles significantly expands its functionality and therefore requires special control of properties.

The identification of the properties of pure mono-phase and nanocrystalline magnetite before and after activation of the samples showed the presence of channels of other radionuclides (^{52}Fe, ^{51}Cr, ^{54}Mn, ^{57}Ni). A comparison of the parameters with standard diffraction on the faces of magnetite crystals shows that magnetite nanoparticles before and after gamma activation have a face-centered cubic structure. While maintaining the structure of properties in ordinary coarsely dispersed magnetite, a decrease in d- and a-parameters is observed in magnetite nanoparticles, which indicates compression of the crystal lattice. The IR spectrum of nano magnetite has two broad bands at 590 and 440 cm^{-1}, which are associated with lattice vibrations of Fe-O bonds in tetra- and octahedron positions. In contrast to nano magnetite, in the IR spectrum of ordinary stochiometric magnetite compositions similar vibrations of Fe-O bonds appear at 570 and 380 cm^{-1}. To this difference, it should be added that the high-frequency band 590 cm^{-1} is decomposed into two peaks 605 and 575 cm^{-1}.

EFFECT OF GAMMA ACTIVATION ON THE STR HARACTERUSTICS OF ^{153}Sm NANOPARTICLES

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Such characteristics of samarium-153 as the average energy emission of beta particles E = 810 keV for therapy, the average energy of gamma photons

E = 103 keV for imaging as well as a short half-life 0f 46.3 hours make this isotope widely used in many countries.

The developed photonuclear technology (E = 23 MeV, C = 700 μA) based on recoil nuclei and LAE nanotechnology made it possible to obtain ~ Ci of samatium-153 per day. A significant advantage in this technology is the use of samarium oxide nanoparticles with a size of 50 - 80 nm, due to which samarium-153 has a high specific activity.

The IR - spectroscopy method was used to determine the structural-phase changes before and after gamma activation of samarium oxide nanoparticles n the range of 4000….600 cm^{-1}. A comporative analysis of the spectra of the samples did not revel significant changes, especially in the absoption of water in the region of 3300 cm^{-1}, as well as in chemical structure and phase composition. The samples do not indicate the presence f impurity isotopes.

BARRIER SORPTION ON THE PATH OF MIGRATION OF ACTINIDES

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At present, there are many causes of environmental pollution by actinides and their fission products. First of all, it is possible the destruction of nuclear power plants with discharges of untreated waters from nuclear power plants into reservoirs, which show a threat not only locally, but to the ecosystem as a whole. Therefore, the study of the migration of actinides and their sorption along the path of water flow is an urgent and important problem. There are various mechanisms for retaining actinides in water, on the surface of a mineral, or blocking its transfer.

Model experiments on the selective sorption of actinides based on radiation-modified nanoparticles of metal oxides and nanoparticles of natural minerals with respect to actinides have been carried out.

Confirmation of the predicted synergism of the effect of radiation and the advantage of the nanostructural state of the studied sorbents (metal oxides and aluminosilicates) in the process of actinide sorption from liquid media has been obtained.

ANALYSIS OF SEARCH SPECTRA AND METHODS FOR DETERMINING PEAKS IN GAMMA SPECTRA

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To process gamma spectra in order to determine reaction cross sections, RFF and other important physical parameters of nuclear reactions, a program for processing spectra "GAMMAPEAKS" is being developed. In the latest version of this program, the algorithms for peaks searching and constructing search spectra (spectra that can be used to mark the boundaries and centers of peaks in the initial gamma spectrum) have been modified and improved. The search spectra were built using the convolution of the initial gamma spectrum with the negative smoothed second derivative of the Gausian, which has the form of a stair. The studies were carried out on real gamma spectra, after which they were compared with the results of marking the peaks of the same spectra with other programs. The analysis showed that the limits and centers of peaks after modification are determined more reliably than when using previous algorithms.

The optimal values of the stair half-width are estimated depending on the full width at half-height of the peaks in the gamma spectra.

RADIATION RESISTANCE OF NATURAL ALUMINOSILICATES OF DIFFERENT STRUCTURAL TYPES BY THE INFLUENCE OF ELECTRONS AND GAMMA QUANTUM

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The complex approach has been developed for studying the properties of clinoptilolite and microcline — inorganic materials that have sorption relatively radionuclides. Radiation modification of natural aluminosilicates has been studied in various research, but some aspects remain unresolved. First of all, it concerns the prediction of the behavior of new modifications of aluminosilicates by effect of different radiation loads and other physical factors.

The elemental content, structural-phase transformations in the studied samples before and after effect by high-energy electrons and gamma quanta were obtained in the presence of gamma-activation analysis, IR spectroscopy, and crystalloptics.

It is shown that by the influence of radiation in natural silicate minerals of various structures, different radiation stimulations of transformation take place in the structural, textural, phase and newly formed petylization products on the grain surface. But in the studied minerals with an ordered structure, only a partial order of the structure occurs, which shows their higher radiation resistance.

A comprehensive analysis of the tested aluminosilicates showed that they can be used as matrix materials for keeping back of radionuclides.

CORRELATION BETWEEN THE CONTENT OF MACRO- AND MICROELEMENTS WITH CRYSTALLOGRAPHIC MORFOLOGY IN KIDNEY STONES

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The use of gamma-activation analysis to determine macro- and microelements in kidney stones, in correlation with crystal optics studies, provides fundamentally new unformation about the peculiaritys of the micromorphology of samples.

After gamma activation of the studies samples on the LAE with energy 22 MeV and current 500 μA according to the intensities of the line of the gamma spectra on the Ge(Li)-detector with an energy distribution of 3.2 keV, elements such as Ca, Mg, Si, Rb, F, Cl, P at the level of ~ 10^{-4} % wt.

The presece of F in kidney stones can assist to the formation of stable centre of crystallization and to carry out the substitution of OH - group for F - ion. The accumulation of traces (~ 1 ppm) of ^{212} , ^{214}Pb, ^{40}K, ^{235,} ^{238}U, ^{214}Bi in kidney stones is associated with regional peculiarities of the content of these elements in the environment and food chains. Drugs are an additional source of ^{214}Bi intake into the vody with sequential fixation of this isotope in the composition of kidney stones.

STATISTICAL ANALYSIS AND SIMULATION PIPELINE SYSTEMS OF NPP STEAM GENERATORS TO OPTIMIZE THEIR NON-DESTRUCTIVE CONTROL

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The annual monitoring of defect formations in the heat exchange tubes (HET) of steam generators of the SG 1000M NPP of Ukraine using nondestructive testing methods and the concentration of long-term measurement data in the form of a representative (over 10^6 measurements) database provided a factual basis for the development of plans for future HET inspections of steam generators for effective selection zones of incomplete control. Mathematical models of the evolution of the considerable-strained metal of the key elements of the piping systems of the steam generator in operating modes were created, which made it possible to study the dependence and sensitivity of the characteristics of defect formations on parameters and operating conditions.

According to the results of the statistical analysis of the data of eddy current control of the using the created mathematical model and algorithms of frequency-probability spatio-temporal description of defectors, taking into account the characteristics of the evolution of defectors obtained by finite element modeling, it became possible to predict the dynamics of defectors at a high confidence level.

With the use of estimates of the probability of the distribution of defect generators in the space of the structure and their development over time, practically significant robust assessments of risks in forecasts of defect generators and hypotheses of the appearance of new defects beyond the already recorded statistics were developed. The assessment of such risks can serve as a criterion for optimizing the planning of periodic monitoring of the state of the SG-1000M tube when modifying the procedures, frequency, and volume of control of the heat exchange tubes, taking into account the peculiarities of the structure of each steam generator.

OPTIMIZATION OF EXCHANGE PROCESSES IN SPIN FILTERS WITH OPTICAL PUMPING OF ^{3}He NUCLEI POLARIZATION

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The analysis of spin exchange processes using mixed alkali-metal vapors was carried out. Polarization of rubidium atoms is done by the method of optical pumping. The maximum polarization of ^{3}He is achieved due to providing the optimal conditions for the spin-exchange interaction between the atoms of the mixed vapor of Rb and K and ^{3}He nuclei. Calculations show that the time to achieve the stationary polarization of ^{3}He nuclei, when using a mixture of rubidium and potassium vapors, is reduced by a factor of 2 compared to pure rubidium at a fixed laser power. The volume ratio of solid (metallic) rubidium to potassium in the helium cell that provides the required volume ratio for the alkali vapors at operating temperatures of 200 – 250 C is VRb/VK ~ 20. The polarization values of alkali-metal vapors were calculated based on the power and width of the radiation spectrum of the laser system, the vapor density and the 3He pressure. In order to provide optimal pumping rates of ^{3}He nuclei polarization with an insignificant temperature gradient in the helium cell, the necessary intensity of the photon beam needs to be 1 W/cm2 at the entrance window of the cell. Calculations of the polarization, transmission and Q factor for the neutron spin filter for a wide range of neutron energies were carried out. The report presents the current state and future directions of the development of the neutron polarizer.

DETERMINATION OF THE EFFICIENCY OF THE MIRROR-LENS SYSTEM FOR LONG-DISTANCE TRANSPORT OF LASER RADIATION PHOTONS

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The light source for the neutron spin filter is given by laser diodes with the emitted light wavelength of 795 nm. The design of the optical system includes an array of laser diodes with the power of 100 W, a polarizer for obtaining circularly polarized light, a fiber-mirror beam transport system and diagnostic and monitoring devices.

The efficiency of the optical system was estimated as the ratio of the transmitted light flux power to the power of the input flux. The high efficiency of the optical system, in the used array of laser diodes, is determined by the properties of the light guide fiber and optical elements at the light entrance and exit. For the developed system of the photon beam transportation, the efficiency of more than 80% can be reached for the light transfer over the estimated distance of 100 m, with the losses due to reflection on optical element surfaces, light absorption inside them and beam collimation being taken into account. The obtained value is achieved through optimization of lens characteristics for the necessary radiation wavelength range and the beam light power density and of optical fiber and mirror properties, as well as by adjustment of focal lengths and alignment. It is planned to set up a measuring stand and perform experimental studies to check the reliability of calculations and optimize the efficiency.

ON RESTORATION OF THE NSC KIPT SPECIALISED COMPUTING FACILITY FOR PROCESSING OF DATA TAKEN IN THE CMS EXPERIMENT AT THE LHC COLLIDER

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The NSC KIPT specialized computer system was set up in early 2000's to participate in the distributed processing of data of the CMS experiment at the Large Hadron Collider (LHC), and, for many years, it has been successfully operating on Tier 2 (T2) of the CMS grid infrastructure being registered there as T2_UA_KIPT. A high level of its operation quality was achieved thanks to the continuous maintenance of operational efficiency and ensuring the fault tolerance of all subsystems. However, the year of 2022 turned out to be extremely difficult to provide due operation of the T2_UA_KIPT center. With the beginning of hostilities (that is, from February 24, 2022), the NSC KIPT territory was subjected to repeated shelling, and further functioning of the facility became impossible. The system was moved to state 'scheduled downtime' (SD) in the worldwide LHC grid (WLCG) infrastructure starting from 05.03.2022 through completing procedures needed for this on the main global-grid operational portal GOCDB. At the same time, a high operation level was provided for the T2_UA_KIPT site before its transition of to the SD state, and the site readiness for CMS data processing for the period of time from the 1-st January to February 23, 2022 was 100%. This result was achieved thanks to the daily hard work of the team that supports the system operation – updating the specialized CMS software and various grid services in due course, as well as a prompt response to software failures and failures of hardware elements of the system that sometimes happen. Subsequently, studies and preparatory work were carried out on the necessary changes in the T2_UA_KIPT configuration, which must be carried out after the shutdown of the complex on 24.02.2022, and compilation and analysis of the corresponding list was performed in order to restore the site operation as soon as the necessary conditions are met. In particular, installation of various system updates, which fix vulnerabilities of the CentOS operating system and the grid middleware, has been prepared. Also, in accordance with the new CMS requirements, changes have been prepared in configuration (on the head system node HTCondor-CE) of the grid user authentication using the CMS 'Identity and Access Management' (IAM) tokens, while the HTCondor batch job processing system has to be simultaneously upgraded to version 9.0. Then, since the CERN has announced suspension of supporting the 'Disk Pool Manager' (DPM) system, we have configured a virtual environment to test the procedure for migration of the T2_UA_KIPT data storage from the DPM to the dCache system. At the beginning of autumn 2022, the damage of the optical line that provides facility's network uplink was repaired with setting up a channel for the remote access to the system. The central router of the computer complex was restored, and the Netping system was restarted for remote monitoring of the general state of the facility (temperature and humidity in the premise, state of power supply, etc.). Then, diagnostics and repair of the damaged external unit of the air conditioner,

which maintains the required temperature in the system premise, was accomplished. The facility's power supply disrupted as a result of hostilities was also restored. Several uninterruptible power supplies (UPS) on the server racks turned out to be out of order. In addition, the long-term absence of the power supply resulted in a strong discharge of the UPS batteries. Diagnostics of one of the UPS revealed that one of the boards in the electronics unit of the source failed. The faulty board was repaired, and the broken batteries were replaced with new ones.

The work was supported in part by a grant from the NAS of Ukraine within the Targeted research program "Collaboration in advanced international projects on high-energy and nuclear physics".

INVESTIGATION OF ROUTES ACCUMULATION OF MEDICAL RADIOISOTOPE ^{103}Pd WITH CHARGED AND NEUTRAL PARTICLE BEAMS APPLICATIONS

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The results of the analysis of experimental data on the accumulation of important medical isotope ^{103}Pd applying charged particle beams (protons, deuterons, helium-3, -4) and neutral particle fluxes (gamma and neutrons) are presented. Summary data on ^{103}Pd activation yields were obtained depending on the irradiation technique of natural and isotope-enriched targets and their content of undesirable accompanying radionuclides. Ways of optimizing ^{103}Pd accumulation are discussed in order to find more promising ones with regard to the requirements of medical radioisotope production.

MINIMIZATION OF GAMMA RADIATION AND FAST NEUTRON FLUX BACKGROUND FOR THE CONCENTRATED AND MODERATED NEUTRON FLUX FORMATION SYTEM

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The physical concept of the concentrated and moderated neutron flux formation system with minimization of gamma radiation and fast neutron flux background for neutron capture therapy of cancer has been developed. The two-stage moderated therapeutic neutron flux formation technique with fast neutrons and gamma radiation background content decreasing is discussed. The general idea of the proposed moderator design for the formation of the concentrated epithermal neutron flux to the irradiated object based on the application of radius centered multi-collimator system is proposed.

ELECTRON ACCELERATORS APPLICATION FOR WASTEWATER AND THIER SEDIMENTS TREATMENT TECHNOLOGY

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An analysis of the world experience of accelerated electron beam applications with energy up to 10 MeV in the technology of wastewater and its sediments treatment is presented. Based on the general requirements for radiation treatment technology, proposals were developed for its introduction into the national economy of Ukraine, taking into account the National Standard of Ukraine: DSTU 7369:2013. "Wastewater: Requirements for Wastewater and Its Sediments for Augmentation and Fertilization." The experimental possibilities of determining the content of heavy elements by the Standard when using the bremsstrahlung radiation of electron accelerators are discussed.

INTERACTION OF FAST AND THERMAL NEUTRON FLUXES WITH AN AQUEOUS SOLUTION OF THE ORGANIC DYE METHYLENE BLUE CONTAINING AND NOT CONTAINING BORIC ACID

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The paper presents the results of the study of decolourization of aqueous solutions of an organic dye: methylene blue (MB) - $C_{16}H_{18}ClN_3S$ under the action of fast and thermal neutrons. Two types of solution were used in the experiments: aqueous and based on 4% boric acid in water. The main purpose of this research is to develop recommendations for the creation of a system for recording fast and thermal neutron fluxes. The experiment was carried out at the LUE-300 accelerator complex of the NSC "Kharkiv Institute of Physics and Technology". The neutron-producing target, consisting of a set of tungsten plates, was located at a distance of 40 cm from the accelerator outlet flange. The electron energy was 15 MeV and the average current was 20 μA. The build of the irradiated samples, the moderator, and the lead shield to suppress the accompanying gamma background was located perpendicular to the direction of electron movement. The calculated neutron fluence at the samples plane without moderator was 10^{11} n/cm^2. The change in the dye concentration as a result of irradiation was determined by the optical absorption spectra.

Based on the analysis of the experiments, it was found that under the influence of thermal and epithelial neutron fluxes with an aqueous dye solution containing 4% boric acid, a 30% discoloration of the solution was obtained. This is sufficient to measure photon fluences in the range from $3 \cdot 10^{10}$ to $3 \cdot 10^{11}$ n/cm^2, if the linearity of the response is maintained.

RADIATION DAMAGE TO A TANGSTEN TARGET OF THE SUBCRITICAL ASSEMBLY NSC KIPT

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Tantalum-coated tungsten targets are used today in a number of accelerator-driven subcritical nuclear systems (ADS) around the world. To create a neutron-generating target of the NNC KIPT, powdered pressed tungsten (purity 99.9) in the form of plates and tantalum foil with a thickness of about 250 μm, were used to protect the target surface from corrosion under irradiation.

The problem in creating a target using the bimetal tungsten-tantalum was to develop a method of connecting them. Taking into account the experience of the NSC KIPT, a high-temperature connection of a tungsten plate and tantalum foils by rolling in a vacuum was applied. The end areas of the plates were covered by the CVD method of gas-phase deposition of Ta on W. The tungsten target had already worked for a total of more than a year under the beam of high-energy electrons with an energy of 100 Mev in the process of adjusting the accelerator and physically starting the installation.

Taking into account the data of the calculations of the maximum damage rate (0.8 dpa/year), and forecasts of the operation of the tungsten targets of the CSNS and ESS neutron sources, the planned service life of the W-Ta target of the NNC KIPT may be about 3-5 years.

HARDWARE AND SOFTWARE OF THE MAGNETIC MEASUREMENT BENCH FOR QUADRUPOLE LENSES BASED WITH USE OF AN INTEGRATED MEASURING COIL

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The paper describes the method of collecting data from an integral measuring coil, based on the coherent data addition method, which significantly increases the accuracy of measurement. Software and hardware means of data reading from a rotating integral coil are also described. These tools and techniques make it possible to determine the magnetic axis in a quadrupole lens with an accuracy not worse than 50 μm, as well as to determine the harmonious composition of the magnetic field of a multipole lens.

BENCH OF MAGNETIC MEASUREMENTS BASED ON HALL SENSORS

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The paper describes the bench of magnetic measurements with use of Hall sensors. The methodology and hardware for measuring the magnetic fields of dipole magnets in the range up to 1.5 T with accuracy of 10-3 are described. The sensors were pre-calibrated using Nuclear Magnetic Resonance methodology. The time and temperature stability of the measurements were also determined.

CONVECTION OF A VISCOUS INCOMPRESSIBLE LIQUID IN A HORIZONTAL CYLINDRICAL PIPE WITH A HEAT CARRIER AND WITH A VERTICAL TEMPERATURE GRADIENT

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An analytical method for solving the problem of convective instability in a long horizontal circular cylinder filled with a viscous, incompressible liquid with a vertical temperature gradient is proposed. The method is based on the use of basic functions that satisfy the original equation. However, the basic functions do not satisfy the boundary conditions. In a rather high approximation, the problem with boundary conditions is solved by dividing the area of a square circumscribed around a cylinder with an area of 1 x 1 into elementary cells, which are squares of a smaller area with a side p times smaller than the side of the circumscribed square, where p - is a large integer.

The proposed division of the square described around the cylinder manages to satisfy the boundary conditions as accurately as possible, the smaller the side of the square of smaller area (elementary cell), the more precisely the boundary conditions are fulfilled. This is explained by the fact that as the size of the elementary cell decreases, the number of corners on the boundary of the cylinder increases, where the streamline function and its first derivative along the radius (corresponding to the algebraic sum of the derivatives along the vertical and horizontal coordinates) are equal to zero (rigid boundary condition).

Using this method of dividing the square circumscribed around the cylinder into elementary cells, analytical values of critical Rayleigh numbers for different locations of current lines in a horizontal cylinder of an incompressible liquid with a vertical temperature gradient were obtained. The calculated analytical expressions for critical Rayleigh numbers differ within 5% from those calculated in previous studies using numerical methods.

EXCEPTIONAL POINTS FOR COUPLED SPASER SYSTEM AND DIELECTRIC WAVEGUIDE

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The purpose of this research is to study the operation of a spaser (plasmon laser) and the possibility of pumping it with energy due to a dielectric waveguide. To solve the given problem, a multimode analytical approach was developed to study the coupled system of a dielectric cylindrical waveguide and a spaser. The considered spaser consists of a gold nanoshell on a dielectric rod, which is surrounded by a dense layer of quantum dots (dielectric layer with gain) [1].

The work obtained exceptional points arising for HE_1 of the spaser plasmon mode and TM_{01} and EH_{11} of the dielectric mode. The obtained results show that the formation of exceptional points significantly depends on the orientation of electromagnetic fields.

It is shown that the external field in the form of an x- or y-polarized Gaussian beam is capable of exciting different types of modes of the considered system.

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HEATING OF TOROIDAL PLASMA DUE TO COMMUNICATION WITH THE WAVES OF THE EXTERNAL CONCENTRIC DIELECTRIC TOROIDAL WAVEGUIDE

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In previous studies, the authors considered the problem of connecting electromagnetic waves of a system of two cylindrical waveguides, the axes of which are located parallel and separated by a certain distance. For such a configuration, the task of heating the plasma in one of the cylinders with the help of special points arising in the system of coupled dielectric and plasma cylindrical waveguides was considered.

In this work, a configuration of concentrically located tori that is close to practical application is considered. The geometry of the considered problem is as follows. Forming tori of radius r_1 and r_2 (small radius of tor 1 and 2) have a common center, and the centers of tor located on the same straight line are separated from the center of tor by distances R_1 and R_2 (large radius of tor 1 and 2). Inside the first tor there is a plasma, and the second tor is filled with a dielectric whose own electromagnetic waves are connected to the electromagnetic waves of the inner tor through the corresponding azimuthal sections of both toruses of a certain width.

The paper shows that for this coupled system, mode excitation in a dielectric toroidal waveguide, due to the coupling of electromagnetic waves of both toruses, leads to heating of the plasma in the inner tor.

The system of connected tor is attractive because it allows controlling the intensity of plasma heating by changing the geometry of the system.

ENHANCEMENT OF DIFFUSION IN UNDERDAMPING SPACE-PERIODIC SYSTEMS BY EXTERNAL HIGH-FREQUENCY FIELDS

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The possibilities of enhancing the diffusion of particles in periodic structures such as crystals by influencing them by external time-periodic fields of various origins have been studied. For example, acoustic or electromagnetic fields. The influence of a rectangular field with frequencies less than $0.01 \cdot \omega_0$ was studied, where ω_0 is the frequency of small self-oscillations of particles in systems with low dissipation. The chosen coefficient of friction in dimensionless units was equal to $\gamma' = 0.03$. It is shown that the diffusion coefficient can be enhanced by several orders of magnitude with the application of a field of the appropriate amplitude and frequency. The greatest amplification of diffusion is achieved at $\omega \to 0$. At low frequencies, maximum amplification is possible only in a narrow range of field amplitudes $F' \propto \gamma'$. With a further increase in the field amplitude, the diffusion coefficient decreases. An increase in the frequency of external influence leads to an expansion of the interval of forces, but the magnitude of the diffusion enhancement decreases. It is shown that when the amplitude of the external field exceeds a certain threshold value, an increase in the diffusion coefficient is observed. The obtained results reveal the prospects for the creation of technologies for managing diffusion processes.

EFFECTIVE ALGORITHM OF SIMULATION OF CHARGED PARTICLE'S TRANSPORT IN RANDOM HETEROGENEOUS MEDIA

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The most straightforward method for radiative transport simulation in random heterogeneous media is the 'double Monte Carlo' (2-MC) algorithm that generates a large number of deterministic realizations of a random environment for which uses the standard Monte Carlo algorithm, and the result is averaged over all of this realizations. However, this method is computationally expensive, because the set of realizations, that is required for the convergence of results of simulation, must be large enough and adequately represent the statistical population of infinite set of realizations of random heterogeneous media.

A more effective approach is when the statistical properties of the random environment are taken into account directly at each step of a MC simulation. For neutral particles, we have already implemented this approach in GEANT4 based code RaT by introducing the ensemble averaged propagation kernel, which demonstrates its significant efficiency in comparison with the 2-MC method. Now we have formulated and implemented in the code RaT 3.1 a new effective algorithm for simulation of the charged particle's transport in a random heterogeneous medium based on the proposed theoretical model of energy losses in a material with fluctuating density. A comparison of the results obtained by this algorithm with the data of simulation by the 2-MC method shows that both methods are in agreement with each other both qualitatively and, in some cases, quantitatively.

THERMAL VACUUM PROCESS FOR DISPERSING HETEROGENEOUS MATERIALS

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The intensification of production processes, as well as solving the problems of energy and resource saving during the dispersion of heterogeneous materials, has recently become increasingly important.

Based on the combination of the process of evacuation and high-speed thermal heating, the scientific and technical development of an environmentally friendly, high-performance, energy-efficient thermal vacuum method for the continuous production of nanodispersed material carried out for the first time.

Established that a dispersed material in thermal vacuum unit is consistently affected force, thermal, deformation, and ionization effects, which significantly speeds up the process of obtaining nanodispersed materials with new physicochemical and mechanical properties in a short period time.

If the existing methods for constructing a new crystal lattice require complex and expensive installations, much energy costs with overcoming activation barriers from several eV to tens of eV, then in a thermal vacuum installation, this occurs due to thermal diffusion and a pulsed shock wave, within a few milliseconds with minimal energy consumption. Crystalline modifications of materials with new properties obtained.

The thermal vacuum method is a progressive means of dispersing heterogeneous materials, increasing the efficiency of the technological process and reducing energy costs.

SELF-CONSISTENT ANALYSIS OF GYROTRON CAVITIES WITH SHORT INHOMOGENEITY OF LONGITUDINAL PROFILE

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One of the possible ways of increasing an output power and reducing ohmic losses in gyrotrons is to provide operation at high-order axial resonance of the gyro-TWT mode [1]. However, realization of such an operation regime requires suppression of the competing cavity mode excited at the first (fundamental) axial resonance. For this purpose, in [1], it was proposed to use a cavity profile with short inhomogeneity, which is designed to shift the field phase of the fundamental mode by π. At present, an analysis of such cavities is only done in the single-mode approximation for certain dimensions of the short inhomogeneity. The effect of mode conversion initiated by the inhomogeneity on gyrotron performance and optimal cavity dimensions remains unknown. In this study, using the previously developed self-consistent approach with mode conversion, the optimal dimensions of the short inhomogeneity for a cavity of the 527-GHz gyrotron are found [2]. In addition, the effect of mode conversion in the gyrotron cavity with short inhomogeneity on its capacity to increase the output power is studied.

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INFLUENCE OF HELIUM 4 MeV ION BEAMS ON SURFACE SPUTTERING PROCESSES

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When creating thermonuclear reactors, the question of the material of the first wall is acute. Among the materials that can be used in the manufacture of reactor walls, tungsten is considered. When tungsten is irradiated with helium ions, the structure of the material is disturbed and its characteristics change. Simulation modeling was used to study the tungsten surface. The studies were carried out using helium ions. Helium ions with an energy of 4 MeV (in the acceleration mode) were obtained at an ion accelerator [1]. The values of energy losses and damage depths were determined [2]. Using the SRIM code, the sputtering coefficients of tungsten from its surface are calculated. Sputtering coefficients are found taking into account the thickness of the sample and the depth of the layer. It was found that at energies of helium ions of 4 MeV, the sputtering coefficient is affected by tungsten layers at depths of no more than 60 angstroms. The amount of tungsten fluff at the edges of craters is less than for helium ions in the injection mode.

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APPLICATION OF HELIUM ION BEAMS TO STUDY EFFECTS ON A TUNGSTEN SURFACE

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The question of changing the structure of tungsten under the influence of helium ions was considered. This situation is realized when tungsten is used as the material of the first wall of a thermonuclear reactor. Helium ions with an energy of 0.12 MeV (in the injection mode), which were obtained at an accelerator [1], were used for research. Flecking and blistering were found on the surface. The number of formed craters significantly exceeds the number of bubbles. The coefficient of sputtering from the tungsten surface was found [2]. Integral and differential characteristics of the sputtering coefficient are obtained. Samples of various purity and with various component compositions were considered. The content of tungsten in the samples was 99.5% and 99.7%. The maximum sputtering ratio of tungsten is in a certain area. This region is in the range of mean free paths of helium ions from 3 angstroms to 17 angstroms. The issue of the formation of vacancies was also studied. The issues of the appearance and redistribution of displacements in samples of pure tungsten were considered.

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https://doi.org/10.46813/2022-139-0836.

STUDY OF RADIATION PROTECTIVE PROPERTIES AND CHARACTERISTICS OF STRENGTH OF POLYSTYRENE TUNGSTEN COMPOSITE MATERIALS

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Experimental samples of composition materials were made. Composition material is used for radiation protection [1]. The composite is made of polystyrene. The composite was reinforced with aluminum powder with grain size of 60-90 μm. Tungsten powder was used as a radiation protective additive. The tungsten grains were 50–60 μm in size. The attenuation values of the ionizing radiation dose are found using the Geant4 v 4.9.6p03 code. Composition materials of the C(PS(10),W(YY),Al(ZZ)) type were studied. It was found that samples of the composition material, with a thickness of 10 mm, absorb X-rays in the energy range up to 100 KeV. The radiation of most devices that are used in medicine (dentistry) is absorbed. The tensile strengths, at break, are found for these composition materials. The ultimate strengths were found at sample temperatures of 250 K, 290 K, 320 K.

The tensile strength depends on the homogeneity of the distribution of metal components over the volume of the composite, the size of the component grains, and the number and type of components. Composite materials have been determined that have maximum radiation-protective characteristics, with maximum strength [2].

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THE INFLUENCE OF THE DISPERSITY OF THE FILLER IN THE POLYSTYRENE TUNGSTEN COMPOSITE ON THE OPERATIONAL CHARACTERISTICS OF THE RADIATION SHIELDING MATERIAL

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The questions of change of characteristics of composition materials were studied [1]. Composite materials are designed to protect electronic equipment from various types of radiation. The compositions of the components and the sizes of their grains were selected for maximum radiation protective and radiation scattering characteristics. Polystyrene reinforced with aluminum powder (aluminum grain size 10–20 μm or 60–90 μm) was used as a base. Tungsten was a radiation shielding additive (grain size 50–60 μm or 230–280 μm). It was found that with a decrease in the size of the grains of the components, an increase in the characteristics of strength and hardness occurs. It was also found that the aluminum component has the main effect on the strength and hardness of the composite. Strength increase can be up to 20%. The attenuation of the dose of ionizing radiation was calculated using the software package Geant4 v 4.9.6p03. It was found that the composite materials C(PS(05),W(YY),Al(ZZ)) absorb gamma rays with energies up to 200 KeV.

The research presented in this article was performed by partial financial support of the Ukrainian state budget program "Support for the development the priority areas of scientific researches" (Budget Financial Code 6541230).

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PROSPECTS FOR THE APPLICATION OF POLARIZATION BREMSSTRAHLUNG IN DIAGNOSTIC RADIATION TECHNOLOGIES

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At present, one of the relevant research directions is establishing the role of the structure of solid bodies in observing the effects of the interaction of ionizing radiation with matter. In general, such parameters as the type of ionizing particle, its energy and the atomic number of the target substance taken into consideration are exhaustive for describing and predicting the result of irradiation. At the same time, in a number of cases, radiation effects caused by the structure of solid bodies, namely polarization bremsstrahlung, are observed. The effects of the interaction of low-energy electrons with atoms and clusters of inert gases [1] make it possible to obtain results that are important for the diagnosis of materials operated under conditions of radiation load and the influence of other extreme factors. Thus, this direction is of interest from the point of view of the development of new diagnostic radiation technologies.

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SOME ASPECTS OF THE APPLICATION OF DUAL-ENERGY X-RAY ABSORPTIOMETRY IN MEDICINE

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The paper examines the main directions and physical aspects of the medical application of dual-energy X-ray absorptiometry (DXA), which is currently considered the "gold standard" for diagnosing osteoporosis.

Model calculations were carried out, within the three-component DXA model of a human body, spectra of X-ray radiation were obtained after passing through fat, soft and bone tissues (for the energy range of 20 keV - 150 keV). Graphs of the energy dependence of the attenuation of X-ray radiation by fatty, soft, and bone tissues of different thicknesses (0.2, 0.8, 2, 8 cm) were obteined.

Using radiographic images of fragments of domestic birds [1], obtained in three different energy ranges (20-50 keV, 50-100 keV, 60-150 keV), a comparison of different techniques [1-3] DXA for determining the mineral density of bone tissue against the background of muscle fabrics was carried out.

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PECULIARITIES OF THE FORMATION OF SCINCILLATION RESPONSE IN ORGANIC MATERIALS WITH STOCHASTIC CHARACTER OF LIGHT PROPAGATION

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In the wide majority of applied problems the transparent scintillators are used. Recently, the idea of using the scintillators with low transparency (“opaque” scintillators) to localize the place of origin of a scintillation pulse has been proposed. Thus, for neutrino detection, the authors [1] used liquid scintillators as “opaque” materials.

The paper examines the possibility of using an organic polycrystal as the “opaque” scintillator. Polycrystals are produced by pressing crystalline grains. When light propagates through a polycrystal, it is repeatedly reflected and refracted at the boundaries of the grains. This makes its passage difficult. We studied the light output and optical transmittance of stilbene and *p*-terphenyl polycrystals with different fractions of crystalline grain: from 0.06-0.1 to 2.0-2.5 mm (the samples 20 mm in diameter and 2 mm in height) was conducted. Modelling of light transmission in polycrystalline samples of stilbene and *p*-terphenyl was carried out and the values of the light collection coefficients were calculated. It was found that in order to obtain the polycrystalline samples with sufficiently high light output and high efficiency of detection of local sites of interaction of ionizing radiations, grains in the range of 0.4-0.8 mm should be used.

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FEATURES OF THE RECONSTRUCTION OF THE ENERGY SPECTRUM OF FAST NEUTRONS OF THE ^{239}Pu-Be SOURCE FROM THE SPECTRUM OF RECOIL PROTONS

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Organic scintillators are widely used in the problems of spectrometry of fast neutrons in the presence of background gamma radiation. A distinct place in the problems of fast neutron spectrometry is occupied by the methods of reconstruction the energy neutron spectrum from the spectrum of recoil protons generated in an organic scintillator [1, 2]. In [1], the value of the detection efficiency of fast neutrons $\varepsilon(E_n)$ with the energy E_n was assumed equal to 1 for all values of E_n. This makes it possible to determine only the position of the neutron peaks in the scale of scintillation amplitudes, and not their initial intensity in the source.

In the work, the values of efficiency ε as the function of E_n were calculated, taking into account the influence of carbon. Using the results of $\varepsilon(E_n)$ calculations, the reconstruction of the neutron spectra of the ^{239}Pu-Be source for crystalline scintillators of stilbene and *p*-terphenyl was carried out.

This work was supported by the National Research Foundation of Ukraine, project № 2021.01/0042 “Development of effective detection systems for the most harmful ionizing radiation for humans, for radioecology tasks”.

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ORGANIC POLYCRYSTALLINE SCINTILATORS BASED ON MATERIALS WITH HIGH PULSE SHAPE DISCRIMINATION CAPABILITY

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Organic polycrystalline scintillators constitute one of the main directions among a relatively new type of scintillation detectors - heterostructured scintillators. Their advantage is the production without the use of additional materials, namely directly mechanical hot pressing. As in the case of most heterostructured scintillators, the use of polycrystalline scintillators makes it possible to get rid of the limitation on the registration area, which is characteristic of single crystals, as well as to avoid the loss of raw materials associated with mechanical processing.

In turn, unlike known single-crystal scintillators, this material is not a continuous medium, but a heterostructured one. For single crystals (as well as liquids), the possibility of separating signals obtained from radiation with different specific energy losses has already been sufficiently studied, but retaining such an approach to the analysis of physical phenomena in heterostructured samples is unacceptable. This is due to the fact that in such systems the migration of T-states, the recombination of which is directly responsible for the pulse-shape discrimination of ionizing radiation, can be limited by the size of the grains, based on which such samples are obtained. Therefore, there is a need to analyse such dependencies. This is the question we are dealing with in this work.

This work was supported by the National Research Foundation of Ukraine, project № 2021.01/0042 “Development of effective detection systems for the most harmful ionizing radiation for humans, for radioecology tasks”.

ON THE FORMATION OF EXCITED YTTRIUM PARTICLES UNDER ION BOMBARDMENT OF YTTRIUM AND YTTRIUM ALUMINUM GARNET

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A comparison of the parameters of the ion-photon emission that occurs during the bombardment of metal yttrium (Y) and yttrium aluminum garnet ($Y_3Al_5O_{12}$) with Ar^+ ions was carried out in the work to determine the mechanisms of the formation of excited yttrium atoms and ions depending on the physical and chemical parameters of the solid.

The emission spectra of sputtered excited particles were analyzed. The dependencies of the excitation efficiency of yttrium atoms and ions $\sigma_j(E_j)$ on the excitation energy E_j of the corresponding states for the studied targets have been determined.

It was established that the knocking-out of sputtered yttrium particles occurs in the processes of multiple or cascade collisions of the primary ion with a solid, as well as in the knocking out of metastable Y_mO_m complexes. Depending on the knocking-out process, sputtered particles can get excited during the separation of the common electron cloud of a solid atom and a primary ion, during adiabatic decay of the solid-sputtered particle system, and due to the decay of the knocked-out metastable complex on the surface of the solid or when it flies away. The formation of the final excited state of the escaping yttrium atoms and ions is influenced by the processes of electron exchange between the solid and the escaping particle and possible cascade transitions from higher excited states.

DETECTION OF ALLOYS CONSTITUTION HETEROGENEITY BY SIMS ANALYSIS OF THEIR INTERACTION WITH HYDROGEN

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Detection of the presence of several phases in the constitution of alloys, in addition to the traditional analysis methods, is also possible by SIMS imaging analysis. This method relies on the capabilities of the instrument, in particular its lateral resolution. Obviously, it cannot be implemented in SIMS instruments lacking the capability of obtaining secondary ion images. The results of a series of SIMS studies of the interaction of various alloys with hydrogen have shown that, based on the difference in the characteristics of the interaction with hydrogen, it is possible to detect the phase heterogeneity of the studied sample during the SIMS analysis of the sample interaction with hydrogen without the use of ion imaging. It is also possible to identify the metals that are part of the detected different phases. Among the studied samples, the constitution heterogeneity was revealed during studies of the LaNi5, Zr65V30Ti5 alloys, as well as the sample of Ti-containing stainless steel. As a criterion for differentiation, the comparison of the dependences of the emission intensities of secondary ions MekHm on the hydrogen pressure with the dependences of the secondary ions' emission intensities on the sample temperature was used. The need to use such a comparison arises from the fact that the dependence of the yields of hydrogen-containing secondary ions on the hydrogen surface concentration can differ significantly even when the ions are emitted from the surface of one phase, as follows from the results of the conducted study series.

INVESTIGATION OF NEW GAMMA TRANSITIONS IN NUCLIDES OF ^{238}U CHAIN

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The purpose of this work is to verify the report on the experimental observation of six new gamma transitions in ^{234m}Pa decay with energies over 2 MeV and relative intensities of gamma rays ($2\cdot10^{-5}$ – $1.8\cdot10^{-4}$)% [1]. The measurements were performed with two U_3O_8 samples produced and certified in the USA with different ^{235}U isotopic abundance: (1) 0.3206(2)% (sample mass of 200 g), produced in 1977, and (2) 93.2330(53)% (sample mass of 230 g), produced in 1990. The samples are placed in hermetically sealed cylindrical aluminum containers with an inner diameter of 70 mm and 2-mm thick window. Measurements with each sample were carried out using a cylindrical HPGe detector with a volume of 70 cm^3 for 46 days. The detector's background has been measured for 8.1 days.

The observation of five gamma peaks with energies of 2022.24(12) keV, 2041.23(13) keV, 2065.80(13) keV, 2093.19(38) keV and 2136.69(14) keV has been experimentally confirmed. The peaks have been determined to be originated in the decay of a nuclide in decay equilibrium with ^{238}U, most likely ^{234m}Pa (except for the 2041.23(13)-keV peak, the origin of the peak is not clear). The energy and radiation intensity for the indicated transitions are consistent with the data of [1]. The 2102.14(15) keV peak was not observed in this work due to the overlap with the intensive 2103.5 keV peak, which is the single escape peak of 2614.5-keV gamma quanta (^{208}Tl).

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URANIUM LEGACY SITES AS SOURCES OF TECHNOLOGICALLY-ENHANCED NATURALLY OCCURRING RADIOACTIVE MATERIALS

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In terms of Radioactive Source Security Assessment (RSSA) it is considered a relatively new approach that assesses the national policies, commitments, and actions to secure radioactive sources and prevent dirty bomb real possibilities. This approach makes considering the concept of radiological terrorism as use or threat of use for terrorist purposes of radioactive substances and materials designed to be used as a damaging factor of ionizing radiation.

Uranium tailings available within uranium legacy sites in Ukraine are a waste byproduct (tailings) of uranium mining. In mining, raw uranium ore is brought to the surface and crushed into fine sand. The valuable uranium-bearing minerals are then removed via heap-leaching with the use of acids or bases, and the remaining radioactive sludge, called "uranium tailings", is stored in huge impoundments. Uranium tailings contain over a dozen radioactive nuclides, which are the primary hazard posed by the tailings. The most important of these are thorium-230, radium-226, radon-222 (radon gas) and the daughter isotopes of radon decay, including polonium-210. A lot of this waste is alpha particle-emitting matter from the decay chains of uranium and thorium. These sites locations are worth studying in terms of naturally occurring radioactive materials and possible natural radioactivity sources that are of great attention in Europe and in the world.

ACCOUNTING OF THE RISKS OF THE DEVELOPMENT OF KARST PROCESSES IN LOCATIONS OF NUCLEAR POWER PLANTS

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An ecological approach to the selection of locations for nuclear power plants in Ukraine requires taking into account natural and man-made factors that can negatively affect the radiation safety of both nuclear power plants and the areas where they are located. In accordance with the "General Regulations for the Safety of Nuclear Power Plants - 2008", for this, a number of factors specific to this site must be taken into account, including dangerous dynamic geological processes, among which karst is the most influential.

The purpose of the work was to develop a proposal for the selection of locations for observation posts for ecological, including geological, monitoring of the territory of the NPP location based on the methods of geo-informational analysis of karst processes in the relevant control zones.

For analysis, the Rivne NPP was selected, which is located in a region where almost the entire territory (~85%) is occupied by rocks capable of karstification. It should be noted that the area of open karst in this region has been increasing in recent years.

The work systematizes the risks of activation of karst manifestations in the area where the station is located. Using the method of GIS technologies, the zones of development of karst processes that directly or indirectly affect the hydrogeological characteristics of the landscape and soils of the monitoring zone are determined. It is shown that the changes in the speed of movement of groundwater, the transfer of pollutants (radionuclides), and the accumulation capacity of rocks caused by karst rocks require the creation of such a network of geoecological monitoring points that would provide representative information about the possible risks associated with the existence of karsts. On the basis of the conducted research, a scheme for the location of such points in the monitoring zone of the Rivne NPP is proposed.

INVESTIGATION OF VACUUM HIGH-GRADIENT BREAKDOWNS FROM THE ION-MODIFIED SURFACE OF COPPER ELECTRODES

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The problem of reducing the probability of high-gradient high-vacuum breakdowns is relevant today because of the need to design new compact linear accelerators of charged particles with high energy at the point of collision. Since kilometers of accelerator structures need to be built to obtain collision energies of several TeV, the task of increasing the maximum permissible acceleration rate is extremely important technically and economically. Assuming that one of the factors affecting high vacuum breakdowns is the surface properties of the electrode material, we proposed to consider the possibility of improving the resistance of the electrodes of accelerator structures to high vacuum breakdowns by modifying their surface.

In this work, we experimentally and theoretically investigate the effect of the development of radiation-induced defects in the near-surface layers of the material for processing the structural materials of accelerator structures in order to target changes in their near-surface properties to improve their resistance to vacuum breakdowns and at the same time determine the optimal parameters of the required ion-plasma surface treatment of these structures.

IONIZATION IN A COLLISION OF A LEAD ION AND AN ALPHA-PARTICLE WITH IRRADIATION BY A SHORT X-RAY PULSE

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The process of ionization of a hydrogen-like lead ion in a collision with an alpha-particle with simultaneous irradiation by a short X-ray pulse is investigated. The process probability is obtained by a nonperturbative numerical solution of the time-dependent Dirac equation using variational approach developed in Refs. [1–3].

The study is focused on the mutual influence of the projectile and X-ray pulse potentials on the process probability. We show the presence of interference effect which manifests itself in a deviation of the process probability from the incoherent sum of "photoionization only" and "collision only" probabilities.

In the case of strong field, the process is dominated by photoionization. However, the interaction with the projectile alpha-particle results in interference effect with orders of magnitude greater than the corresponding probability of ionization by alpha-particle impact.

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FORMATION OF X-RAY IMAGES USING PHASE CONTRAST METHODS FOR MEDICAL APPLICATIONS

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The theoretical basis of X-ray image formation by phase contrast methods are considered, which allows visualize the internal structure of objects with small gradients of substance density with high spatial resolution and gives significant advantages for applications in medicine. These methods are based on the phenomenon of X-rays refraction, which leads to a change in the phase front of the wave. The phase contrast method allows to indicate a more dense formation in the research object, which is important for early medical diagnosis. It can also be combined with tomographic methods. Algorithms for calculating the distribution of radiation intensity after passing through test multicomponent objects have been developed in the case of various characteristic dimensions and refractive indices. The actual problem is under consideration with respect to designation of potential capabilities of phase contrast based end-station and required parameters for optimal visual contrast imaging.

HIGH RESOLUTION PROBE-FORMING SYSTEM WITH SPHERICAL ABERRATION CORRECTION FOR NUCLEAR MICROPROBE

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Improving the resolution of the nuclear microprobe to the level of 10 nm in the mode of proton beam writing and 100 nm for microanalysis is an urgent problem. To solve this problem, probe-forming systems based on a separated orthomorphic quadruplet of magnetic quadrupole lenses with a small working distance of 4 cm were considered. Changing the position of the first doublet along the optical axis allows changing the demagnification within 500...900.

Such systems have very large spherical aberrations, which prevents their implementation in practice. Therefore, octupole lens systems were used to correct aberrations. Optimization of the microprobe formation process was carried out based on the value of the reduced collimated acceptance, which is characterized by the maximum phase volume formed by rectangular object and aperture collimators, provided that the beam is focused into a spot on a target of given dimensions.

Calculations show that with full compensation of aberrations with the help of three octupoles, with an energy spread of ions in the beam at the level of 10^{-5}, modes of microprobe formation in the range of 10...100 nm with the necessary current values for the corresponding techniques, which can be implemented in practice, are realized.

Розрахунки показують, що при повної компенсації аберацій за допомогою трьох октуполів при енергетичному розкиді іонів у пучку на рівні 10^{-5} реалізуються режими формування мікрозонда у діапазоні 10…100 нм з необхідними величинами струму для відповідних методик, які можна реалізувати на практиці.

EFFECT OF ELECTRON IRRADIATION WITH 14 MeV ENERGY ON PHOSPHORESCENCE AND OPTICAL ABSORPTION OF Al_2O_3:Nb CRYSTALS

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It is well known, Al_2O_3 crystals grown in the presence of graphite are used for thermoluminescent dosimetry. At the same time, anionic vacancies are created due to the binding of oxygen by graphite, which significantly increases the number of traps for electrons and, thus, the output of thermoluminescence. In this work, the Al_2O_3 samples tested for thermoluminescence dosimetry are enriched with niobium Nb due to the use of thermal protective screens made of niobium-containing ceramics.

The studied samples were irradiated on the M-30 microtron of the Department of Photonuclear Processes of the IEP NASU, in the radiation field of scattered electrons with an energy of 14 MeV, accompanied by bremsstrahlung radiation with fluences in the range of 10^{10} - 10^{16} e cm^{-2}. In the irradiated samples, the resulting phosphorescence, optical absorption, and thermoluminescence were investigated depending on the dose.

On the thermoluminescence curves of the Al_2O_3: Nb samples, in contrast to the unalloyed samples, two peaks of 170ºC and 225ºC are observed, in which a significantly higher thermoluminescence yield, approximately 2 times, is observed. The obtained results indicate that Al_2O_3: Nb is a promising material for thermoluminescent dosimetry.

RADON IN THE SOURCE WATER OF THE THERMAL BASIN TRANSCARPATHIA

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Radon's problem is extremely relevant in the modern conditions of human existence. By knowing the radon problem, a person receives more than half of the annual effective dose of radioactive exposure. Radon is a radioactive gas that is formed during the decay of Uranium and Thorium and enters the atmosphere from the soil, water, natural gas, etc. Since radon is an inert gas, it is characterized by a high migration capacity and can accumulate in indoor air, reaching high concentrations. At the same time, it is advisable to pay attention to the concentration of radon in the spring waters of the thermal pools of Transcarpathia.

In this work, a study of the concentration of radon in natural thermal pools of the Berehiv district was carried out; for this purpose expeditions were organized to take water samples to measure the volumetric activity (VA) of water according to Radon-222. Water samples from the thermal pools of the springs were taken in containers with a volume of 1.5 dm3 by immersion in the source and marked (sample number, date and hour of sampling). Water samples were collected, and measured according to the USEPA test (USEPA, 1991). In total, samples of thermal water from 21 natural springs were collected. All the thermal springs studied exceeded the recommended (USEPA) relative limit values for radon, but these values are within the limits of radiation protection standards recommended by the countries of the European Union.

SIMULATION OF THE NEUTRON MULTIPLICITY OF PHOTOFISSION OF ACTINIDE NUCLEI FOR THE ENERGYS OF FIRST CHANCE

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A parametric description of the dependence of the average number of instantaneous neutrons on the mass of fragments (A) from the photofission of actinide nuclei ^{232}Th, ^{235}U, and ^{238}U has been developed for the range of energies of the first chance of fission (from thresholds (γ,f) to thresholds (γ,nf) of reactions) [1]. To verify our parameterization, according to [2], calculations were performed for actinide fissile nuclei ^{234}U* (E* = 6.8 MeV), ^{236}U* (E* = 6.5; 7.0; 12.0 MeV), ^{238}Np* (E* = 6.3; 11.0 MeV), ^{240}Pu* (E* = 6.5 MeV), formed as a result of neutron fission reactions for which experimental data exists [3]. It should be noted that the numerical values of the dependence of the instantaneous neutron yields on A of the photofission fragments for the specified fissile nuclei, obtained as a result of simulations using our parametric description and additionally performed calculations by the GEF and TALYS codes, are qualitatively consistent with each other and reflect the structure characteristic of existing experimental data.

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