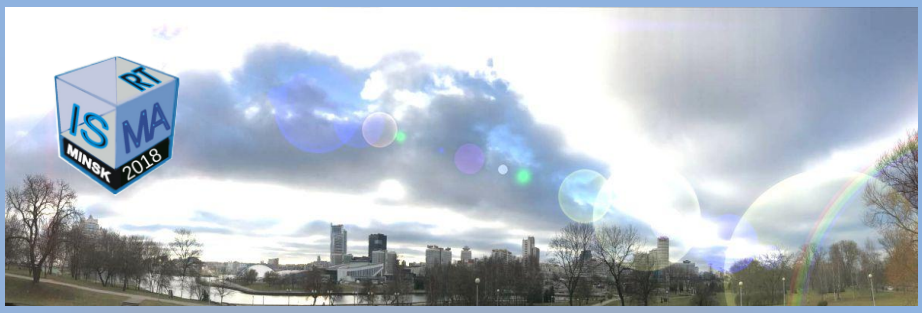

Sixth International Conference

ENGINEERING OF SCINTILLATION MATERIALS AND RADIATION TECHNOLOGIES
ISMART 2018

BOOK OF ABSTRACTS

9 – 12 October 2018
Minsk, Belarus

Шестая Международная конференция

ИНЖЕНЕРИЯ СЦИНТИЛЛЯЦИОННЫХ МАТЕРИАЛОВ И РАДИАЦИОННЫЕ ТЕХНОЛОГИИ
ИСМАРТ 2018

СБОРНИК ТЕЗИСОВ ДОКЛАДОВ

9–12 октября 2018 г.
Минск, Беларусь

INSTITUTE FOR NUCLEAR PROBLEMS,
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За пятнадцать лет своего существования конференция стала известной платформой для эффективных дискуссий ведущих экспертов по последним достижениям в области развития детектирующих материалов ионизирующих излчений, и их применения в детекторных системах различного типа, от физики высоких энергий до медицинской диагностики и систем радиационной безопасности.

Мультидисциплинарность конференции позволяет объединить современные достижения ведущих ученых, технологов и инженеров в фундаментальных и прикладных исследованиях, а также новейшие технологии и инженерные решения для разработки детекторов радиации.

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PROGRAM

9.10.2018

8.30.00-10.00 **Registration*, Renaissance Minsk Hotel,*** Second floor, in front of the Conference Room

Chairman: Grinyov B.

***Plenary Session* (Ball Room 1)**

10.00-10.10 **Shumilin A.,** Opening of the Conference
10.10-10.20 **Korzhik M.,** Welcome from Chairman
10.20-10.30 **Grinyov B.**, Welcome from the International Organizing Committee
10.30-11.00 **Auffray E.*, Invited talk,*** CERN, Fast scintillators for high energy physics and medical applications

11.00-11.30 Coffee Break and Registration

***Plenary Session* (Ball Room 1)**
Physics of the materials for radiation detection-I

11.30-12.00 **Vasil'ev A.,** ***Invited talk***, SINP MSU, Physics of fast processes in scintillators
11.50-12.20 **Gektin A.,** ***Invited talk,*** ISMA, Key trends in scintillation physics
12.20-12.50 **Tamulaitis G.,** ***Invited talk***, Vilnius University, Transient Phenomena in Scintillation Materials. New Results

13.00-14.30 Lunch and Registration

***Plenary Session* (Ball Room 1)**

Detectors for high energy physics

Chairman: Korzhik M.

14.30-15.00 **Iyudin A.,** ***Invited talk***, SINP MSU, Application of scintillation detectors in cosmic experiments

15.00-15.20 **Singovski A.,** ***Invited talk,*** Minnesota University, CMS ECAL detector Phase II upgrade

15.20-15.40 **Moritz M.,** Justus Liebig University, The Electromagnetic Calorimeter for the PANDA Target Spectrometer

15.40-16.00 **Gilewsky V.,** ***Invited talk,*** JIPNR-Sosny, Antineutrino detectors

16.00-16.20 **Kireyeu V.,** ***Invited talk***, JINR, Project NICA

16.20-16.50 ***Coffee Break and Registration***

Plenary Session **(Ball Room 1)**
Detectors and materials for radiation detection-I
Chairman: **Vasil'ev A.**

16.50-17.10 **Kornoukhov V,** FOMOS-Materials**,** Enriched $^{40}Ca^{100}MoO_4$ single crystalline material for search of neutrinoless double beta decay

17.10-17.30 **Zhmurin P.,** ISMA, Plastic scintillators with the improved radiation hardness level

17.30-17.50 **Rusiecka K.,** Jagellonian University, Investigation of the properties of the heavy scintillation fibers for hadron therapy monitoring

17.50-18.10 **Dimova T.,** Novosibirsk State University, Calibration and performance of the CMS electromagnetic calorimeter during the LHC Run-II

18.10-18.30 **Vasilyev M., Khabashesku V., Trat'siak Ya.**, Baker Hughes a GE Company, Nanoengineered $Gd_3Al_2Ga_3O_{12}$ scintillation materials with disordered garnet structure for novel detectors of ionizing radiation

18.30-18.50 **David E. L.,** Development of a submillimeter portable gamma-ray imaging detector, based on a GAGG:Ce-silicon photomultiplier array

14.00-19.00 ***Poster session*** **– Technologies, materials and instrumentation (Conference room 5)**

1. **Gordienko E.,** NRC "Kurchatov Institute", Scintillator powder and ceramics of multicomponent oxides with a garnet structure – problem of a composition control
2. **Dubovik A.,** ISMA, Growing and properties of $Zn_xMg_{1-x}WO_4$ mixed crystals

3. **Galkin S.,** ISMA, ZnSe scintillators, growing technology and luminescent parameters
4. **Krech A.,** ISMA, Radiation hard compoiste scintillators
5. **Gorbachova T.,** ISMA, The impact of deep traps of structural origin on the optical and scintillation characteristics of organic scintillators
6. **Nepokypnaya T**.,ISMA, New composite detectors for medical x-ray diagnostics
7. **Vashchenko L.,** ISMA, On new aspects of metrological activity at our institute with the entry into force of the new Law of Ukraine "On Metrology and Metrological Activity"
8. **Kuznetsova D.,** NRC "Kurchatov Institute", YAG:Ce micro- and nanostructured powders – technological considerations
9. **Khoroshko L., Gaponenko N., Rudenko M., Sukalin K., Shaidakova K., Raichyonok T., Mudry A.,** BSUIR, Sol-gel derived nanostructured yttrium-aluminum garnets powders doped with lanthanides
10. **Khoroshko L., Baglov A.,** BSUIR, Radioluminescent nanostructured yttrium-aluminum perovskite doped with terbium embedded in porous anodic alumina matrix
11. **Gurdjian N.,** ISMA, Statistical estimation of quality of measurement of minimal detected activity of radionuclides by plastic scintillators for portal monitors
12. **Onyfriev Yu.,** ISMA**,** Scintillation elements for the CMS High Granularity Calorimeter
13. **Galenin E**., ISMA, Low activated SrI_2:Eu detectors
14. **Makarevich K**., INP BSU, "Fluence-to-dose" conversion coefficients for whole body irradiation geometry
15. **Afanasiev K.**, INP BSU, Measurement system for characterisation of new type GEM-detectors for MPD experiment at NICA
16. **Haurylavets V.**, INP BSU, The electromagnetic shower simulation in GEANT4 with taking into account crystalline structure of medium
17. **Orsich P.,** INP BSU, Longevity Evaluation of the PANDA EMC at FAIR
18. **Mechinsky V.,** INP BSU, Portable bench to evaluate coincidence time resolution of scintillation materials in temperature range
19. **Lazarev V.,** ISMA**,** An evidence of light yield anisotropy for a small p-torphenyl single crystal
20. **Grishin S.**, SSPA "Optics, Optoelectronics and Laser Technology", Experimental investigation of on-board charged particles spectrometer and gamma-ray telescope detecting modules characteristics

21. **Grishin S.,** SSPA "Optics, Optoelectronics and Laser Technology", Prototyping and experimental research of radiation detection modules
22. **Yamniy V.,** ADANI, X-ray security scrining system for introscopy of heavy vehicles
23. **Trat'siak Ya.,** IPCP BSU, Novel luminescent materials for wide applications
24. **Pokidov A.,** ISSP RAS, Improvement of light yield and spatial resolution in scintillation composites transformed to nanofibers
25. **Dybatovka D.,** ATOMTEX**,** Radiation control station comprising scintillation detection unit of spectrometric type
26. **Opolonin A.,** ISMA**,** Multi-energy radiography, physical principles, applications
27. **Kozlov D.,** INP BSU**,** Setup for characterization of scintillators to detect neutrons
28. **Tolkachev A.,** Stepanov Institute of Physics NANB, Scintillant florescence of of cis-azoalkanes
29. **Onufriyev Yu.**, ISMA, Radiation hard reflectors for scintillation modules for HEP
30. **Garankin Je.,** Center of Physical Science and Technology, BF-e using in ionizing radiation detection
31. **Vujčić I.,** University of Belgrade, Gamma radiation effects on structural and optical properties of Eu-doped $(Y_{0.7}Gd_{0.3})_2O_3$ scintillators

10.10.2018

Industrial Exhibition (Conference room 6)

Plenary Session **(Ball Room 1)**

Materials production technologies-I

Chairman: **Kornoukhov V.**

9.00-9.30 **Dosovitskiy G.,** ***Invited talk,*** NRC "Kurchatov Institute", Pure raw materials for scintillation detectors of ionizing radiation

9.30-9.50 **Cherginets V.,** ISMA, Obtaining and functional characteristics of Eu^{2+}-activated scintillation materials on the basis of congruent compounds of alkali and alkaline earth metal chlorides and bromides

9.50-10.10 **Sokolov P.,** ***Invited talk,*** NRC "Kurchatov Institute", Towards new production technologies: 3D printing of scintillation materials

10.10-10.30 **Sidletskiy O.C.,** ***Invited talk,*** ISMA, Issues of carbon doping in garnet scintillators

10.30-11.10 ***Coffee Break and Registration***

Materials production technologies–II

Chairman: **Dosovitskiy G.**

11.10-11.30 **Taranyuk V.,** ISMA, Novel approaches to produce scintillation materials

11.30-11.50 **Gerasymov Ia.,** ISMA, Progress in fabrication of long YAG-based scintillation fibers for HEP experiments

11.50-12.10 **Karpuk P.,** NRC "Kurchatov Institute", Processing of scintillation ceramics based on complex oxides with garnet structure

12.10-12.30 **Spassky D.,** SINP MSU, Luminescence characteristics of undoped and Ce^{3+} doped $LuAsO_4$ and $LaAsO_4$

12.30-14.30 ***Lunch***

Instrumentation–I

Chairman: **Iyudin A.**

14.30-15.00 **Mazzi A.**, ***Invited talk***, Fondazione Bruno Kessler, Performance of FBK silicon photomultipliers in fast timing applications

15.00-15.15 **Khodyuk I.,** CapeSym, ScintiClear based radiation detectors for high-precision gamma spectroscopy

15.15-15.45 **Uglov T.,** Lebedev Physical Institute, K-long and muon registration system of the Belle-II detector

15.45-16.00 **David E. L.**, University of West Attica**,** Evaluation of a small field of view personal gamma-spectrometer under ^{137}Cs irradition conditions

16.00-16.15 **Lobko A.,** INP BSU, Specifics of 3D printed electronics

16-15-16.30 **Babin V.I.,** The Institute in Physical Technical Problems, The polymerizer with an air-convection method of heat transfer for plastic scintillators production. Advantages and technology features

16.30-17.00 ***Coffee Break***

Neutron detection–I

Chairman: **Gilewsky V.**

17.00-17.20 **Fedorov A.,** INP BSU, Simulation and experimental study of GAGG:Ce detector of fast neutrons

17.20-17.35 **Dormenev V.,** Justus-Liebig-University, Responce of different types of Gd based scintillation materials to Am-Be netron sourse

17.35-17.50 **Yakimenko I.,** Kharkov National University, Detectors of fast netrons, the mechanisms to register fast neutrons

17.50-18.05 **Kavrigin P.,** CIVIDEC**,** Neutron cross section measurement with diamond detector

18.05-18.20 **Fiserova L.,** University of Defence, Thermal neutron detector based on LaOBr:Ce/LiF

18.20-18. 35 **Opolonin A.,** ISMA**,** Multi-energy radiography, physical principles, applications

18.35-18.50 **Kruglov V.,** JINR, Wide-aperture backscattering detector for the IBR-2 HRFD diffractometer

16.00-19.00 ***Poster session*** **– Technologies, materials and instrumentation Continuation (Conference room 5)**

<u>11.10.2018</u>

Industrial Exhibition (Conference room 6)

Plenary Session **(Ball Room 1)**

Physics of the materials for radiation detection-II

Chairman: **Tamulaitis G.**

9.00-9.20 **Omelkov S.,** ***Invited talk,*** Insitute of Physics, University of Tartu, New properties and prospects for hot intraband luminescence

9.20-9.40 **Ogurtsov A.,** Kharkov National Technical University, Renormalization of atomic cryocrystals luminescence spectra stimulated by excitonicaly induced defect formation

9.40-10.00 **Ulyanenkov A**, ***Invited talk,*** Atomicus GmbH, Investigation of microstructure of irradiated multilayer ZrN/Si_3N_4 thin coatings revealed by X-ray diffraction techniques

10.00-10.20 **Nargelas S.,** Vilnius University, Transient absorption technique as a tool for characterization of scintillator timing properties

10.20-10.40 ***Coffee Break***

Instrumentation–II

Chairman: **Brinkmann K.-Th.**

10.40-11.00 **Krainukovs I.**, Baltic Scientific Instruments**,** Application of $LaBr_3$(Ce) scintillation detectors in radition monitoring equipment

11.00-11.15 **Drobyshev G.,** ADANI**,** Development of the X-ray security screening systems at ADANI

11.15-11.30 **Baev V.,** INP BSU, Research complex for Mossbauer spectroscopy with a closed cycle cryostat for determining the local state of Fe atoms in iron-containing materials

11.30-11.45 **Sytova S.,** INP BSU**,** Information tool for support activities in supervision for nuclear and radiation safety

Instrumentation–III

Chairman: **Drobyshev G.**

11.50-12.05 **Alekseichuk I.,** ATOMTEX, Enhancement of multifunctional AT1117M radiation monitor

12.05-12.20 **Komar D.,** ATOMTEX, $LaBr_3$(Ce)-based smart detection unit for investigation of capture gamma radiation field with energies from 30 keV to 10 MeV

12.20-12.35 **Lukashevich R.,** ATOMTEX, Application scintillation comparators for calibration low intense gamma radiation fields by dose rate in the range of 0.03 – 0.1 μSv/h

12.35-12.50 **Kozemyakin V.,** ATOMTEX, Gamma-radiation detection units and equipment for using as part of unmanned remotely operated radiation control systems

12.50-13.10 **Kazimirov A.,** The scintilletary detectors usage in spectrometric devices and systems for radiation and environmental monitoring

12.50-14.30 Lunch

Instrumentation–IV

Chairman: Gektin A.

14.30-14.45 **Slavashevich I.,** ADANI, Optimization of physical-topological parameters of two-energy X-ray detectors used in inspection and examination equipment

14.45-15.00 **Gorshkov D.,** ATOMTEX, Sample counter for gross alpha/beta activity measurements based on phoswich detector

15.00-15.15 **Lukashevich R.,** ATOMTEX**,** Generation of low-intensity X-ray radiation fields for investigation of energy dependence of high-sensitive radiation monitoring instruments based on scintillation detection units

15.15-15.30 **Yamniy V.,** ADANI, Development of X-ray generator of 80 to 160 keV energy and 1.2 mA current

15.30-15.45 **Kudin A.,** National University of Civil Defence, Experimental manifestation of CsI:Na crystal hygroscopicity

15.45-16.05 **Mokrousov M.,** Space Research Institute, Prospective space based equipment on a base of $LaBr_3$ and $CeBr_3$ scintillators for exploration of the solar system planets

14.00-18.00 Training cource for dosimetry of ionizing radition at ATOMTEX facilities (Transportation Hotel –ATOMTEX and back)

16.20-18.30 Excursion. Victory Museum

19.00-22.00 Conference Dinner

12.10.2018

***Plenary Session* (Ball Room 1)**
Instrumentation–V

Chairman: Lobko A.

10.00-10.20	**Zhukouski A.,** ATOMTEX, Method for nuclides mix identification in analysis of gamma ray scintillation spectra
10.20-10.40	**Onyfriev Yu.,** ISMA, Radiation resistance of scintillators based on diamond micropowders
10.40-11.00	**Demin A.,** ISMA, Cluster ISMA-UA as an High Energy Physics Instrument
11.00-11.20	**Pedash V.,** ISMA, Characterization of position sensitive detectors with positioning algorithms trained by simulated reference data
11.20-11.40	**Verenich K.,** INP BSU, Control of organ and tissue doses to patients during Computed Tomography
11.40-12.00	**Korzhik M.,** Closing of the Conference

EVALUATION OF A SMALL FIELD OF VIEW PERSONAL GAMMA SPECTROMETER UNDER ^{137}Cs IRRADIATION CONDITIONS

Adamis K.[1], Metallinos A.[1], Andarakis I.[1, 2], David S.[1, 2, *]

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Due to the increased radiation pollution in the environment as a result of the often nuclear accidents taking place around the world, the need for efficient, reliable, smart and handheld radiation measurement systems has been born especially in daily routine. Cerium (Ce) ion doped scintillators are of high interest in radiation monitoring detector devices, due to their very fast response and very good emission characteristics. In this study, a series of measurements regarding the energy resolution, photofraction, sensitivity, as well as the figure of merit, of $Gd_3Al_2Ga_3O_{12}$:Ce (GAGG:Ce) scintillator crystals, is presented.

All GAGG:Ce crystals have a surface area of 3×3 mm^2 with varying thicknesses, from 5 up to 20 mm. These crystals were exposed to γ radiation, using a ^{137}Cs (0.662 MeV) radioactive source. Each crystal was measured individually and was optically coupled to a KETEK PM3350 SiPM, an optical sensor with high gain, suitable to operate in room temperature. The digitization of the pulses was accomplished using CAEN DT5720 desktop digitizer and its corresponding digital pulse processing (DPP) firmware. Each measurement was performed in a light-tight box and had duration of 30 min. The best energy resolution value was measured for the GAGG:Ce crystal with dimensions 3×3×15 mm^3, equal to ~6% at 662 keV. Results were evaluated and compared to previous published data.

Acknowledgement. This research is implemented through IKY scholarships programme and co-financed by the European Union (European Social Fund - ESF) and Greek national funds through the action entitled "Reinforcement of Postdoctoral Researchers", in the framework of the Operational Programme "Human Resources Development Program, Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) 2014 – 2020.

SCINTILLATION ISOTOPE-ENRICHED CALCIUM MOLYBDATE $^{40}Ca^{100}MoO_4$ MONOCRYSTALS FOR EXPERIMENTS ON NEUTRINOLESS DOUBLE BETA DECAY SEARCH

Alenkov V.V., Buzanov O.A., Kornoukhov V.N.

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The discovery of neutrino oscillations confirmed that these particles have a nonzero mass. As a result of these "oscillatory" experiments, only the differences in the squares of neutrino masses have been established, but the values of their effective masses, as well as the nature of the particle (Dirac or Mayoran) are still unknown. At the presence, experiments for neutrinoless double beta decay search are the key way to fill the gaps in our knowledge about this elementary particle. A number of such experiments are currently under preparation, among them the AMORE (Advanced Mo-based Rare Process Experiment) experiment, the purpose of which is to search for the neutrinoless double beta decay of the Mo-100 isotope using scintillation isotope-enriched calcium molybdate $^{40}Ca^{100}MoO_4$ monocrystals as a source, and the detector as well. In the material of the crystal, molybdenum and calcium of natural isotopic composition are replaced by isotopically enriched Mo-100 and Ca-40, respectively. In the experiment, two signals are recorded by low-temperature sensors: the phonon and scintillation ones. The requirements to the quality of $^{40}Ca^{100}MoO_4$ single crystals (high light output and its homogeneity in volume, high transparency for intrinsic scintillation light, and ultra-low content of radioactive impurities in the crystal material) are extremely stringent.

JSC "Fomos-Materials" (Moscow) for the first time developed the technology of growing of scintillation isotope-enriched $^{40}Ca^{100}MoO_4$ monocrystals, which makes it possible to manufacture scintillation elements with dimensions of Ø40 mm and length up to 50 mm, with their subsequent annealing and machining, which completely satisfies the requirements of the experiment. The first batch of scintillation elements based on $^{40}Ca^{100}MoO_4$ monocrystals with total mass of 1.89 kg was installed in the AMORE-Pilot detector and successfully passed the tests. Another 9 scintillation elements with a total mass of 3.39 kg have been fabricated and delivered for installation in the AMORE-I detector (the first phase of the AMORE experiment).

The report presents the main results of the work carried out at JSC "Fomos-Materials" on the development of the technology for growing scintillation isotope-enriched calcium molybdate $^{40}Ca^{100}MoO_4$ monocrystals and their successful testing by the AMoRE collaboration.

THE POLYMERIZER WITH AN AIR-CONVECTION METHOD OF HEAT TRANSFER FOR PLASTIC SCINTILLATORS PRODUCTION. ADVANTAGES AND TECHNOLOGY FEATURES

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A schematic diagram of the air polymerizer operation is shown. A comparative analysis of scintillators obtained in the air and liquid polymerizers with equal polymerizate layout is given. Different layouts of the polymerizate in the moulds were tested at polymerization in the air polymerizer. The stages of development of the photomultiplier tube selection bench for the bottle-type scintillators are shown.

THE ELECTROMAGNETIC SHOWER SIMULATION IN GEANT4 WITH TAKING INTO ACCOUNT CRYSTALLINE STRUCTURE OF MEDIUM

Bandiera L.[2], Haurylavets V.[1,]*, Leukovich A.[1], Lobko A.[1], Sytov A.[2], V. Tikhomirov V.[1]

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*bycel@tut.by

Strong crystalline field may lead to increase the probability of electron-positron pair production and intensity of bremsstrahlung if particles move along crystal axes or planes [1]. Such effects arise for electrons, positrons and gamma quanta with the energy exceeding 1–10 GeV. We simulated the electromagnetic shower development in a PWO crystal and calculated the angular distribution of primary and secondary particles with the energy exceeding10 GeV after passage through the crystal. These simulations are supported by the experimental data.

The probability of electron positron pair production and intensity of bremsstrahlung were modified in GEANT4 in accordance with [2]. It is shown that most of particles with the energy exceeding 10 GeV move at the angles of few mrad w.r.t. the crystal axis. This approves the approximation [2] of low angles with respect to the crystal axes.

It is shown that the length of electromagnetic shower strongly decreases in the case of initial beam alignment along crystal axes. The maximum of energy deposition in amorphous material for electrons is shifted with respect to this maximum for gamma quanta. However, when crystalline effects are strong, these maxima almost coincide.

1. L. Bandiera et al., arXiv:1803.10005 (2018)
2. V. Baryshevsky et al., Nucl. Instr. Meth. B 402 (2017) 35

CLUSTER ISMA-UA AS AN HIGH ENERGY PHYSICS INSTRUMENT

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More recently, complex computer calculations were the prerogative of theoretical physics. Now any modern experiment is inconceivable without the usage of large computing powers. The most striking example of modernity is the CERN collaboration. When choosing between a large supercomputer and a set of computational clusters, the model of distributed computations won.

The Large Hadron Collider (LHC) is by far the largest experimental installation in the world. Six large experiments in high energy physics are carried out simultaneously. One of them is the A Large Ion Collider Experiment (ALICE). The main purpose of this experiment is to study strong interactions.

In the study of such collisions on LHC, the ALICE experiment is able to conduct deep research in confinement physics to study the properties of vacuum and mass generation in strong interactions, and to get an idea of how matter behaved directly after the Big Bang. The ALICE experiment detector, like other LHC detectors, generates a huge amount of data that needs computer processing. In addition, computing power is required for simulation. Simulation of physical processes during collisions is carried out, as well as the modeling of all detectors and the entire collider as a whole. For computing, the WLCG (Worldwide LHC Computing Grid) was introduced, which brings together the settlement clusters of all collaborators members. As a result of the stable functioning of the WLCG, a large number of scientists quickly perform data analysis on grid resources, and scientific results appear at an unprecedented rate within a week after receiving data from the LHC.

ICMA has joined the ALICE virtual organization in 2009, one of the first to use the new version of the operating system SL6 to work with packages of intermediate software EMI, Alien. In 2016, due to political reasons, the ISMA stopped participating in the ALICE Collaboration and the cluste "fell out" from payments in its virtual organization. In order to reintegrate the ISMA cluster of the National Academy of Sciences of Ukraine into the European grid infrastructure of EGI and to continue participating in the international grid project ALICE, the installation, basic configuration and operation of the middleware EMI2 has been done. The installation of EMI2 was performed without separating the cluster's settlement capabilities into a separate

pool in order to maintain support for the common cluster queues and simultaneous operation of the two grid systems (ARC andEMI2 + gLite) using a single general task manager.

Conclusions

The Heavy-Ion Collision Experiment (ALICE) is important for modern physics and requires large amounts of grid computing for processing results and simulations.

On the cluster of the Institute for Scintillation Materials, software was installed and configured in the standards of the ALICE virtual organization. Grid computing for the needs of this experiment has been organized.

RADIATION-RESISTANT COMPOSITE SCINTILLATORS

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This paper describes studying the radiation resistance of composite scintillators. Previously [1] we investigated the composite scintillators based on single crystal grains Gd_2SiO_5:Ce (GSO:Ce), $Gd_2Si_2O_7$:Ce (GPS:Ce) and Al_2O_3:Ti as a radiation resistance materials. The composite scintillators with grains of Tikor (Al_2O_3:Ti) were irradiated to dose 400 Mrad at the rate 1500 Mrad/hr and to dose above 125 Mrad at a rate of 0.2 Mrad/hr. The composite scintillators with grains of GSO:Ce and GPS:Ce were irradiated to dose above 170 Mrad at rate of 0.2 Mrad/hr. GSO:Ce is also irradiated at a dose rate of 1500 Mrad/hr to 250 Mrad.

This paper is a direct continuation of the previous work. In this work, the irradiation of composite scintillators was continued to large doses. Therefore, the composite scintillators based on grains of GSO:Ce or GPS:Ce were irradiated to dose above 200 Mrad at dose rate of 0.2 Mrad/hr. The composite scintillators with grains of Al_2O_3:Ti were irradiated to dose 550 Mrad at dose rate 1500 Mrad/hr. Also we have designed and studied a series of composites scintillators based on inorganic single crystalline grains YSO:Ce and YAG:Ce. These composite scintillators were irradiated to dose above 150 Mrad at dose rate of 1500 Mrad/hr and to dose above 100 Mrad at dose rate of 0.2 Mrad/hr.

Relative light output of the scintillators decreases less than 2-time. Therefore, such scintillators can be regarded as radiation resistant materials to these doses. The possible mechanisms of such the processes as well of light collection in these systems are discussed. The processes that determine the change in the properties of scintillators after irradiation can be divided into irreversible primary processes that arise as a consequence of the destruction of matter

without its rapid recovery, and secondary processes when radiation damage of a substance follows its rapid recovery. Two possible series of the secondary processes were proposed. These processes are associated with a change in the shape of the spectrum or its invariance. The composite scintillators containing grains of inorganic crystals change form luminescence spectra can both an observer (Al_2O_3:Ti), or not (GSO:Ce, GPS:Ce, YSO:Ce and YAG:Ce).

1. Boyarintsev A.Yu., Galunov N.Z., Grinyov B.V. et al. Radiation-resistant composite scintillators for registration a large flux of ionizing radiation // Fifth International conference "Engineering of scintillation materials and radiation technologies ISMART 2016". Book of abstracts, 26 – 30 September 2016. 149 p. P.34

CALIBRATION AND PERFORMANCE OF THE CMS ELECTROMAGNETIC CALORIMETER DURING THE LHC RUN II

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Many physics analyses using the Compact Muon Solenoid (CMS) detector at the LHC require accurate, high resolution electron and photon energy measurements. Excellent energy resolution is crucial for studies of Higgs boson decays with electromagnetic particles in the final state, as well as searches for very high mass resonances decaying to energetic photons or electrons. The CMS electromagnetic calorimeter (ECAL) is presently operating at the LHC with proton-proton collisions at 13 TeV center-of-mass energy, 25 ns bunch spacing, and an unprecedented instantaneous luminosity. High pileup levels and the ageing of crystals from exposure to large particle fluences necessitate a retuning of the ECAL readout, trigger thresholds, and reconstruction algorithms, to maintain the best possible performance in these increasingly challenging conditions. In addition, the energy response of the detector must be precisely calibrated and monitored, injecting laser light to correct for crystal transparency changes due to irradiation. A dedicated calibration of each detector channel is performed with physics events exploiting electrons from W and Z boson decays, photons from pi0/eta decays, and from the azimuthally symmetric energy distribution of minimum bias events. This talk presents the new reconstruction algorithm and calibration strategies that have been implemented and the excellent performance achieved by the CMS ECAL throughout Run II.

RESPONSE OF DIFFERENT TYPES OF Gd BASED SCINTILLATION MATERIALS TO Am-Be NEUTRON SOURCE

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Neutron detectors have a wide range of the application like for example non-destructive inspection, safety systems and scientific research using different types of physical methods and equipment for detection of different types of ionizing radiation. Gadolinium based scintillation materials can be considered as candidates for such kinds of detectors because two gadolinium isotopes ^{155}Gd and ^{157}Gd have the highest of all known stable isotopes of the thermal neutron capture cross section, 61,000 and 254,000 barns, respectively. It provides high registration efficiency of a gadolinium based materials. Here we report test results of different types of Gd contained scintillators, glass, ceramics and single crystals, obtained with standard Am-Be neutron source.

PURE RAW MATERIALS FOR SCINTILLATION DETECTORS OF IONIZING RADIATION

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Scintillator properties are strongly influenced by wide range of defects, from cracks and pores to color centers and impurities. Many types of them could have their origin in raw materials. Further production processes, evidently, could compensate raw materials faults or, on the contrary, introduce new. In case of industrial application, scintillator cost is very important, which is determined by both starting compounds and used production processes. So, it is reasonable to discuss raw materials considering special requirements for certain application and all the planned technological chain of material fabrication.

Purity of initial compounds is one of the universally important parameters. Impurities could cause coloring, light yield decrease, afterglow, degradation of crystal growth or sintering. Radioactive impurities create signal background, as could do easily activated impurities under high neutron flux. Common purity requirements are considered by large producers of chemicals, and rare demands may require tailored product, which would be substantially more expensive. However, if certain further technological processes make contamination by some elements inevitable, considering this helps to avoid unnecessary costs. Some promising scintillators are complex oxides, such as $(Gd,Y)_3(Ga,Al)_5O_{12}$:Ce family. Composition, i.e. ratio of main components, is an important parameter for such materials. Direct control of composition may be even more difficult, then for micro-impurities content. However, it has to be controlled at least with better than 1% precision (depending on certain material). Finally, microstructure and particle size distribution of starting powders becomes important for ceramic scintillators. Powder particles size and shape are determined by synthesis method and conditions, which influence powder cost, in some cases – dramatically. Cheap synthesis methods followed by additional treatment, such as milling, could give acceptable results, but possible contamination should be taken into account.

DEVELOPMENT OF THE X-RAY SECURITY SCREENING SYSTEMS AT ADANI

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ADANI is one of the worldwide leading company in the field of X-ray equipment for various applications such as security systems, medical diagnostics, non-destructive analysis and analytic instruments.

a) b) c)

Fig.1. a) CONPASS; b) BV; c) DTP 200LV (left) and DTP 750LV

The biggest branch of our activity is a development and production of various X-ray Security Screening Systems. All security systems divides onto three families:

CONPASS is a family of low-dose people X-ray screening systems (Fig.1a);

BV is a family of equipment for parcels, baggage and small cargo inspection (Fig.1b);

DTP is a family of equipment for cargo and vehicle inspection (Fig.1c).

All these systems include two inherent components: an X-ray source and a linear array(s) of scintillation detectors.

We use various X-ray generators with energies up to 320 kV as well as high energy sources: betatrons or linear accelerators with energy in the region from 6 to 9 MeV.

Wide variation of scintillation detectors are in use depending an application. Acquiring a simple shadow image is possible with relatively cheap single energy detector. However, a simple monochrome image isn't informative enough in many cases, especially, when a single energy source is in use. Recognition of objects by materials (metal, non-metal, and organics) requires a use of more sophisticated dual – energy detectors that consist two rows of scintillators detecting different energies.

Unfortunately, just few of many known scintillation materials are in use in the field of security up to now. Among them: CsI(Tl) and Gd_2O_2S:Tb(Eu) (GOS). Both of them have some disadvantages that's why we are constantly looking for new options in field of X-ray detection.

Up to now, ADANI imports all types of detectors from abroad. Taking into account high cost and an annual need in many thousands of detectors, ADANI carries projects on a development of own detectors. We expect that use of our own components will reduce dependence from importation and will reduce cost of end-product.

The report describes the variety of existing products and outlines challenges and needs in detections techniques for near future.

GROWING AND PROPERTIES OF $Zn_xMg_{1-x}WO_4$ MIXED CRYSTALS

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Tungstate single crystals have found a number of applications as scintillation detectors for detecting of ionizing radiation, tomography, digital radiography and for registration of rare nuclear events. Recently, there has been an active search for new materials with improved scintillation characteristics as well as mixed crystals.

The mixed crystals of zinc and magnesium tungstate $Zn_xMg_{1-x}WO_4$ were grown by Czochralski method on air. High-temperature solid-phase synthesis method was used to obtain the charge for the single crystal growth from initial oxides of ZnO, MgO and WO_3 at a predetermined ratio. The purity of the initial oxides was ≥ 99.995% by the weight. Their structural, optical and scintillation parameters have been investigated.

The research of phase transformations and chemical reactions in a mixture of initial oxides at a predetermined ratio during heating was carried out by thermal gravimetry and differential temperature analysis. The solid-phase interaction temperatures are established and the synthesis conditions of the initial charge are optimized. For the first time the cooling curves were obtained and the melting diagram of the $MgWO_4$-$ZnWO_4$ system was constructed. It was found that the constituents of a mixture are completely miscible in all proportions with each other in both the liquid and solid states and don't form chemical compounds. The liquidus line of the melting diagram has a maximum at a ratio of zinc and magnesium tungstates nearly 50 mol% (Fig. 1).

According to X-ray powder diffraction (XRD) the structures of obtained $Zn_xMg_{1-x}WO_4$ single crystals are monoclinic (wolframite). A linear change of the crystal lattice volume via composition is observed.

The obtained samples are transparent in the region of intrinsic luminescence, the maximum of the X-ray luminescence spectrum is at $\lambda \sim 480$ nm.

The luminescence decay time of $Zn_xMg_{1-x}WO_4$ single crystals varies linearly from 27 μs to 33 μs then x decreases from 0.9 to 0.5. Microhardness change of mixed single crystals depends on the composition and has a maximum at $x = 0.5$. The light output values of the scintillators also have a maximum for the composition $Zn_{0.5}Mg_{0.5}WO_4$ and exceed by 45% the light output of zinc tungstate single crystal.

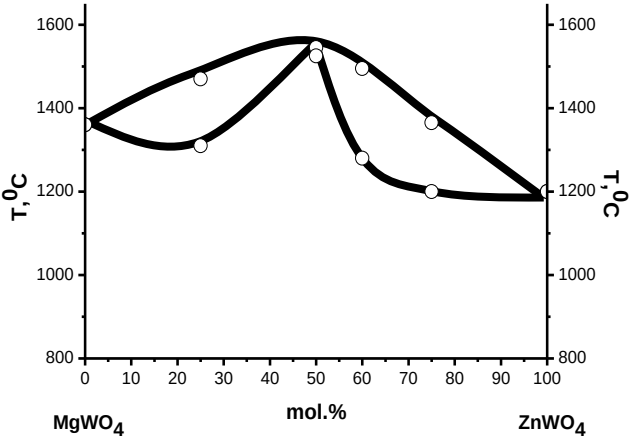

Fig. 1 The phase diagram of $MgWO_4$ - $ZnWO_4$ system

The obtained results show the promising of $Zn_xMg_{1-x}WO_4$ mixed single crystals for scintillation technique creation.

THERMAL NEUTRON DETECTOR BASED ON LaOBr:Ce/LiF MIXTURE

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The work follows up the previous studies which proved the group of lanthanide oxybromides (LnOBr) to be very sensitive to the detection of heavy particles and therefore for the detection of neutrons when mixed with appropriate conversion material. From the group of LnOBr, lanthanum oxybromide activated by cerium LaOBr:Ce showed to be the most sensitive for detection of alpha particles. This led to the construction on novel small thermal neutron detector based on the mixture of LaOBr:Ce and lithium-6 fluoride. The detection efficiency and effective n/γ separation was achieved by using pulse shape discrimination. The results were compared to the reference detection system based on standard ZnS:Ag/LiF mixture. The detector is based on the mixture of LaOBr:Ce and LiF fixed on the thin optical carrier and optically coupled on 1" PMT. The dependence of different shape of photocathode (standard, spherical, 2pi) on the detection efficiency was studied as well as the dependence on the shape and arrangement of scintillation layers.

LOW ACTIVATED SrI_2:Eu DETECTORS

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The SrI_2:Eu is an efficient scintillator [1], which parameters have been improved (light yield 120000 phot/MeV and energy resolution ~3% at 662 keV) by material optimization from invention time at 70th [2]. However, the widely deployed applications of SrI_2:Eu for homeland security detectors are limited by the high cost of crystal production. There are several reasons of the high cost – expensive raw material (SrI_2) and activator (EuI_2 activator), strict claims to raw material purity and concentration of activator. It is particularly an issue for the "optimal" 5% Eu doping activator cost which is reaches twice the cost of starting SrI_2 raw material. So, the best cost efficiency could be achieved in the case of these components optimization. At the same time a good energy resolution of 3.5% was achieved at Eu^{2+} concentration around 0.5% reducing thus the EuI_2 consumption by 1 order of magnitude while preserving the required performances [3].

This work is devoted to the study of the scintillation properties of SrI_2:Eu detectors with low doping by Eu^{2+} in order to defind the optimal composition with compromise between the cost of detectors and their scintillation parameters. It was necessary to find the appropriate balance regarding the raw material purity activator concentration.

SrI_2:Eu crystals with activator concentration in the 0–5% range were grown by the Stockbarger method under the same conditions. Light yield, energy resolution, optical and luminescent properties were studied in dependence on the activator concentration.

The light yield is reduced when decreasing the Eu concentration below 1%, and weakly changes in the 1–5 % range. But we demonstrate that a good energy resolution (< 4 %) of 20 mm diameter size detectors is still obtained even at the Eu concentration of 0.3% (energy resolution is less then 4%). The study shows that optimal performance corresponds to 1–2 % of EuI_2 doing.

The work is partially supported by the NATO multiyear SPS Project NUKR.SFPP 984958 "New sensor materials and detectors for ionizing radiation monitoring".

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ZnSe SCINTILLATORS, GROWING TECHNOLOGY AND LUMINESCENT PARAMETERS

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The ZnSe scintillators have a high conversion efficiency (22%), radiation hardness and low level of afterglow. It has essential preferences compared other scintillators for low-energy detection.

Due to the appearance of new types of ZnSe scintillators doped with not isoelectronic impurities ZnSe-Dopant (ZnSe-D), particularly ZnSe(Al), we have considered the influence of the composition and structure of point defects on the kinetic scintillation parameters of zinc selenide doped with donor cations Al, In, Ga and Bi which are capable of forming substitutional solid solutions with the matrix. The formation of "slow" and "fast" scintillators occur by growing of ZnSe bouls from doping initial charge and thermal treatment of crystals in Zn vapor. The "fast" centers characterized higher thermodynamic stability and make it possible to obtain high uniform crystals. This effect we associate with Zn isomorphic substitution on the donor element and generation of vacancy in near of donors area.

ZnSe doping with donor elements with the ionic radius close to zinc leads to decrease in the lattice parameter of ZnSe due to the generation of vacancies.

Our theoretical and experimental studies laid a solid foundation for development of full technological cycle of production of ZnSe semiconductor scintillators. The technological process includes the following stages: 1) synthesis of initial raw material of required composition; 2) thermal treatment – purification of the raw material, preliminary formation of solid solution ZnSe(D); 3) growth of ZnSe(D) single crystals; 4) after-growth thermal treatment – achievement of amplitude-spectral and kinetic characteristic of scintillators optimized for each specific application.

Due to high radiation purity of the ZnSe crystals it is promise material for the study of the neutrinoless double beta decay of ^{82}Se using scintillating bolometers.

BF-e USING IN IONIZING RADIATION DETECTION

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The goal of this study is to evaluate scintillation detectors based on BF-e possibilities in ionizing particles energy spectrums measurements. Various ionizing radiation particles like alphas, betas, gammas, protons, neutrons were detected and spectrums measured by scintillation in detector using photomultiplier.

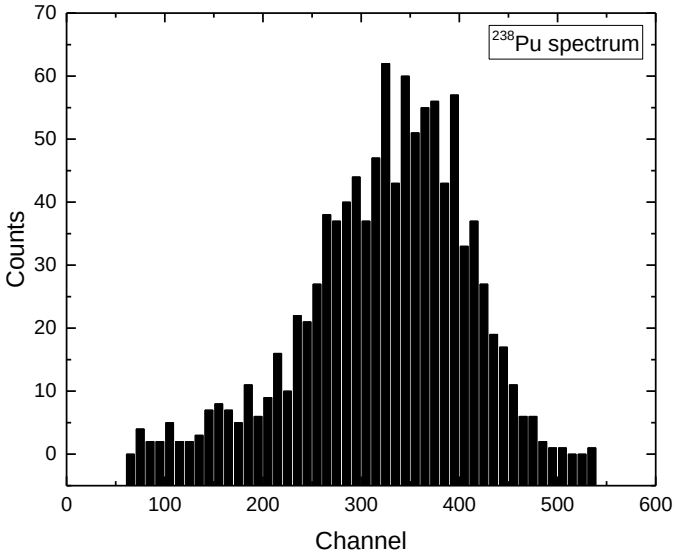

Fig. 1. ^{238}Pu spectrum measured using polystyrene detector with BF-e dye

BF-e was used as single crystalline thin film detector and as effective wavelength shifter in polymers. ^{238}Pu spectrum provided in Fig. 1, spectrum was measured using Bf-e as dye in polystyrene scintillation detector. Dissolved crystals in acetone also was used like scintillation detector. BF-e showed good wavelength shifter properties. BF-e quantum efficiency is more than 72% moreover it has a shots exited state lifetime (1.5 – 2.5 ns), this parameter is very important to use it as dye in pulse shape discrimination detec-

tors. Pulse shape discrimination properties were investigated. BF-e crystalline film was used to alpha/beta radiation separation.

It was found that material could be used as perspective dye in scintillating detectors.

PROGRESS IN FABRICATION OF LONG YAG-BASED SCINTILLATION FIBERS FOR HEP EXPERIMENTS

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Single-crystal scintillation fibers are alternative to bulk crystals in high granularity detectors for new high energy physics experiments at colliders [1]. Rare earth garnets are among the most attractive materials for this application due to high density, high light yield and possibility to detect both scintillation and Cherenkov signal by Ce-doped and undoped fibers, respectively. According to the current specification, the length of the fiber should be > 20 cm, light attenuation length L_{att} should be at least 40 cm, and the decay time is < 40 ns. At the moment, μ-PD is the only method to produce the garnet single crystalline fibers of such length without mechanical treatment. In the prior work [2], we reported the production of 22 cm long LuAG:Ce fibers with the attenuation length of up to 104 cm, however, YAG-based fibers should be more promising for mass production accounting to the less raw material cost.

In this study, YAG: Ce and YAG: Ce,Mg fibers of 2 mm in diameter and up to 55 cm mm in length were grown by the μ-PD method under Ar flow from the melts of both stoichiometric and nonstoichiometric compositions. To accelerate garnet scintillation decay time, the fibers were codoped with Mg^{2+} ions. Unlike LuAG: Ce, the surface of YAG: Ce fibers grown from the stoichiometric melt is rough. As the result the attenuation length does not exceed 20 cm. Mg^{2+} codoping further decreases the L_{att} down to 10–12 cm. Since Al_2O_3 evaporates from the garnet melts, it was assumed that the surface defects garnets are associated depletion by oxygen and Al^{3+}. The excess of up to ~ 600 ppm of aluminium oxide relatively to the garnet stoichiometric composition was introduced to the melts. Optimization of thermal conditions of the growth, as well as post-growth thermal annealing provides the fabrication of 22 cm long fibers with the L_{att} of up to 50 cm. In YAG: Ce,Mg the attenuation length of 35 cm was achieved. Meanwhile, the scintillation decay

time in Mg-codoped fibers is still slightly longer compared to the target decay time.

The work is partially supported by the Marie Skłodowska-Curie Research, Innovation Staff Exchange Project H2020-MSCA-RISE-2014 no.644260 “INTELUM”.

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THE IMPACT OF DEEP TRAPS OF STRUCTURAL ORIGIN ON THE OPTICAL AND SCINTILLATION CHARACTERISTICS OF ORGANIC SCINTILLATORS

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Growing bulk single crystals is always a fairly complex and costly task. One of the ways to reduce the cost of scintillation detectors is the use polycrystalline and composite materials, which can be obtained in virtually any size. Understanding the physics of processes that determine the formation of a scintillations in organic scintillators has an important practical application. It gives the initial data for determining the possibility of more efficient use of such scintillators in specific problems of science and technology, and for obtaining initial data for the creation of effective polycrystalline mosaic detectors and the development of new composite materials.

This work is devoted to the study of the regularities of the influence of deep traps of structural origin that arise in compositional and polycrystalline scintillators based on stilbene, anthracene, n-terphenyl and doped n-terphenyl on their optical and scintillation characteristics. It is shown that materials with deteriorated structure have new luminescence peaks in the long-wave part of the spectrum. This additional luminescence has its own excitation spectrum shifted to the long-wavelength region of the spectrum with respect to the excitation spectrum of the main luminescence of the scintillator that corresponds to one in pure single crystals. It is shown that the appearance of additional peaks during the radiation excitation of composite and polycrystalline scintillators is associated with the existence of deep trap centers. It has been proved that the formation of deep charge traps in polycrystalline scintillators leads to a decrease in the absolute light output and the decay time in comparison to single crystalline samples. The time of localization of charge carriers on deep traps is by several orders of magnitude longer than the scintillation signal shaping time. It is shown that an increase in the duration of the rise front in organic polycrystalline scintillators occurs as a result of localization of charge carriers on small dynamic traps of polarization origin. It is established that the localization of charge carriers on deep traps of structural origin in organic scintillators is equivalent to quenching of the scintillation. Light-collecting coefficients were determined using the model of discrete optical medium of for polycrystalline and single crystal scintillators. These

coefficients were used for calculation of the light yield. The light yield of scintillation materials of the same chemical composition has close values. The patterns of changes in the light output associated with the increase in the average length of the light path to the detector's output window were found both in the case of transition from single crystal to polycrystalline sample as well as in the case of transition from volume to local excitation.

SCINTILLATOR POWDERS AND CERAMICS OF MULTICOMPONENT OXIDES WITH A GARNET STRUCTURE – PROBLEM OF COMPOSITION CONTROL

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Polycrystalline scintillation materials find applications in imaging equipment, for example, in medical imaging (CT), and have prospects for use in other areas of ionizing radiation registration (e.g. homeland security, research, non-destructive analysis). Complex oxides with garnet structure of the general formula $(Gd,Y)_3(Ga,Al)_5O_{12}:Ce^{3+}$ are actively studied during the last decade and considered as one of the most promising scintillators for a wide range of applications. Powders of this composition, consisting of dense transparent particles, can be considered as phosphors, and powders consisting of nanosized particles are used as a starting material for scintillation ceramics. It was shown recently, that Gd-loaded garnets are a promising material for detection of neutrons in a wide energy range [1].

For both types of use, it is necessary to obtain a powder with a certain granulometric composition and microstructure. For practical use, the production cost of powders and ceramics based on them is also of great importance. The co-precipitation method is suitable from the point of view of manufacturability of production, and also allows to obtain powders with controlled particle sizes and the required characteristics of the microstructure.

However, due to the different chemical nature of gallium and gadolinium, the complete precipitation of these elements is achieved under various conditions, which can lead to deviation of the obtained composition from the initially desired. This work is devoted to the investigation of the influence of key parameters at various stages of synthesis of $(Gd,Y)_3(Ga,Al)_5O_{12}:Ce^{3+}$ powders by coprecipitation, which affect their composition in relation with other characteristics.

Powders of multicomponent oxides of composition $(Gd,Y)_3(Ga,Al)_5O_{12}:Ce^{3+}$ were obtained using different precipitants. When using NH_4OH as a precipitant, dense luminescent particles with a size of several tens of microns

were obtained, and when using NH_4HCO_3 solution precipitate powders with a primary particle size below 100 nm were formed. Completeness of precipitation at various synthesis parameters was studied, as well as some approaches to control the composition. Powders were studied by optical, scanning and transmission electron microscopy, X-ray diffraction, laser diffraction. Photoluminescence and scintillation characteristics were studied as well, including experiments to study the effect of deviation of the composition from stoichiometry on these properties. It was shown, that slight deviations of the composition from stoichiometry lead to appreciable changes in scintillation characteristics.

The work is supported by grant № 14.W03.31.0004 of Russian Federation Government.

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EXPERIMENTAL INVESTIGATION OF ON-BOARD CHARGED PARTICLES SPECTROMETER AND GAMMA-RAY TELESCOPE DETECTING MODULES CHARACTERISTICS

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The characteristics and reliability of spectrometric equipment installed on space vehicles and intended for monitoring cosmic radiation and particles flows depend to a large extent on the quality and completeness of ground-based adjustment work and testing performed using specially developed test equipment (TEQ).

Fig. 1 Test equipment (a), spectrometer of charged particles "ZINA-NT" (b), detecting modules of gamma-ray telescope "GAMMA-400" (c)

The report presents results of development and application of specialized TEQ (Fig. 1a) for investigation and monitoring of functioning of charged particle scintillation spectrometer "ZINA-NT" (Fig. 1b) developed in collaboration by SSPA "Optics, Optoelectronics and Laser Technology" and

National Research Nuclear University "MEPhI". The TEQ provides power supply for scintillation spectrometer units; reception and digitization of signals from multilayer scintillation module of spectrometer; selection of logical signals and generation of trigger signals; control of connections; operating temperature control; generation of digital test signals; testing of scintillation spectrometer units; amplitude analysis of data; acquisition, accumulation and transfer of information arrays through communication channels; visualization and documentation of working results. Number of channels for receiving signals from detector system – 44, number of monitored parameters – 17, number of control commands – 15.

Based on the results of TEQ utilization and investigation of scintillation detection modules of gamma-ray telescope "GAMMA-400" (Fig. 1c) characteristics, an architecture for constructing a robotic hardware and software complex for such modules adjustment and testing has been developed.

PROTOTYPING AND EXPERIMENTAL RESEARCH OF RADIATION DETECTION MODULES

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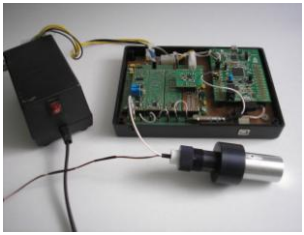
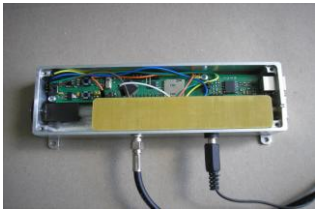
At present, there is a need for detectors with improved characteristics for solving problems in the field of high-energy physics and for creating monitoring systems of ionizing radiation on Earth and in space. In turn, progress in manufacturing new types of vacuum photomultiplier tubes (PMTs) and silicon photomultipliers (SiPMs), scintillators, high-performance processors and FPGAs is a good prerequisite for creating small-size detectors with high spatial, temporal and energy resolution and with long-term stability and radiation resistance.



a



b

c

Fig. 1. Detector module based on vacuum PMT Hamamatsu R5611 and NaI (Tl) scintillator (a), detector module based on SiPM and plastic scintillator (b), instruments and equipment for experimental research (c)

The report presents the results of prototyping and investigation of two types of detector modules: the detector module based on vacuum PMT Hamamatsu R5611 and NaI (Tl) scintillator (Fig. 1, a) and the detector module based on SiPM (with an active area 6×6 mm^2) from SensL and plastic scintillator (Fig. 1, b). Design and computer modeling were carried

out during prototyping. Blocks of amplification, discrimination, peak detection, power supply, multi-channel pulse analyzer with FPGA and ARM 32-bit microcontroller and events buffer were developed. USB interface was used to connect the detector modules to a computer. The software, for data processing and visualization of results on the monitor screen in the form of time dependencies and spectra, was developed. Characteristics of the detector modules were studied using the equipment shown in Fig. 1, c. Optimum thresholds for discriminators were determined, dark currents and temperature effects were investigated, spectra of ionizing radiation were obtained and analyzed.

STATISTICAL ESTIMATION MINIMALLY DETECTABLE ACTIVITY MEASUREMENT QUALITY FOR RADIONUCLIDES BY PLASTIC SCINTILLATORS OF PORTAL MONITORS

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An important characteristic of portal monitors, along with sensitivity, is the small amounts radioactivity detection limit value on a natural radioactive environment background. The minimally detectable activity (*MDA*) is used as a criterion for this limit estimating.

In this paper, the quality of *MDA* measurement of plastic scintillators (PS) produced by the Institute for scintillation materials National Academy of Sciences of Ukraine is estimated. We used the experimental approach in accordance with the DSTU GOST ISO 5725-1:2005. The quality of the measurement is determined by processing the experimental statistical material. This allows us to take into account the factors of results scattering, without compiling a model equation (GUM method). The precision obtained in this case corresponds to combinations of factors characterizing certain measurement conditions.

Measurements, in counts/s, of counting rate n and background n_b of PS with dimensions of 500×300×50 mm (7500 cm^3) and 500×500×50 mm (12500 cm^3) in the energy range (0.02–3.0) MeV were carried out using a standard spectrometric channel in conditions of natural radioactive background of the environment. A photomultiplier of the type R1307 was used. The gamma sources ^{137}Cs and ^{60}Co were located at distances h = 10 cm and h = 50 cm from the center of the PS input surface. The values of *MDA*, in kBq, were calculated using the formula:

$$MDA = \frac{2}{\eta}\sqrt{\frac{2n_b}{t}}\ , \qquad (1)$$

where η – scintillator sensitivity, count/s·kBq, t – exposure time equal to 1 s.

The *MDA* results measurements and $S_{r\ MDA}$ precision measurements estimation for 9 measurements under repeatability conditions are presented in Table 1 and Fig. 1.

Table 1. *MDA* and $S_{r\ MDA}$ for PS

Volume, cm^3	Nuclide	h = 10 cm; n_b/n = 11-16 %		h = 50 cm; n_b/n = 53-56 %	
		MDA, kBq	$S_{r\ MDA}$, %	*MDA*, kBq	$S_{r\ MDA}$, %
7500	^{137}Cs	1,54	3,87	13,42	7,05
	^{60}Co	0,56	3,14	4,57	4,32
12500	^{137}Cs	1,80	3,55	12,30	6,89
	^{60}Co	0,56	3,21	3,70	3,39

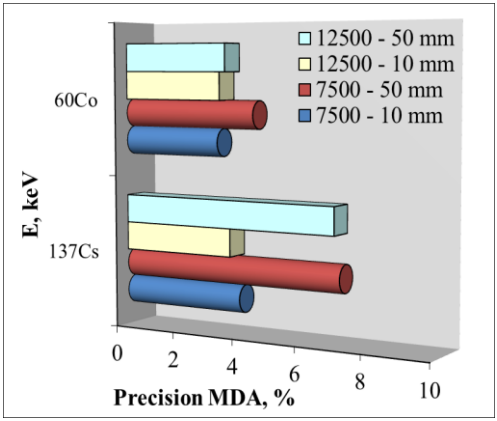

Fig.1. *MDA* precision measurements for PS

It is seen from Table 1 and Fig. 1 that $S_{r\ MDA}$ increases with distance h from the source and decreases with increasing energy of the detected rays. This is associated with the value of the ratio of background and scintillator count rates n_b/n.

THE TIME ANALYSIS OF THE FAST IMPULSE RESPONSE FROM COMPOSITE DETECTORS BASED ON SCINTILLATORS: ZWO, GSO, BGO TO FAST NEUTRONS

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We obtained comparative measurements of the sensitivity to fast neutrons from the source ^{239}Pu-Be for composite detectors based on scintillators ZWO, GSO, BGO.

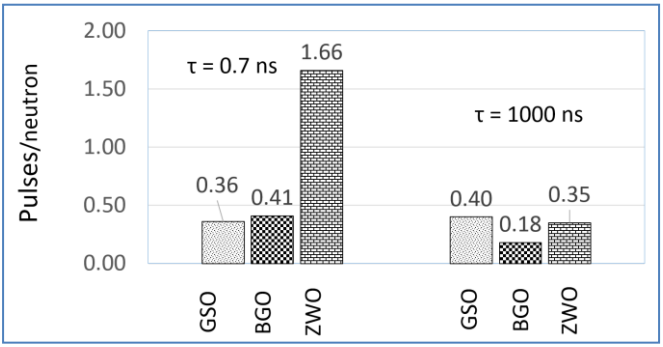

Fig. 1. The number of the response pulses to the interaction to one fast neutron with the detector mass

The detectors were made by using multilayer technology. The response signals were recorded simultaneously in two timing intervals, narrowband by using a spectrometric amplifier (the time of formation τ = 1000 ns) and in a wideband by counting path using a fast (rise time τ = 0.7 ns) amplifier. The results of the measurements could be explained by the presence of a contribu-

tion from the additional interaction mechanisms that appear when the primary neutron energy going to decrease inside the detector material. The sensitivity rising is explained by the use of the resonant scattering mechanisms. The results of the analysis at the figure shows the number of response pulses per one interaction inside the detector. The statistical error of the measurements was ~ 7–8%.

ON NEW ASPECTS OF METROLOGICAL ACTIVITY AT OUR INSTITUTE WITH THE ENTRY INTO FORCE OF THE NEW LAW OF UKRAINE "ON METROLOGY AND METROLOGICAL ACTIVITY"

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Since January 1, 2016, the Law of Ukraine "On Metrology and Metrological Activity" (hereinafter referred to as the Law) entered into force. This document is aimed at the implementation of Ukrainian legislation to European norms and the harmonization of the basic concepts in the field of metrology with international ones.

Approaches to various aspects of the metrological industry have changed, but the principles of unity and accuracy of measurements, observance of consumer rights and analysis of the state of measurements at all stages from development to production are the priorities.

Adoption of the new edition of the Law is aimed at creating conditions for the development of Ukrainian production by increasing its competitiveness on the domestic and foreign markets, development of enterprises producing measuring equipment (ME) in Ukraine.

After analyzing the innovations of the Law, we note that a number of terms and concepts that were used previously do not coincide with the International Dictionary of Basic and General Terms in the field of Metrology (VIM) and therefore are consistent. This Law allows us to resolve a number of issues, such as reducing customs barriers, mutual understanding with foreign customers in the field of metrology, and this gives more confidence in our products. In connection with this, our institute needed to organize the metrological activity so that the requirements and wishes of foreign customers were taken into account and the requirements of the current legislation in the field of metrology were met. The institute needed to determine how to maintain unity and accuracy of measurements.

The Law changed the concept of "calibration of the ME", which became more understandable for our foreign customers, so there was a need to understand what ME requires checking, and which calibration.

We also conduct metrological control of those ME that are used in carrying out measurements in a non-legislatively regulated area, where there is no

need to carry out ME calibration and to determine the uncertainty of measurements.

It should be noted that the Law practically says nothing about measuring laboratories and does not provide control of the metrological characteristics of the ME at enterprises and organizations. Therefore, we are building our metrological activity so that all ME at all stages of development and manufacture of our products meet the accuracy requirements regulated for these facilities under the established conditions of their operation.

As our institute delivers its products to far abroad, as previously mentioned, we passed the assessment of the state of the measurement system and have a conclusion of the competence of our measuring laboratory in accordance with the requirements of the Basic Provisions of the Ukrainian System of Voluntary Assessment of the measurement state and DSTU ISO 10012.

Thus, as a result of all the actions that are now required by metrology legislation, we have brought our metrological activity to the international one, which resulted in greater confidence in foreign customers and, as a result, our products became more competitive on the foreign market.

APPLICATION OF SCINTILLATION DETECTORS IN COSMIC EXPERIMENTS

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Scintillation detectors (SDs) based on application of organic plastic scintillators (OPSs), or of inorganic scintillators (IOSs), are widely used in modern space physics, and, generally speaking, in cosmic experiments. Here we review different detection technics, as well as technologies for production of OPS and of IOSs different shapes, like strips and tiles (extrusion, injection molding, etc.), optical and physical characteristics of scintillators, and methods of light collection based on the use of direct optical contact, or of wavelength-shifting (WLS) fibers use, to couple scintillators with different type photosensors.

Examples are given of the use of SDs in the past and present, historically and physically important cosmic experiments, as well as of modern experiments planned to be carried-out in the space, and/or on ground-based SDs arrays, developed for astro-particle and gamma-ray experiments aimed to search for new (astro)-physics, like new states of matter, antiparticles, neutrino oscillations, and to study astrophysical phenomena and cosmic particles in a wide mass and energies range.

Especially we ‘ll discuss our experience in application of the new scintillator Ce:GAGG in pixellated gamma spectrometer elaborated in the frame of Russia – Belarus collaboration in space.

Scintillation detectors hold great promise for future space and ground-based cosmic experiments due to their properties of a high segmentation, radiation hardness, possibility to apply WLS fiber light collection and multipixel silicon PMT readout.

PROCESSING OF SCINTILLATION CERAMICS BASED ON COMPLEX OXIDES WITH GARNET STRUCTURE

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Scintillating materials, based on complex oxide phases with garnet structure attract a lot of attention recently due to their properties. It was shown, that their composition could be purposefully engineered to achieve a combination of high light yield and density, large effective charge and high radiation hardness [1]. There are compositions, showing good performance, with high Gd content; Gd high absorption cross-section for neutrons in a wide energy range [2] allows using these composition for promising neutron detection scintillators. This kind of scintillators is being developed in a single crystal form, which is rather expensive. As an alternative, ceramic form of material can be used; this form gives more flexibility in performance-production costs balance, and composition engineering.

Here we report on synthesis and scintillation properties of ceramics with various compositions in system $(Gd,Y)_3(Ga,Al)_5O_{12}$:Ce, such as $Y_{2,97}Ce_{0,03}Al_5O_{12}$ (YAG:Ce), $Y_{1,485}Gd_{1,485}Ce_{0,03}Al_2Ga_3O_{12}$ (GYGAG:Ce), etc., which could be used in various roles within neutron detectors. Ceramics was obtained using previously elaborated approach. Powders were obtained by coprecipitation method with following heat treatment and milling. Calcination temperature, average size of powder particles, method and parameters of compaction (pressing or casting) and sintering conditions are main factors, which have an influence on final ceramics characteristics. Uniaxial pressing and colloid approaches were used for powders compaction. Sintering in an air allows to obtain ceramics with density about 98-99% of theoretical density, suitable for measurements of certain scintillation properties. Scintillation properties depending on host composition is discussed in relation to application of such ceramics for neutrons detection.

The work is supported by grant № 14.W03.31.0004 of Russian Federation Government.

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NEUTRON CROSS SECTION MEASUREMENTS WITH DIAMOND DETECTORS

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Diamond is one of the most robust, versatile and radiation tolerant material for use in beam diagnostics with a wide range of applications in beam instrumentation. Diamond detectors are successfully used with charged particles, photons and neutrons.

Diamond detectors can be used as neutron monitors using two different measurement techniques. In the case of the measurements with thermal neutrons, a neutron converter is used. The thermal neutron interactions in the converter create charged particles which interact with the diamond detector. The common converter materials are ^{6}Li, ^{10}B and ^{235}U. Fast neutrons directly interact with carbon nuclei of the diamond detector, so the detector simultaneously acts as a sample and as a sensor.

Single-crystal diamond detectors were used in the measurement performed at the Van de Graaff facility of EC-JRC, Geel, Belgium. A dedicated method of the ionization current pulse-shape analysis allowed to measure the cross section of $^{13}C(n,\alpha_0)^{10}Be$ reaction relatively to $^{12}C(n,\alpha_0)^{9}Be$ reaction. This method is based on the unique property of sCVD diamond sensors that the signal shape of the detector current is determined by the initial ionization profile. It allows discrimination between different types of interactions in the detector and a background rejection. In the measurement presented in this report the pulse-shape analysis method was used to obtain the spectra of the two nuclear reactions of interest in order to calculate the cross sections.

This pulse-shape analysis method is especially relevant for neutron diagnostics in harsh radiation environments, e.g. fission and fusion reactors. It allows the separation of the neutron spectrum from the background, and it is particularly useful in neutron flux monitoring and neutron spectroscopy.

THE SCINTILLETARY DETECTORS USAGE IN SPECTROMETRIC DEVICES AND SYSTEMS FOR RADATION AND ENVIRONMENTAL MONITORING

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For several decades our company is developing, implementing and supporting for the maintenance of the spectrometric instruments and systems for the wide area of the oradiation monitoring tasks. We have accumulated experience, allowing assessing the adequacy of the nuclear power plants safety barriers control and the possibilities for improving the state of affairs in the area for radiation monitoring hardware. The report presents the main characteristics of gamma, beta spectrometers, whole body counters, spectrometric complexes for nuclear power plants.

Most of the devices are developed with the use of scintillation detectors of β- and γ-radiation. This includes laboratory spectrometers of β- and γ-radiation; whole body spectrometers of the series "ICH-AKP" mobile γ-spectrometric units, which allowing the activity and radioisotope composition of solid radioactive waste determination, solving the field spectrometry tasks, operation in dry and water filled wells. Over time have worked well and proved the systems for nuclear power plants:

– Detection device of the "UDZHG" type for measuring the volumetric activity of γ-emitting nuclides in the liquid of technological circuits of the NPP.

– Software and technical complex for detecting leaks in steam generators based on ^{16}N activity in the acute steam "Azot-16-PG".

– Spectrometric complex for monitoring the activity of the coolant of the primary circuit of the STPC 01 on the basis of a semiconductor detector.

There are analyzed the possibilities and prospects of the scintillation spectrometry instruments usage in solving a wide range radiation monitoring of issues of technogenic and natural radionuclides in the environment, as well as developments for radiation monitoring systems of nuclear power plants.

DEVELOPMENT OF A SUBMILLIMETER PORTABLE GAMMA-RAY IMAGING DETECTOR, BASED ON A GAGG:Ce - SILICON PHOTOMULTIPLIER ARRAY

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In this study we present the development of a gamma-ray detector based on 1 mm pixel $Gd_3Al_2Ga_3O_{12}$:Ce (GAGG:Ce) scintillators and a silicon photomultiplier array (ArraySL-4) for possible applications in medical imaging detectors (with focus in PET applications) as well as in personal gamma radiation monitoring applications (with focus on ^{137}Cs radioisotope recognition). A 12×12 matrix of pixellated scintillators is coupled to a 4×4 pixel elements of a SIPM array covering an active area of 13.4bmm^2. Experimental evaluation was carried out with ^{22}Na and ^{137}Cs sources and the parameters studied were energy resolution and peak-to-valley ratio.

ArraySL-4 is a commercially available, 4x4 array detector covering an active area of 13.4 mm^2. The GAGG:Ce scintillator array used in this study has 1×1×10 mm^3 pixel size elements with 0.1 mm thickness $BaSO_4$ reflector material between the crystals. A symmetric resistive charge division matrix was used reducing array's 16 outputs to 4 position signals. A Field Programmable Gate Array (FPGA) Spartan 6 LX150T was used for triggering and signal processing of the signal pulses digitized using free running Analog to Digital Converters.

Raw images and horizontal profiles of the 12×12 GAGG:Ce scintillator array produced under 511 keV and 662keV excitation are illustrated. Moreover, the energy spectra obtained with ^{22}Na and ^{137}Cs radioactive sources are shown. The peak to valley ratio and the mean energy resolution values are reported.

All GAGG:Ce central pixels were separated in the 2-dimensional position histograms with an average peak-to-valley (P/V) ratio of 1.75 for 511 keV and P/V ratio 1.85 for 662 keV. The energy resolution was 16.9% for 511 keV and 14% for 662 keV. Those encouraging results, prove that this system could build up to a compact miniature ^{137}Cs spectrometer (with 2D isotope mapping capability) for homeland security applications as well as can be used in small animal imaging PET detector systems.

Acknowledgement. This research is implemented through IKY scholarships programme and co-financed by the European Union (European Social Fund - ESF) and Greek national funds through the action entitled "Reinforcement of Postdoctoral Researchers", in the framework of the Operational Programme "Human Resources Development Program, Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) 2014 – 2020.

SOL-GEL DERIVED NANOSTRUCTURED YTTRIUM-ALUMINUM GARNETS POWDERS DOPED WITH LANTHANIDES

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The lanthanide-doped materials obtained by the sol-gel method demonstrate intense photoluminescence (PL) and radioluminescence (RL) and are promising for the conversion of ionizing radiation [1, 2]. In this paper, the results of sol-gel synthesis and analysis of the morphology and PL of nanostructured powders of yttrium-aluminum garnet (YAG) doped with terbium, neodymium and erbium are considered.

YAG powders doped with terbium, erbium, and neodymium were prepared by sol-gel method with multistage drying of sols with final annealing at 1000° C for 30 min (for Tb, Er-doped) and 3 h (for Nd-doped). The formation of monophasic garnet powders $Y_3Al_5O_{12}$ was confirmed by X-ray diffraction analysis, the size of crystallites was 25–48 nm. The intense terbium PL with a maximum at 543 nm (λ_{exc} = 270 nm) and neodymium and erbium PL (λ_{exc} = 532 nm) in the infrared range with maxima at 1064 and 1540 nm, respectively, were obtained in the nanostructured powders. The YAG:Er powders also reveal up-conversion upon excitation by radiation with a wavelength of 979 nm and 1535 nm. Up-conversion in the blue spectral range was obtained under the 495 nm in YAG:Tb with perovskite structure formed on porous anodic alumina [3]. RL under the X-ray and electron beam excitation also registered for the terbium in various types of YAG matrix [4, 5].

The sol-gel obtained nanostructured monophase powders of doped YAG showing luminescence of lanthanides are promising for the formation of phosphors on various substrates from the powders dispersed in film-forming sols for detection of ionizing irradiation. The up-conversion of erbium in YAG receives interest for the development of coatings formed on the back side of solar cells that do not have a bottom metal contact.

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CATHODOLUMINESCENCE OF NANOSTRUCTURED YTTRIUM-ALUMINUM PEROVSKITE DOPED WITH TERBIUM EMBEDDED IN POROUS ANODIC ALUMINA MATRIX

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The terbium-doped aluminum-yttrium composites which demonstrate luminescence under the X-ray, gamma, electron beam and other ionizing radiation excitation can be obtained in low-dimensional nanostructured matrices, such as porous anodic alumina (PAA), and it's of interest in the development of scintillators used in safety monitoring systems the nuclear industry, the means for controlling the distribution and circulation of radioactive materials, in medical diagnostics.

Yttrium-aluminum perovskite (YAP) with various concentrations of terbium were obtained on the PAA/Si substrates by the nitrate-citrate sol-gel synthesis with heat-treatment at 1000 °C, as described in [1]. The pulse cathodoluminescence (PCL) spectra in the visible spectral region were excited by an electron beam generated by the *RADAN* accelerator (current density 1 A/cm^2, electron energy 180 keV, pulse duration 3 ns) and recorded in pulse accumulation mode (30 pulses) using a CCD-camera with post-registration signal processing, see more in [2].

PCL spectra of YAP with the terbium concentration from 0.085 to 2.11 at.% contain the typical Tb^{3+} luminescence bands. The most intensive band with maximum at 543 nm for all Tb concentrations is associated with $^5D_4 \rightarrow {}^7F_5$ Tb^{3+} transition and characterized by presenting of Stark component corresponding to a transition with a width of 19 ± 4 meV is less than the width of the main transition.

With an increase in the concentration of Tb from 0.085 to 2.11 at.%, the half-width at half-maximum (HWHM) of the luminescence band with a maximum of 543 nm smoothly increases from 2.28 to 5.5 nm. The intensity of the luminescence peak with increasing terbium concentration increases for 3.3 times with an increase in the terbium concentration by a factor of 25, and the integrated intensity of the luminescence band increases by a factor of 6, respectively. The profile of the luminescence band approximately corresponds to the Gaussian profile, which indicates an irregularly broadening of the spectrum. Empirical dependence of the integrated luminescence intensity on the concentration is approximately described by the equation:

$$L = 2{,}38 \ln(C/C_0) + 1{,}89,$$

where C is the considered Tb concentration, C_0 is the minimal Tb concentration in the selection. The value of determination is $R^2 = 0.94$ and it's acceptable.

This approximation can allow controlling predictably the luminescent parameters of the YAP:Tb/PAA/Si structures by the variation of the terbium content in the composite compared with the initial concentration. Thus, the sol-gel synthesized YAP:Tb with tuning luminescent properties has promising characteristics for use in light-emitting structures excited with the ionizing radiations.

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NANOENGINEERED $Gd_3Al_2Ga_3O_{12}$ SCINTILLATION MATERIALS WITH DISORDERED GARNET STRUCTURE FOR NOVEL DETECTORS OF IONIZING RADIATION

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The search for engineering approaches to improve the scintillation properties of $Gd_3Al_2Ga_3O_{12}$ crystals and enable their production technology is of current interest. This crystal, while doped with Ce, is considered to be a good multi-purpose scintillation material for detecting gamma-quanta and neutrons. We observed that co-doping with Mg affects intrinsic defects in the crystal structure which creates a shallow electronic traps. Other point structure defects, which are based on local variation of the stoichiometry in the crystal, can be significantly diminished by use of co-precipitated raw material. Nano-structuring of the raw material allows to obtain a homogeneous precursor mixture enabling the growth of crystal with minimal level of evaporation of Ga from the melt. The demonstrated nanoengineering approach promotes an increase of the light yield from the crystal by about 20%, sufficient for enabling its applications in well logging.

SETUP FOR CHARACTERIZATION OF SCINTILLATORS TO DETECT NEUTRONS

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Here we describe facility for characterization of neutron sensitivity of the scintillation materials with different readout sited in Giessen University. It includes Am/Be source and set of PMT and readout electronics. Neutron flax can be modified by application of different absorbers on a base of Boron acid, Cd, Pb, Cu. We describe appropriate measurements methodic and setup properties to construct compact neutron detectors with detection of each particle individually with registering its specific response in a wide energy range for different purposes.

APPLICATION OF $LaBr_3$(Ce) SCINTILLATION DETECTORS IN RADIATION MONITORING EQUIPMENT

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Despite the excellent energy resolution of $LaBr_3$(Ce) scintillation detectors, their use in radiation monitoring equipment is still quite limited. The probable reason of this is the own radiation background typical of $LaBr_3$(Ce) crystals which might be unfavorable for solving some spectrometry problems. Another drawback of $LaBr_3$(Ce) crystals is their high price which is 15-20 times as high as the price of NaI(Tl) crystals of the same size.

This paper takes up the performance of the radiation monitoring equipment based on $LaBr_3$(Ce) detectors and highlights the advantages and disadvantages of such equipment related to the peculiarities of these scintillation detectors. All the equipment considered contains the $LaBr_3$(Ce) crystals of various dimensions manufactured by Saint Gobain and photomultiplier tubes (R6233, R6231) manufactured by Hamamatsu. Depending on the size, the spectrometry systems mentioned provide the energy resolution of 2.8% - 3.1% at 662 keV which is typical of this type of scintillation detectors. The aspects related to design and technology of the $LaBr_3$(Ce) based spectrometry systems are also considered. Special attention is paid to stabilization of the spectrometers' performance providing their operation within a wider temperature range.

Discussed is the radiation monitoring spectrometry equipment based on $LaBr_3$(Ce) and designed for various application areas such as:

- monitoring of spent nuclear fuel in water pools;
- monitoring of underwater radioactive waste;
- monitoring of aerosol radioactive pollution in the atmosphere;
- environmental monitoring of territories polluted by radioactive waste and their free release.

YAG:Ce MICRO- AND NANOSTRUCTURED POWDERS – TECHNOLOGICAL CONSIDERATIONS

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Yttrium-aluminium garnet doped with Ce^{3+} ($Y_3Al_5O_{12}$: Ce^{3+}) is a well-known luminescent material used in various fields. YAG:Ce (and close compounds) powders, consisting of dense transparent particles, are well-known solid state lighting phosphors. As the material possess scintillator properties, it can be used for phosphor screens. Nanostructured powders are starting materials for ceramic scintillators. As this is a well-studied composition, it could be used for model objects in studies of complex oxides with garnet structure.

The microstructure of powders with a garnet structure significantly influences optical and luminescent properties of the powders themselves and the materials obtained on their basis, as well as the density of the ceramic materials obtained from them. Another important technological factor for obtaining materials based on YAG:Ce is presence of impurities, which influence luminescence properties.

Co-precipitation method from nitrate solutions is used in this work to obtain YAG:Ce powders; NH_4OH and NH_4HCO_3 are used as precipitants. The precipitates are subject to subsequent separation, washing, drying and heat treatment in the temperature range 1000 –1600°C. When using NH_4OH as a precipitant, dense luminescent pieces of xerogel consisting of 20 nm particles forming agglomerates with a size of several tens of microns were obtained, and when using NH_4HCO_3 solution precipitate powders with a primary particle size below 100 nm, forming less dense agglomerates of 1–20 microns in size were formed. Co-precipitation approach to synthesis is technological and allows the production of powders with controlled particle sizes and the required characteristics. However, the process is to be fine-tuned, because parameters of each stage of synthesis can influence on the principal characteristics of the powder: the size and shape of the primary particles, their transparency, size and porosity of aggregates and grains formed during heat treatment.

The microstructure was investigated depending on the type of precipitant, the heat treatment temperature, the concentrations of solutions, mixing regimes during the synthesis, drying conditions and other technological parameters. Powders were studied by optical, scanning and transmission electron microscopy, X-ray diffraction, laser diffraction. The effect of impurities of rare-earth, alkaline, alkaline-earth and 3d elements on the luminescent characteristics was studied as well.

EVIDENCE OF THE LIGHT YIELD ANISOTROPY FOR SMALL *P*-TERPHENYL SINGLE CRYSTAL

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Monoclinic crystal lattice is typical structure for the most of organic single crystals. It is characterized by different values of translations along the axes ***a***, ***b***, ***c***. In particular, the values of crystal lattice translations for *p*- terphenyl single crystal are as follows: ***a*** = 8.12 Å, ***b*** = 5.62 Å, ***c*** = 13.62 Å. The most common organic single crystal scintillators of cylindrical shape that are grown from melt by the Bridgman method have cylinder base plane, which is orthogonal to the axis ***c***. Usually this plane coincides with the photodetector plane. However, it was unknown whether passage of light splashes along the ***c*** axis is optimal for receiving maximum values of the technical light yield The purpose of given investigation was to study the possibility to derive the light yield as large as possible from *p*-terphenyl single crystal by measuring scintillation signals along all three crystalline axes.

In order to investigate anisotropy in scintillator technical light yield we manufactured cubic sample of *p*-terphenyl single crystal doped by 1,4-diphenyl 1,3-butadiene with dimensions of 6×6×6 mm^3. The sides of this cubic sample have been oriented along the crystallographic axes ***a, b*** and ***c***. The orientation was carried out using a laser beam emitting in the red spectral region.Two series of experiments have been done. In the first series the sources of monoenergetic conversion electrons, radioactive isotopes ^{137}Cs and ^{207}Bi, were arranged in such a way that β-particles flown almost in parallel to the plane of the silicon photomultiplier with an active area of 6×6 mm^2. Energy spectra of β-particles and characteristic X-ray radiation from ^{137}Cs and ^{207}Bi isotopes, registered along the crystallographic axes ***a***, ***b*** and ***c,*** are shown in Fig.1. In the second series of experiments, particle beams flown mainly orthogonally to the photodetector plane.

Results of investigations shown the best technical light yield of the scintillation detector based on the *p*- terphenyl single crystal of regular shape registered when a scintillation signal derived along the ***b*** axis of its crystallographic lattice. The difference in technical light yield values obtained along different axes of the lattice can reach ~ 2 ÷ 20%, depending on the position of an ionizing radiation source relatively to photodetector plane.

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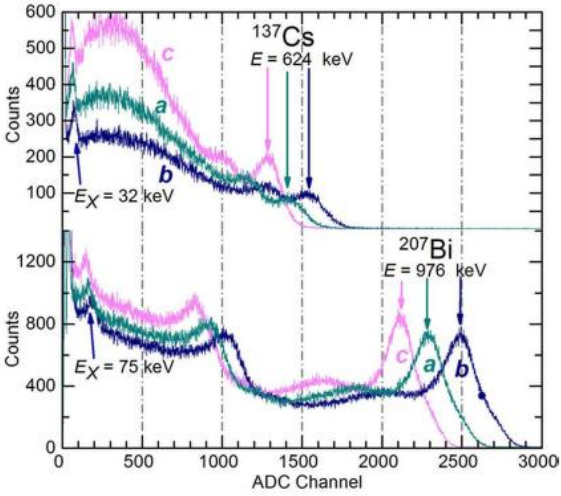

Fig. 1. Energetic spectra of β-particles and of characteristic X-ray emission from ^{137}Cs and ^{207}Bi radioactive sources when particle fluxes and photodetector plane are in parallel

SPECIFICS OF 3D-PRINTED ELECTRONICS

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3D printing – also known as additive manufacturing – offers number of benefits for production of innovative electronic objects that could not have been produced through conventional means. Electronics and parts manufacturers can improve their technologies such as: by printing on non-flat surfaces, have opportunity of mass customization, get lower material wastage, avoid usage of harmful chemicals, reduce product dimensions, and simplify assembly [1]. Additive technologies also vary by the type of materials they can use. The list of materials available for 3D-printed electronics is currently limited, but growing mainly due to development of new nano-materials.

In the contribution we will give concise review of 3D printed electronics opportunities describing benefits and challenges including design software, accuracy issues, temperature processing, adhesion problems, and suitable materials.

Then we will share our initial results of distributed high voltage resistor 3D-printing. Shape of the prototype resistor has been chosen as parallelepiped with truncated pyramids at the both ends serving as the contact adapters. Overall sample dimensions were 30×10×10 mm and its structure represents 3D lattice. ABS plastic filled by carbon fibers of various concentrations was used as material for the printing. Results of materials and prototypes characterization will be presented as well. Approach to the calculations of 3D resistor properties will be discussed.

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"FLUENCE-TO-DOSE" CONVERSION COEFFICIENTS FOR WHOLE BODY IRRADIATION GEOMETRY

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Reference conversion coefficients for effective dose and organ absorbed doses for various types of external exposures were presented in the 116 Publication of the International Commission on Radiological Protection [1]. As these coefficients were prepared by using the model of external beams of mono-energetic photons or particles and idealized whole-body irradiation geometries, they could not be used directly to assess doses of patients from conventional X-ray examinations. Therefore, for our software of X-ray dose assessments the computer codes DosesMale.nb and DosesFemale.nb were developed by our team for calculating organ doses and effective dose basing on Monte Carlo modeling results.

In order to validate the correctness of these codes the simulation of ICRP reference male and female phantoms whole body irradiation by a broad unidirectional photons beam was performed. Four types of irradiation geometry were considered: AP, PA, LLat and RLat. The modelling was made for mono-energetic photons with energy from 60 keV to 100 keV by means of MCNP code [2]. The energy deposition in critical organs and tissues was estimated. Fluence in free vacuum (without phantoms) was calculated also. "Fluence-to-dose" conversion coefficients were obtained on the basis of MCNP output data by the instrumentality of DosesMale.nb and DosesFemale.nb.

The results of comparison of calculated "fluence-to-dose" conversion coefficients with the reference ones from [1] showed quite good agreement for both phantoms. For example, the maximum relative difference for male phantom is observed for breast, and it is less than 7%. This discrepancy can be explained by the fact that we calculated the "fluence-to-dose" conversion coefficient only for mammary gland while authors of [1] most likely estimated these coefficients for the whole breast, including glandular and adipose tissues.

For the female phantom the largest differences were observed for esophagus. In the range of photons energy from 60 keV to 100 keV they are more than 15% for AP and PA projections, and exceed 30% for lateral projections. This circumstance can be connected with the fact that reference conversion coefficients were estimated on the basis of results obtained by averaging,

smoothing, and fitting different Monte Carlo radiation transport codes, while our results were drawn only from MCNP data.

For most other organs of both phantoms the relative difference did not exceed 5% and was within the statistical error of the simulation.

The abovementioned comparison confirms the correctness of DosesMale.nb and DosesFemale.nb calculations. Thus, these programs can be used for further estimation of radiation doses of patients' critical organs and tissues from conventional X-ray examinations.

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PERFORMANCE OF FBK SILICON PHOTOMULTIPLIERS IN FAST TIMING APPLICATIONS

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In this contribution, we report the recent achievements of FBK SiPMs in fast timing measurements for medical and high-energy physics applications. We describe the measurement techniques and we discuss the possible future prospects.

First very promising measurements have been done with "old" FBK RGB and NUV SiPM technologies, between 2013 and 2015. Starting from these, we developed the high-density SiPM technologies, with smaller cell pitch but higher detection efficiency [1, 2]. RGB-HD has peak sensitivity at 550 nm, whereas for NUV-HD the sensitivity is peaked at 420 nm. Generally, FBK HD SiPM technologies show a very high peak photodetection efficiency, of more than 50% with 30 μm cell pitch. Further improvements in the SiPM fabrication, regarding the substrates, the trench technology and the microcell edge effects, allowed to reduce the primary and correlated noise components, thus increasing the signal to noise ratio in the same operating conditions and extending the maximum operating bias of the SiPM.

The single-photon time resolution (SPTR) results obtained with FBK photodetectors (i.e. single SPADs and SiPMs) prove the capability of our technology to be successfully employed in fast timing applications. With 4×4 mm^2 NUV-HD SiPMs with 25 μm cell pitch, a SPTR of 180 ps FWHM was obtained [3], whereas the typical SPTR of a small SiPM is below 100 ps. The SPTR of a single SPAD is generally lower than 50 ps.

FBK SiPMs coupled to inorganic scintillators were extensively tested for time-of-flight positron emission tomography (TOF-PET) application. In particular, the coincidence time resolution (CTR) of 511 keV gamma rays was measured with several combinations of SiPMs and scintillation crystals. The impact of the photodetector operating parameters, as well as the scintillator geometry and the SiPM readout technique were studied and optimized to achieve the best time resolution [3-5]. SiPM technology improvement leading to a lower correlated noise proved to be very important in CTR results.

NUV-HD 4×4 mm^2 SiPMs with 25 μm cell pitch were tested optically coupled to 2×2×3 mm^3 LYSO:Ce and LSO:Ce,Ca pixels, resulting in a CTR FWHM of 87 ± 3 ps and 75 ± 3 ps, respectively. By using larger pixels, with a size of 3×3×20 mm^3, the time resolution was still as good as 137 ± 3 ps and

126 ± 2 ps, respectively [3]. Moreover, $CeBr_3$ pixels 4×4×5 mm^3 read out by 4×4 mm^2 NUV-HD SiPMs with 40 μm cell pitch achieved a CTR of 84 ps [6]. More recently, gadolinium aluminum gallium garnet (GAGG) pixels of size 3×3×5 mm^3 co-doped with Ce and Mg were tested coupled to RGB-HD 4×4 mm^2 SiPMs with 25 μm cell pitch, with a CTR of 165 ± 3 ps [7].

FBK SiPMs showed top-performance results also in high-energy physics applications. Timing measurements were performed by exposing NUV-HD SiPMs coupled to LSO:Ce,Ca 3×3×5 mm^3 to a 150 GeV muon beam, obtaining a CTR of $\sigma_t = 14.5 \pm 0.5$ ps [8].

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THE ELECTROMAGNETIC CALORIMETER FOR THE PANDA TARGET SPECTROMETER

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The future PANDA experiment with a next generation detector will focus on hadron spectroscopy. It will use cooled anti-proton beams with a momentum between 1.5 GeV/c and 15 GeV/c interacting with various targets. This allows to direct form all states of all quantum numbers and measure there widths with an accuracy of a few tens of keV. The experiment will be located at the exceptional Facility for Anti-proton and Ion Research in Germany, which is currently under construction.

The electromagnetic target calorimeter of the PANDA experiment has the challenging aim to detect high energy photons with excellent energy resolution over the full dynamic range from 15 GeV down to a few tens of MeV within a 2T solenoid. To reach this goal, improved $PbWO_4$ scintillator crystals, cooled down to −25°C have been chosen. They provide a fast decay time for highest count rates, short radiation length for compactness, improved light yield for lowest thresholds and excellent radiation hardness.

The target calorimeter itself is divided into a barrel and two endcaps. The individual crystal will be read out with two precisely matched large area avalanche photo diodes. In the very inner part of the forward endcap vacuum phototetrodes will be used instead.

The talk will give an overview of the PANDA experiment and focuses on its calorimeter including the scintillator material and its production status. Furthermore, the construction and assembly procedure of the calorimeter will be presented.

TRANSIENT ABSORPTION TECHNIQUE AS A TOOL FOR CHARACTERIZATION OF SCINTILLATOR TIMING PROPERTIES

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The time resolution of radiation detectors required for future high-luminosity high energy physics experiments and medical imaging with better spatial resolution and lower irradiation dose is substantially better than that obtained up to now. The current development of photodetectors, especially of silicon photomultipliers, moved their time resolution well below 100 ps. Thus, the time evolution of luminescence in scintillating materials in general and the front of the luminescence response in particular gain the key importance for the time characteristics of scintillator-based radiation detectors. Excitation transfer processes in picosecond domain, which are difficult to trace in conventional cathodoluminescence spectroscopy experiments, become important for the fast performance of the detectors. In this report, we overview the capabilities of exploitation of nonlinear optical absorption to characterize these processes.

The study was performed in pump and probe configuration based on a femtosecond laser with its output split in two beams. The first beam was used for excitation of the sample under study. Application of harmonics generators and optical parametric oscillator allowed shifting and tuning the emission wavelength down to 211 nm and ensured selective excitation of different structural units in the crystal. The induced absorption due to nonequilibrium carriers generated by the pump beam was probed with a tunable delay by a white-light continuum generated by the second beam of the laser output. The resulting capability to follow the evolution of the nonlinear absorption spectrum in time enabled revealing the contributions of free carriers and the carriers at trapping centers and populating radiative centers.

The capabilities of the technique are illustrated by the current results obtained by studying self-activated scintillator led tungstate Pb_2WO_4 (PWO) and Ce-doped garnets GAGG:Ce, YAGG:Ce and oxyorthosilicates LSO:Ce and LYSO:Ce, which are currently considered to be prospective scintillators in fast radiation detectors. It is shown that the optical pump and probe measurements might be useful for fast nondestructive selection of scintillation crystals before fabricating the radiation detectors.

NEW COMPOSITE DETECTORS FOR MEDICAL X-RAY DIAGNOSTICS

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Development of cost-efficient radiation detectors is an actual requirement. Composite materials based on scintillation granules are an alternative to structured 0.2 mm-thick CsI:Tl films and allow producing inexpensive large area detectors for medical diagnostic, security systems and portal monitors [1]. In this work scintillation composite detectors for formation of medical images in dental and mammography were developed.

Design of detectors were based on CsI:Tl, ZnSe:Al, Gd_2O_2S:Pr, $CeGd_3Al_{2.5}Ga_{2.5}O_{12}$:Ce and $Y_3A_{1.25}Ga_{3.75}O_{12}$:Ce composites applied directly onto CMOS sensors or photodiode array. Selection of scintillators was due to high light output and density, spectral passing to range of sensitivity of photosensors, low hygroscopicity, high performance and commercial availability. During detector development such parameters as refractive index *n* of granules and binder, size and shape of granules, uniformity and concentration of granules, optimal thickness of the composite were considered.

It was found that transparency of composites based on granules and binder with similar refractive indexes is close to transparency of bulk material (e.g. LiF granules n = 1.39 and siloxane binder n=1.40). This is due to reduction in number of light scattering boundaries in volume of composite. Scintillation granules (n = 1.79–2.61) and siloxane and epoxy optical binders (n = 1.40–1.76) were used for composite fabrication.

Optical transmission of composites, binders and original single crystals was measured using Shimazu UV-2450 spectrophotometer within 190–800 nm spectral range. Stand for measuring of relative light output of composites under x-ray irradiation (40–100 keV) was used. Optimal materials of scintillation granules and binder for composite fabrication were determined. It was found, that transparency and light output of composites are increased when the difference between refractive indexes of scintillation granules and binder are decreased.

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RENORMALIZATION OF ATOMIC CRYOCRYSTALS LUMINESCENCE SPECTRA STIMULATED BY EXCITONICALY INDUCED DEFECT FORMATION

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The fundamental excitation of non-metallic solids by photons and beams of particles with kinetic energy below the threshold of knock-on of atoms from lattice sites – subthreshold excitation – is a powerful tool for materials modification [1]. The scission of the bonds, stabilizing the ground-state configuration, by transfer of electronic excitation energy to the lattice requires the trapping or self-trapping of the electronic excitations. However the range of materials which exhibit inelastic processes induced by electronic excitation is limited to specific classes of materials, such as alkali halides, alkali earth fluorides and fused quartz. Recently the atomic cryocrystals – solid xenon, krypton, argon and neon – manifests themselves as a new class of insulators, which demonstrates pronounced excitonically induced defect formation and desorption processes [2]. As a consequence of the closed electronic shells, atomic cryocrystals are the simplest solids known to us with smallest binding energy between atoms in the lattice. On the other hand, solid argon and neon have band-gap energies exceeding that of LiF and may be cited as widest band-gap insulators. Therefore, atomic cryocrystals – the model systems in condensed matter physics – are very promising systems for investigation the mechanisms of subthreshold inelastic electronically induced processes.

Because of strong interaction with phonons the excitons and holes in atomic cryocrystals are self-trapped, and a wide range of electronic excitations are created in samples: free excitons (FE), atomic-like (A-STE) and molecular-like self-trapped excitons (M-STE), molecular-like self-trapped holes (STH) and electrons trapped at lattice imperfections. Radiative decay of these excitations forms the wide range of luminescence bands in the luminescence spectra of atomic cryocrystals. The STE-luminescence is a sensitive tool for investigation of a local surrounding of the STE-center. It was used as a short-range probe in studies of defect formation induced by electronic transitions and creation of charged centers in atomic cryocrystals.

The photoluminescence experiments were carried out at the SUPERLUMI experimental station at HASYLAB, DESY, Hamburg. Selective photon excitation was performed with $\Delta\lambda = 0.2$ nm. The luminescence was spectrally dispersed

with 0.5 m Pouey monochromator with $\Delta\lambda$ = 2 nm. In luminescence spectra of atomic cryocrystals the *M*-band is formed by radiative decay of molecular self-trapped excitons (*M*-STE). The interplay of various subbands of *M*-band as a result of selective photon excitation of atomic cryocrystals in the energy range $E_1 < E < E_g$ (E_1 is the threshold energy for the defect subband excitation, E_g – the gap energy) allows to reveal the internal structure of various luminescence subbands and to recover the general scheme of branched relaxation pathways in which these subbands are formed.

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RADIATION HARD REFLECTORS FOR SCINTILLATION MODULES FOR HEP

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The main requirements for detectors for experiments of high energy physics are the possibility of overlapping large areas and stability of detectors parameters after radiation doses. Scintillation modules can be based both organic and inorganic scintillators.

One of the important element of the scintillation module is reflective coating. The criteria for selection the reflector are high reflection coefficient, radiation hardness (stability characteristics), light output nonuniformity, easy fabrication and use.

Diffuse and mirror reflectors are well known. Commonly diffuse reflectors consist of materials based on polymer materials, such as polytetrafluoroethylene, polypropylene, acrylic, epoxies with MgO, TiO_2 fillers. Reflection properties significantly depend on the ratio of the polymer base and filler. Today powder reflectors are practically not used because of technological limitation of such reflective coating. The goal of this work was development of reflective coating for high radiation dose.

In this work radiation-hard diffuse reflectors based on epoxy, acrylic and polysiloxane optically transparent polymers with powder fillers were developed. Reflection coefficients were more than 90% in the visible range. Reflective properties are not changed at integrated radiation dose of 6 Mrad. It was determined experimentally that developed reflectors can be used in the temperature range of -30°C to +60°C without degradation of mechanical properties. The nonuniformity of the light output distribution in these scintillation modules with developed reflective coating was determined.

RADIATION RESISTANCE OF SCINTILLATORS BASED ON DIAMOND MICROPOWDERS

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The main aim of work was estimating of resistance to electron irradiation with E= 8,3 MeV of scintillators, based on diamond micropowders. Luminescent methods was used for investigation of diamond micropowders and composite scintillators on their base. Diamond micropowders were synthesized in Institute for Superhard Materials using Fe, Co, Ni as the metal solvents of carbon at 1300–1900°C and 5–6 GPa. After synthesis, some powders were further annealed at 1100°C during 20 minutes in Ar atmosphere. Some powders were separated in magnetic field, and non-magnetic fraction of powder was used in further experiments. Radiation resistant polysiloxane elastomer Sylgard 184 was used as a binder for diamond composites fabrication.

Before irradiation the wide emission band of 480–650 nm with maximum of 520–530 nm are observed in luminescent spectra of diamond powders at T=300 K. There are emission of Ni-center with 484 nm phononless line and 503 nm line (H3 center) in spectra of cooled to T=77 K powders. The 488 nm center is typical for synthetic Ib-type diamonds grown from nickel containing melt-solvent of carbon by method of high pressure and high temperature. H3 center consists of two substitutive neighboring nitrogen atoms separated by a vacancy in neutral charge state (N-V-N). With increasing temperature from T = 77 K to T = 300 K, luminescence intensity of 484 nm center decreases approximately in 50 times, while intensity of H3 center almost does not change. As a result, emission of H3 center are dominated at T= 300 K. After electron irradiation with 50 Mrad dose, luminescence intensity of diamond powders decreased in hundreds times, and emission of 389 nm center connected with nitrogen-containing defects of interstitial type appeared.

Light output of composites based of diamond powders was compared with characteristics of reference YSO:Ce single crystal with light output taken as 100%. After electron irradiation with integrated dose 50 Mrad light output of diamond composites decreased by 6–10 times and was 0.2–3% of

reference YSO:Ce light output. The most radiation resistant composites were scintillators based on annealed "non-magnetic" diamond powders consisting of single and agglomerated crystals. Scintillators based on large non-annealed powders consisting of only single crystals had the least radiation resistance.

LONGETIVITY EVALUATION OF THE PANDA EMC AT FAIR

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The PANDA detector is a new detector system which will be installed at the international FAIR accelerator facility (Darmstadt, Germany) with a wide research program. One of the major detector components will be the Electromagnetic Calorimeter (EMC) in the target region based on second generation lead tungstate scintillation crystals (PWO-II) with significant improvements in light yield compared to the PWO crystals of the CMS experiment at the LHC (CERN, Swietzerland).

The operating temperature of the PANDA EMC was chosen as -25°C. At that temperature the light yield reaches a 3.5 times higher value relative to room temperature without significant contributions of slow components.

The main mechanism of the radiation damage in PWO is degradation of optical transmittance under ionizing radiation. The radiation induced damage of optical transmittance leads to light collection losses of full size PWO crystal and results in the degradation of energy resolution of the EMC in general. In particular, the impact is critical at low temperatures, when spontaneous recovery processes are suppressed or frozen. One of the approaches to minimize radiation induced damage and increase longevity in operation mode is the effect and the option for direct implementation into the calorimeter assembly of the stimulated recovery.

In this research we present an evaluation results of longevity of PANDA EMC.

CHARACTERIZATION OF POSITION SENSITIVE DETECTORS WITH POSITIONING ALGORITHMS TRAINED BY SIMULATED REFERENCE DATA

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High resolution dedicated PET scanners for brain imaging or preclinical studies with small trans axial field of view require scintillation detectors capable of recording point of interaction (POI) in 3D space. This allows minimization of degradation of spatial resolution in the area close to edges of the image caused by parallax effect. Recently several techniques which allows depth of interaction (DOI) reconstructing in detectors based on homogeneous and pixilated crystals were proposed. These techniques among others include advanced signal procession for one and dual side readout schemes where DOI information is encoded in light distribution on the output surface of scintillation crystal and consequently in the ratio of signals of position sensitive photodetector. In PET detectors with common size of no more than 50×50 mm^2 based on homogeneous crystals the light naturally spreads on the whole output surface and the width of light spread function (LSF) rapidly increases with thickness. In the detectors based on pixilated crystals the dependence of light distribution on DOI is provided by light sharing between pixels either by light guides between crystal and photodetector or intentional light leakage through the reflector between pixels.

POI reconstruction algorithms one can roughly divide on two intersectional classes. The older first class uses analytical approach based on empirical assumptions on the shape of LSF and its dependence on DOI. Usually, such algorithms produce images with linear distortions and requires additional correction steps based on calibration data from real detectors. The newer second class uses no apriory information about detector signals and completely relies on machine learning approach which uses experimental calibration data. In both cases the recording of calibration data is a complicated procedure which requires special equipment and usually time consuming. However, calibration data can be relatively easily obtained using simulation. The main idea of this work is to generate calibration data for several scintillation detector designs using GEANT4 toolkit, then use them to train POI reconstruction algorithms and finally measure performance of the detectors.

We characterize 15×15×20 mm^3 scintillation detectors based on both homogeneous and pixilated crystals with one side readout by Hamamatsu S13361-3050AE-04 SiPM. The homogeneous crystal has all polished surfac-

es, diffusive reflector on the surface opposite to the output window and diffusive reflector or black absorber on side surfaces. Pixilated detector is built from 3×3×20 mm^3 bars with all polished surfaces. The light sharing between pixels is controlled by scattering distance of the optical glue in septa. The POI reconstruction for each dimension is performed either by artificial neural network (NN) with 16 inputs, 2 hidden layers each containing 16 neurons and 1 output or by k-nearest neighborhood (kNN) algorithm with k = 5. Spatial resolution for each dimension for each variant of the detector is determined as the best value calculated using NN with several activation functions or by kNN algorithm.

The spatial resolution of the detectors based on homogeneous crystal is in the range of 0.9–1.2 mm in XY plane and 1.1–1.7 mm along Z axis. The correspondent values for pixilated detectors are – 1.4-2.2 mm in XY plane and 0.9–1.3 mm along Z axis. In all cases detectors show no signs of linear distortions in XY plane. However, in homogeneous detector severe linear distortions are observed in the region of 3–5 mm near the surface opposite to photodetector. This can be attributed to minimal dependency of signals distribution on Z coordinate of the POI in this region.

SUBSTITUTION PREFERENCES AND CHARGE COMPENSATION MECHANISMS OF ALIOVALENT IMPURITIES IN DIFFERENT GARNETS

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Aliovalent co-doping by optically non-active ions is one of the major tools to improve the time response and the light yield of various scintillator materials [1]. The positive role of co-doping of oxide materials by Ca^{2+} or Mg^{2+}, when substituting for 3^{+} lattice sites, was demonstrated in Ce-doped orthosilicates [2] and garnets [3] and related to transition of considerable fraction of cerium to the Ce^{4+} state. Monovalent impurities however may exhibit dissimilar behavior in various garnets; e.g. in LuAG:Ce Li^{+} ions substitute for Lu^{3+} sites favoring Ce^{4+} states, while in YAG:Ce they go mainly to interstitials reducing the amount of anion vacancies, for charge compensation [4].

In this presentation the functional role of aliovalent impurities (Li^{+}, Na^{+}, Ca^{2+}, Li^{+} + Ca^{2+}, Hf^{4+}) will be considered in several Ce-doped garnet compositions. Ce-free YAG crystals were studied to determine to what extent introduction of monovalent impurities can be efficient to decrease the trap density and improve transparency in the UV range and the radiation tolerance. All compositions were grown by the vertical Bridgman method. Measurements have included X-ray diffraction, optical absorption, response to irradiation (^{60}Co; 1-10 kGy) and radioluminescence decay.

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IMPROVEMENT OF LIGHT YIELD AND SPATIAL RESOLUTION IN SCINTILLATION COMPOSITES TRANSFORMED TO NANOFIBERS

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Earlier we developed composite scintillators from inorganic nanoparticles and organic phosphors with record combination of high light yield and nanosecond decay time. Preparation of long oriented nanofibers from these composites by centrifugation gave further improvement of scintillation light yield and rate of registration. The nanofibers have been formed due to superfast solidification of thin jets of the suspension from inorganic nanoparticles and solution of organic phosphor in toluene pushed out from quickly rotating substrate. The improvements of scintillation properties in nanofibers are explained by three main reasons. All electron excitations produced by relaxation of the energy of the initially absorbed gamma quantum are distributed along the fiber in a very narrow angular sector. The angular distribution of light photons which can be emitted by these excitations is rather narrow and directed along the nanofiber as well. Coincidence of highly anisotropic needle-like densities of electron excitations and localized virtual photons enhances essentially the probability of the light emission along the nanofiber like super-luminescence [1]. Moreover we found that fast solidification of nanofibers during centrifugation created modulation of their refractive index with periods of the order of the light wavelength. This modulation is ascribed to spatial oscillations of the density of inorganic nanoparticles captured by the jet of the suspension pushed out from the rotating substrate. Periodical oscillations of the refractive index along the fiber provide distributed feedback for emitted photons inducing further enhancement of light emission along the fiber. So the nanofibers provide enhancement and acceleration of scintillations.

Assembling of a matrix radiation detector from parallel oriented nanofibers improves significantly the percentage of scintillation light collected by photodetectors positioned at the ends of the fibers. This improvement of the light collection improves the energy resolution of scintillation detector. On the other hand the spatial resolution of this matrix is determined by the expansion of the amount of excited nanofibers occurred after initial absorption of the first gamma quantum by one of these fibers. For example for 20 KeV gammas the dimensions of the excited region will not exceed several mi-

crometers due to high density of inorganic nanoparticles. Hence the X-Ray microscope with micrometer resolution can be prepared by rather simple technologies. In addition to the matrix X-Ray detector from scintillating nanofibers a point X-Ray source should be used. In this case the scheme of an obscure camera will be applied excluding the necessity of any X-Ray optics. Resolving of rather complicated problem of X-Ray optics by this way provides constructing of X-Ray microscope in the nearest future using relatively simple technologies. This kind of X-Ray microscopy with micrometer resolution is actual for bio-medical applications where direct *in situ* microscopic observations of processes inside cells, vessels and other micro-components of living objects will clarify many bio-medical problems. On the other hand X-Ray microscopy of various solids in processes of their deformation, thermal or chemical treatments will be useful for development of many new technologies revealing kinetics of structural transformations, deformation mass transport, chemical reactions etc.

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BLINKING FLUORESCENCE OF CIS-AZOALKANES

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The nature of extraordinary broad fluorescence spectra of cis-azoalkanes, observed for the first time about half of century ago, is studied experimentally and a theory of the phenomenon is proposed. Such spectra are observed for many cis-azoalkane molecules of C_{2v} symmetry for which the excited state π^*-system is localized only on -N-N- group. Recent experiments showed that a) the spectrum of fluorescence which is times broader than that of absorption conserves the form and diffusivity of a longwave part while decaying in broad region of temperatures in vapor and condensed states, b) the longwave part of the fluorescence spectra is of negative polarization and the shortwave part is of positive one conserving in the decay, c) no significant influence of the fluorescence quencher and solute on the fluorescence spectrum has been noted. Nevertheless, the dual polarization does not match with the single 0-0 electronic transition for the fluorescence, as shown by the method based on the Frank-Condon principle [1], which almost coincides with the excitation transition. To explain the event, it has been applied the long ago proposed idea [2] that the asymmetric in nature -N-N- group *n*-electron excitation localized on nitrogen produces (n,π^*) state with π^*-system localized on both nitrogen but asymmetric in accordance with the excitation asymmetry. It was supposed that the asymmetry spontaneously migrates between nitrogen atoms. The simple tunneling theory of the event shows that the migration results in asymmetric splitting of the excited state level to two sublevels. Emission from the sublevels for C_{2v} symmetry molecules has opposite polarization and transition rules. Its shortwave part relates to absorption and longwave one is orthogonal. Modulation periods (for the migrating states overlapping integral S) of upper T_a to lower T_l sublevels are related as $T_a/T_l = (1+S)/(1-S)$. For the small asymmetry ($S \cong 1$) $T_l \cong 2\pi h/\Delta E$ (ΔE is splitting), so the emission is diffuse at high ΔE, besides the lower sublevel is about ΔE down, but the upper sublevel situated close to the ground level is manifested in absorption, but is slightly higher in energy. So far, no experimental contradiction is found for the proposed theoretical model.

Calculated charge density on nitrogens is the same for symmetric molecules, but it differs for the molecules asymmetrised by substituents, mostly if

the link is not covalent. The emission spectra are not so broad for asymmetrised molecules.

The presented model introduces the internal quantum state modulation revealed by emission. This mechanism must not be always accompanied by emission. For example, it seems that the tunneling barrier in -S-S-group will be lower than that for -N-N-group, so when the migration frequency and splitting are higher, energy of the lower sublevel will be nearby the ground level simulating internal conversion, as observed for non fluorescing *cis*-dithioalkanes.

The nature of the migration mechanism stimulation and a possibility of outer monitoring are very attractive for application.

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OBTAINING AND FUNCTIONAL CHARACTERISTICS OF Eu^{2+}-ACTIVATED SCINTILLATION MATERIALS ON THE BASIS OF CONGRUENT COMPOUNDS OF ALKALI AND ALKALINE EARTH METAL CHLORIDES AND BROMIDES

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Inorganic single crystalline scintillators have been used over the years to convert incident ionizing radiation into UV or visible photons. The main requirements for the scintillators used for radiation detection are: high light yield, good energy resolution, fast decay of scintillation light, low hygroscopicity and long-time phase stability. Now there are no scintillators meeting simultaneously all these requirements. This necessitates the searching for new materials with certain high functional parameters available for narrow applications.

In recent years, the attention of material scientists working on the development of new halide scintillators was focused materials activated with Ce^{3+} or Eu^{2+}. This communication discusses some results concerning new Eu^{2+}-activated scintillation materials of $AB_{1-y}Eu_yX_3$ common composition (A=K, Rb, Cs; B=Ca, Sr, X=Cl, Br, $0 \leq y \leq 0.1$) developed in Institute for Scintillation Materials of National Academy of Sciences of Ukraine. The single crystals were grown using the vertical Bridgman-Stockbarger method from charge preliminary synthesized by the solution method from the alkali metal halides, alkaline earth metal carbonates, europium (III) oxide and the corresponding commercial hydrogen halide acid. The distribution coefficients of Eu^{2+} at the directed crystallization in all the systems were shown by chemical analysis to be near 1.

Comparative studies of the operational characteristics (sensitivity to atmospheric moisture, light yield, energetic resolution and decay constant of scintillation light) were performed using the samples of $\varnothing$ 12 mm × 2 mm. It has been found that the best scintillation characteristics for all the obtained concentration rows are observed within y values of 0.05–0.08. The maximal

values of light yield of $ACa_{0.92}Eu_{0.08}X_3$ materials in the sequence A=K, Rb, Cs were observed for Rb-containing crystals: 38500 photons per MeV for $RbCa_{0.92}Eu_{0.08}Cl_3$ and 54000 photons per MeV for $RbCa_{0.92}Eu_{0.08}Br_3$. Somewhat lower light yield values were achieved for $KCa_{0.92}Eu_{0.08}Cl_3$ (34000 photons per MeV) and SrX_2-based materials: $CsSr_{0.95}Eu_{0.05}Cl_3$ (33400 photons per MeV) and $CsSr_{0.95}Eu_{0.05}Br_3$ (31300 photons per MeV).

As a rule, the materials based on the complex compounds possess lower sensitivity to the atmospheric moisture comparing with the materials on the basis of the individual alkaline metal chlorides and bromides. CsX-based materials have the lowest hygroscopicity among the studied ones and the hygroscopicity of the RbX-based materials is efficiently higher.

INVESTIGATION OF THE PROPERTIES OF THE HEAVY SCINTILLATION FIBERS FOR HADRON THERAPY MONITORING

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Recent development in the production of inorganic scintillators resulted in a variety of materials, many of which show excellent timing properties and large light yield. Moreover, due to large densities and effective atomic numbers, those materials are well suited for detection of a-few-MeV prompt gamma radiation, which is emitted as a by-product of hadron therapy. Additionally, when combined with modern silicon photomultipliers (SiPM), they allow compact and granular detector designs. Therefore, heavy scintillators seem to be promising candidates for prompt gamma imaging (PGI) detectors, such as Compton cameras.

In order to investigate properties of heavy scintillating materials for their potential use in hadron therapy monitoring, a dedicated test bench has been built. The study was focused on lutetium based crystals, including LuAG:Ce and LYSO:Ce. Additionally, recently developed gadolinium aluminum gallium garnet doped with cerium and magnesium (GAGG:Ce:Mg) was investigated. Examined samples had an elongated, fiber-like shape, with variable length and square cross sections. Moreover, in order to optimize performance of scintillators the influence of coating and coupling to the SiPM was investigated.

The following parameters of the materials were investigated: attenuation length of the scintillation light, light yield and timing characteristics. The study has shown that scintillating materials based on lutetium are promising candidates for applications in PGI. However, GAGG crystal, despite its excellent timing properties and large light yield, is unsuitable for some detector designs due to small attenuation length.

MULTI-ENERGY RADIOGRAPHY, PHYSICAL PRINCIPLES, APPLICATIONS

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The development of digital radiography has made it possible to create digital radiographic systems (DRS), heaving a radically new possibility (in comparison with the traditional film radiography capability) to separate the substances included in the control object by the effective atomic number Z_{eff}.

For more than 20 years of development was created a large number of CRS, using the principle of Dual-energy X-ray absorptiometry (DXA, previously DEXA). The method of two and multi-energy radiography is based on a significant difference in the energy dependence of the attenuation coefficient $\mu(E)$ for substances with different atomic number.

The article considers the possibilities and limitations for the three main areas of application of multi-energy DRS: medicine, security systems, non-destructive testing.

In the experimental part of the work, shadow radiographic images of various objects with Z_{eff} from 7 to 29 obtained in three energy ranges ($E_{1eff} \approx 30$ keV, $E_{2eff} \approx 60$ keV, $E_{3eff} \approx 100$ keV) are given.

Using various visualization techniques, shows the possibility of determining differences in the calcium content of bone tissue on the background of the muscle tissue (osteoporosis diagnostic) as well as the possibility of separating the "light" materials with Z_{eff} from 7.08 to 8.07 (simulators of explosives).

ISSUES OF CARBON DOPING IN GARNET SCINTILLATORS

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The work is motivated by the need for more fast and bright garnet-based scintillators for new high energy physics experiments at colliders and medical equipment. During recent years, garnets became among the most studied scintillators due to a drastic enhancement of light yield achieved in $(Lu,Y,Gd)_3(Al,Ga)_5O_{12}$:Ce. Meanwhile, the production process of YAG- and LuAG-based crystals is easier and less expensive compared to the multi-component garnets, and other methods to enhance light yield and accelerate luminescence decay in "simple" garnets should be explored. For example, fast emission of other emission centers can be studied, as the Ce^{3+} intrinsic luminescence lifetime in garnets is slow (>60 ns), and the fast d-f emission band of Pr^{3+} is located in deep UV.

In this work the optical and scintillation properties of YAG, YAG:Ce and LuAG:Ce crystals are studied at doping with carbon (C) ions. C is incorporated into crystals due to the crystal fabrication conditions under Ar+CO atmosphere. At least 200 ppm (~1 at%) of C have been registered in YAG. Colored as-grown YAG crystals are bleached after thermal annealing. This bleaching is irreversible, contrary to YAG grown under inert atmosphere (Ar). The bleaching can be attributed to C-related centers competing with oxygen vacancies for electron capture. The same annealing effects are observed with YAG:Ce and LuAG:Ce. The annealed YAG:C and YAG:Ce,C crystals possess a good radiation hardness.

YAG:C crystals, apart of exciton-related luminescence in UV-band possess a very fast emission of F^+-centers peaked at 400 nm with the decay time of 4–7 ns, and the highest ever published light yield (22700 phot/MeV). Meanwhile a drastic light yield enhancement of up to 28800 phot/MeV and a

good energy resolution of ~8 % at 662 keV is achieved in YAG:Ce,C crystals. The contribution of fast ~100 ns luminescence decay component in air-annealed YAG:Ce,C reaches 79 %. By analogy to YAG:C, the light yield enhancement in Ce-doped crystals is evidently related to formation of some C-related trapping centers competing with traps inherent to garnet lattice, such as antisite defects, or oxygen and Al^{3+} vacancies. Optical and scintillation properties of LuAG:Ce and other garnet scintillators at C-doping are explored as well.

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TOWARDS NEW PRODUCTION TECHNOLOGIES: 3D PRINTING OF SCINTILLATORS

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Currently, one of the most promising methods to produce complex ceramics is 3D printing. Three-dimensional printing has evolved into a paradigm shifting technology in recent years. Researchers attracted by the ability to design and replicate complex structures at home or in small laboratory conditions at prices lower than 10 K$.

Garnets are well-known scintillation materials with cubic crystal structure that allows for the preparation of transparent ceramics, which can prevent expensive single-crystal growth. Additionally, the low hygroscopicity, high radiation stability and high hardness of materials are beneficial for practical applications [1]. It has been recently shown, that Gd-containing garnets can be used as efficient fast neutron detectors [2]. Ceramics 3D printing gives additional possibilities for shaping of scintillation materials, and elaboration of sophisticated detector designs for different radiation types – neutrons in a wide energy region, gamma and X-rays.

The 3D printing begins from digital three-dimensional model; then this information is sent to the special machine. The machine considers the provided information as a blueprint and creates a solid physical body, usually through a layer-by-layer material deposition process. Under the term of 3D printing several completely different technologies are combined. The most commonly used 3D printing techniques for ceramic production are Fused Deposition Modeling (FDM, via extrusion) and Vat Photopolymerization (VP). FDM 3D printing is performed by the extrusion of a plastic filament through a thin nozzle, constructing a geometry layer-by-layer. VP approaches use UV light to selectively polymerize liquid inside a resin bath. Usually, as a source of UV light, laser (classical stereolithography, SLA) or digital OLED projector (Digital Light Processing technology, DLP) is used.

This review aims to note advances in 3D printing of ceramics. Technical limitations and practical challenges are emphasized and design considerations are also discussed. Also, we report our recent achievements in this field [3].

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LUMINESCENCE CHARACTERISTICS OF UNDOPED AND Ce^{3+} DOPED $LuAsO_4$ AND $LaAsO_4$

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The present study is focused on the prospects of using lutetium and lanthanum arsenates for detection of ionizing radiation. $LuAsO_4$ and $LaAsO_4$ are compounds of relatively high density (6.92 and 5.36 g/cm^3, respectively), which favours their scintillating applications. Moreover, Ce^{3+} doped arsenates could be expected to act as fast scintillators due to the fast decay of the dopant emission. However, the processes of energy transfer to the luminescence centre have to be paid a particular attention. To the best of our knowledge the luminescence properties of undoped or Ce^{3+} doped arsenates have not been studied so far. Here we present the results of electronic band structure calculations as well as luminescence studies of undoped and Ce^{3+} doped $LuAsO_4$ and $LaAsO_4$ powders. The samples were synthesized using the chemical co-precipitation method. An intrinsic emission was detected at $T < 200$ K in undoped samples and ascribed to the radiative decay of self-trapped excitons. Cerium doping results in the appearance of the emission band peaking at 420 nm, which is attributed to the 5d – 4f transitions in Ce^{3+}. However, the intensity of the dopant emission under high-energy excitation is low, supposedly due to a low efficiency of energy transfer from the host to the Ce^{3+} emission centres. The bandgap values were estimated as 6.04 eV for $LaAsO_4$ and 6.35 eV for $LuAsO_4$. A relatively intensive hot intraband luminescence was detected in $LaAsO_4$. The differences of the intraband luminescence in $LaAsO_4$ and $LuAsO_4$ are discussed based on the features of the electronic band structure. General conclusion is done that arsenates are promising compounds for application as ultrafast scintillators.

INFORMATION TOOL FOR SUPPORT ACTIVITIES IN SUPERVISION FOR NUCLEAR AND RADIATION SAFETY

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The purpose of the project considered is to create an information tool for effective control (supervision) of ensuring safety during construction and commissioning of the Belarusian NPP, as well as in the field of radiation safety of nuclear material, nuclear waste and ionizing radiation sources. The following problems are solved within the project realization: providing quick access to the necessary information, simplification of creation, acceleration of receiving and increase of safety of information and data on control in the field of nuclear and radiation safety. All this leads to formation of conditions for the exchange, accumulation and preservation of information, data and knowledge at a level that ensures the safe, stable and efficient development of nuclear industry of the Republic of Belarus.

Let us consider this information tool eLab-Control. It was developed for Department for Nuclear and Radiation Safety of the Ministry for Emergency Situations of the Republic of Belarus (Gosatomnadzor). Gosatomnadzor is the belarusian regulator in the field of nuclear and radiation safety. Software eLab-Control is a number of integrated applications with a single interface forming the intellectual information system of the Gosatomnadzor employee.

Framework eLab [1] that is the basis of eLab-Atom was developed initially for the implementation and harmonization of the electronic document management of accredited testing laboratories in accordance with international ISO/IEC 17025, ISO 9001 and ISO 9004. It has a client-server architecture based on free software: Debian GNU/Linux, Web-server Apache, Firebird database server, PHP application server. The system runs under Windows and Linux operating systems. The work is carried out through the Internet in multiplayer mode, with the division of access rights by way of widespread browsers: Internet Explorer, Mozilla Firefox, Google Chrome, Opera etc.

Features of proposed software are the next. It is open to modifications by users and is easily adjusted to the specifics of each individual project. System runs on a secure server. It is not required to install some software on the client computer. It is sufficient only a standard browser. System can operate

both on a local intranet, or the global Internet. Software has customizable user interface and ensures the preservation of its current state.

A virtual private network (VPN) instrument is implemented to improve safety in the system. It allows for users to work across shared or public networks as if their computers were directly connected to the private network. So, there is the guaranteed level of security during the operation of the system.

Some useful instruments were realized in the system such as full-text semantic search for documents and generator of reports allowing to vary forms of different reports prepared in the system.

Framework eLab on the whole, as well as eLab-Control in particular, can be easily customized for varied needs and can be implemented in different applications.

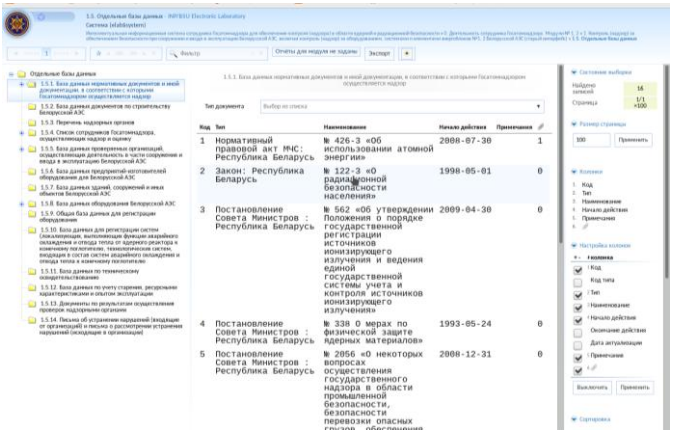

Fig. 1. Screenshot of eLab-Control

1. Sytova S.N. et al. Information system eLab for accredited testing laboratories. Informatics (2017), N.55. P.49-61

TRANSIENT PHENOMENA IN SCINTILLATION MATERIALS

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In view of the current quest for substantially better timing properties of radiation detectors, the excitation transfer in scintillating materials becomes a hot topic. The influence of trapping of nonequilibrium carriers on the excitation transfer through the crystal matrix to the radiative centers is on the focus of this report. The results obtained by studying the optical absorption of nonequilibrium carriers are discussed. The pump and probe configuration exploited in this study enabled selective excitation of different energy levels in the matrix and activator ions. Probing the nonlinear absorption by a variably delayed white light continuum ensured the measurement of the evolution of absorption by free carriers and the carriers populating traps and radiative recombination centers in subpicosecond domain.

Due to a good combination of radiation hardness, light yield, matching to the sensitivity spectrum of silicon photomultipliers and fast luminescence response, single crystals of Ce-doped garnets $Gd_3Al_2Ga_3O_{12}$ (GAGG:Ce) and oxyorthosilicates Lu_2SiO_5:Ce (LSO:Ce) were studied. As reported before, the timing properties of these scintillation materials are considerably improved by codoping by divalent ions. To better understand the influence of the alio-valent codoping of these scintillators on the excitation transfer, GAGG:Ce and LSO:Ce codoped with Mg and Ca were studied.

The comparison of the response to population of the excited Ce^{3+} levels below and above the conduction band shows that the delay in luminescence response is related to electron trapping. The introduction of divalent Mg into the matrix of GAGG:Ce facilitates the transfer of nonequilibrium electrons to Ce^{3+} ions and makes the luminescence response faster, though the light yield is slightly decreased, since Mg-related defects act also as nonradiative re-combination centers. Electron trapping is also observed in LSO:Ce, where codoping by divalent ion results in the improvement of both time response and light yield. A figure of merit to characterize the influence of electron trapping on the luminescence response time in different LSO:Ce crystals is suggested.

K-LONG AND MUON REGISTRATION SYSTEM OF THE BELLE II DETECTOR

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The K-long and muon registrations system, based on solid organic scintillator with WLS fiber light collection and SiPM read-out, for the Belle II experiment have been proposed, designed, produced, installed, and tested. A few simple improvements in the strip production technology which allow significant increases in the light collection efficiency have been developed, thus increasing the efficiency and robustness of the entire detector. The new system should work efficiently at background rates and radiation doses < 100 times larger than those observed for the Belle experiment. As demonstrated by many tests, the system has sufficient robustness to operate well in a strong magnetic field and high radiation and interaction environment with no significant degradation anticipated after many years of data taking. While this system was designed for a particular experiment, namely Belle II, our study can be applied to the construction of muon systems in many experiments.

INVESTIGATION OF MICROSTRUCTURE OF IRRADIATED MULTILAYER ZrN/Si_3N_4 THIN COATINGS REVEALED BY X-RAY DIFFRACTION TECHNIQUES

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The development of structural materials for nuclear applications is an essential part of materials research. The study on radiation tolerant coatings is a perspective trend in the design and engineering of materials exposed to radiation. The nitride-based ceramics (TiN, ZrN, CrN) are often used as protective coatings due to its specific combination of properties suitable for the application in reactors: high melting point and hardness, stability under elevated temperatures, etc. Radiation environment induces different kinds of damages in the materials, which results in their degradation. The appearance of point defects is one of the manifestation of such damages. The presence of interlayer boundaries proved to be very effective in reducing the number of such defects.

The use of the materials in nuclear applications requires the evaluation of the effects of radiation damage. In the present study, we consider multilayer thin coatings ZrN/Si_3N_4 with different thicknesses of monolayers, both unirradiated and irradiated by He^+ ions. In order to estimate the effect of radiation on these coatings, we investigate the modification of microstructure before and after irradiation.

X-ray diffraction (XRD) [1] is an effective technique used for structural characterization of materials. The change in the microstructure affects the shape of the measured diffraction profiles. Due to the presence of texture (preferred orientation of crystallographic structure), performing the measurements in coplanar geometry (e.g. conventional $\theta/2\theta$ scan) turns out to be not effective: it does not enable to obtain a sufficient number of Bragg reflections for a reliable analysis. In order to perform more comprehensive and reliable analysis of microstructure, it is necessary to use more Bragg reflections. The performed X-ray measurements have been analyzed using

specific theoretical methods of analysis. The diffraction profile broadening is found to be conditioned by a small grain size and instrumental function. The measured profiles are combined into a single scan for the simultaneous fitting by a theoretically simulated curve. As a result, the microstructural parameters of multilayer coatings have been evaluated, which are in a good agreement with those obtained from high-resolution and scanning transmission electron microscopy (TEM) images. Comparing the results of XRD analysis and those retrieved from TEM images for unirradiated and irradiated samples, it was revealed that the microstructure of investigated samples is proved to do not undergo a significant change under the irradiation process.

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PHYSICS OF FAST PROCESSES IN SCINTILLATORS

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Development of new generation of accelerators for high energy physics with extremely high luminosity and new demands from medical imaging with PET requires fast scintillators with response of 10 picoseconds. During last few years the physics of fast processes in scintillators attracts attention of the community. These processes include (1) fast emission which occur in parallel with relaxation of electronic excitations (intraband luminescence, crossluminescence and other types of hot emission), (2) fast energy transfer to activators and new ways of fast creation of emission centers like capture of an electron by Ce^{4+} ions, (3) excitonic and bi-excitonic emission in semiconductors like ZnO, (4) reduction of radiative lifetime due to increase of oscillator strength in nanocrystalline systems, and some other phenomena. The presentation reviews the formation of scintillating signal in such systems.

This research is carried out in the frame of Crystal Clear Collaboration and is supported by a European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie grant agreement No 644260 (INTELUM) and COST ACTION TD1401 (FAST).

GAMMA RADIATION EFFECTS ON STRUCTURAL AND OPTICAL PROPERTIES OF Eu-DOPED $(Y_{0.7}Gd_{0.3})_2O_3$ SCINTILLATORS

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Eu^{3+} activated $(Y_{1-x}Ln_x)_2O_3$ (Ln=Y, Gd, Lu) phosphors are widely used as commercialized scintillators in medical and industrial scanning applications, with high performance and attractive properties. In this work, effects of high-energy radiation on luminescence properties of $(Y_{1-x}Gd_x)_2O_3:Eu^{3+}$ powders with different particle sizes in the nanometric range are analyzed. Powders were prepared by polymer complex solution route, followed by annealing. Samples were exposed to gamma-irradiation (doses up to 4 MGy) on a commercial gamma-irradiation plant. The effect of irradiation on different particle size is followed by XRD, SEM and monitoring their luminescence properties. Analysis of radiation effects on luminescence has been carried out under UV excitations in all samples. No change was observed in structure, morphology and steady-state emission. On the opposite, after irradiation excited-state lifetimes and quantum efficiency values are particle size dependent.

X-RAY SECURITY SCREENING SYSTEM FOR INTROSCOPY OF HEAVY VEHICLES

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ADANI has a more than 20 years experience in development and production of X-ray equipment for security systems, medical diagnostics, non-destructive analysis and analytic instruments. Among security screening systems produced by ADANI are: CONPASS - low-dose people X-ray screening systems, BV – systems for parcels, baggage and small cargo inspection and DTP – systems for cargo and vehicle inspection.

The most expensive parts of any screening system are X-ray source and detection sub-system. Up to now, ADANI imports thousands of detector every year from Europe and China. To reduce a dependence from importation and a cost of an end-product ADANI initiated a series of R&D projects.

The recently developed screening system contains a pulse radiation source with an energy up to 8 MeV (betatron) and a pulse repetition rate from 300 to 400 Hz, a set of highly sensitive radiation detectors (up to 2048 detectors can be installed), a subsystem for control and data acquisition, appropriate interfaces and software. The system has a penetration capacity of up to 350mm of steel equivalent and a spatial resolution on the wire of 3 mm.

A feature of the system is an increased sensitivity due to the accounting of the pulse nature of the betatron radiation and its high duty cycle. To do this, an additional pre-amplifier is introduced, which contains low and high-pass filters with optimally selected bandwidth. It allowed to increase the gain without increasing the noise. Due to the high pulse duty cycle, one can use CsI(Tl) scintillation crystals without deterioration of the image contrast, since our studies have shown that at a duty cycle greater than 400, the afterglow effect does not exceed 0.1% of the signal level. To increase the speed of transmission from the detection units to the computer, the original scheme was used, which allowed to increase the number of detection units to 64. The block diagram of a security screening system is shown in Fig. 1. A pilot series of detectors is under production now.

The report provides information on the tests of the security screening system elements and the results achieved.

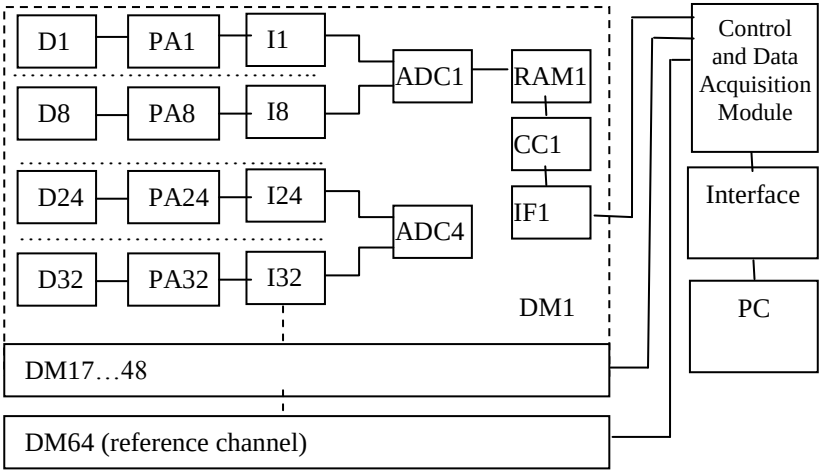

Fig. 1. Block diagram of a security screening system: D – detection cell (scintillator + photodiode), PA – preamplifier, I – integrator, ADC – 20 bit ADC, CC – control circuit, IF – interface of detection module, DM – detection module

DEVELOPMENT OF X-RAY GENERATOR OF 80 TO 160 KEV ENERGY AND 1.2 MA CURRENT

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ADANI is a high-tech innovation center working in field of X-ray equipment for various applications such as security systems, medical diagnostics, non-destructive analysis and analytic instruments.

ADANI produces a wide range of security screening systems. Among them: CONPASS - a family of low-dose people X-ray screening systems, BV – a family of equipment for parcels, baggage and small cargo inspection and DTP – a family of equipment for cargo and vehicle inspection.

A core and very expensive part on any of these apparatus is a source of X-rays.

For many applications an X-ray generator with an energy of 80-160 keV and current up to 1.2 mA is sufficient. ADANI have to import hundreds of such generators every year from United States and China.

All such generator have similar structure, which includes a voltage source + 400 V with a power factor corrector, positive and negative polarity voltage multipliers for feeding an anode and a cathode of the X-ray tube, a tube heating regulator, a voltage control circuit for the tube and its heating current, voltage and current measurement elements with data output via the interface on a computer.

Recently, ADANI engineering team has developed a similar X-ray generator. During R&D work we have developed electric schematic diagrams of the generator subunits, the mechanical design, software, methods for parameters control. Our generators have very competitive cost in compare with budgetary analogs of other producers, but its parameters are seriously improved. A series of confirmed good performance of the developed generator was performed. Achieved characteristics are closer to high-end expensive products of the world leading producers, rather than to budgetary units. Fig. 1 presents experimental curves of the dose rate vs tube voltage at different current.

A pilot series is under production now.

The report describes the details of the construction of all principal parts of the generator, software interface and results of the tests.

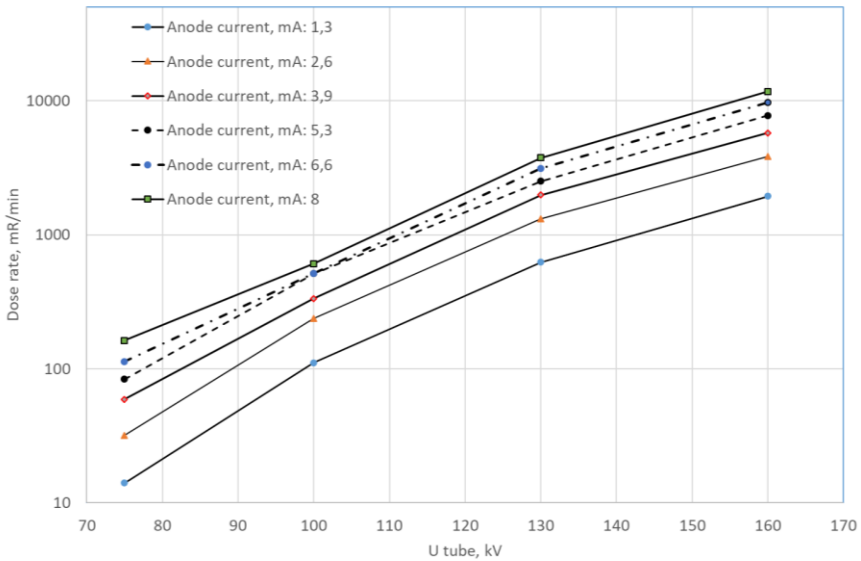

Fig. 1. Experimental curves of the dose rate vs tube voltage at different current

PLASTIC SCINTILLATORS WITH THE IMPROVED RADIATION HARDNESS LEVEL

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Modern experiments in high-energy physics put forward increased requirements for radiation resistance to the detecting devices used. Plastic scintillators are widely used in experiments on high energy physics in creation of various types of veto systems, calorimeters.

A traditional plastic scintillator based on polystyrene has the radiation hardness level of several Mrad. It is well known, that during irradiation in the polymer base of the plastic scintillator, some radicals are created that form various centers of energy capture, in consequence of various chemical transformations. The spectral region of the formed capture centers extends from 300 nm to 500 nm, that leads to significant decrease of the light output of plastic scintillators.

To preserve the properties of the plastic scintillator (PS) under the influence of irradiation, it is necessary to reduce the radical lifetime as much as possible, and to shift the main luminescence band of the plastic scintillator to the longer wavelength spectral range where the polymer base will retain its transparency.

The shorter life time of radicals can be achieved by adding various types of diffusion enhancers into the polymeric base of the plastic scintillator, as a consequence the mechanical properties of PS are significantly degraded. To preserve them, it is necessary to "crosslink" the polymer backbone, at the same time. By this way it is possible to achieve a level of radiation hardness up to 12 Mrad. But at the same time, the technology of manufacturing bulk plastic scintillators becomes very complicated.

Therefore, the most acceptable approach to the creation of radiation-resistant plastic scintillators is associated with the possibility of using activators with the long length of Stokes shift, for example, with 3HF (trihydroxyflavone) molecules. PS activated by only 3HF molecules increase the radiation hardness level of the PS almost twice. It turned out that the modification of 3HF molecules by fluorine atoms, contributes to improvement of radiation resistance of the PS, created on their basis.

It was shown that with increase of replacement of hydrogen atoms by fluorine atoms in the 3HF molecule, the radiation hardness of the plastic scintillator increases too. And with a fourfold substitution, it was possible to reach the level radiation hardness level of 20 Mrad, without using various kinds of additives to increase the mobility of radicals. This approach opens the way for the production of large-scale radiation-resistant plastic scintillators.

METHOD FOR NUCLIDES MIX IDENTIFICATION IN ANALYSIS OF GAMMA RAY SCINTILLATION SPECTRA

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Measurement of gamma-emitting radionuclides in environmental materials is an important task of applied scintillation spectrometry. Its solution is based on the identification of gamma-emitters forming the experimental spectrum. The fundamental difficulty of multicomponent radiometric measurements is due to the nontrivial form of the spectrum of scintillation detectors and low energy resolution.

The experimental spectra of the samples under study are often so complex that their decipherment with the aim of quantifying the content of radionuclides becomes unlikely. Moreover, there are problems of manufacturing standard samples and the formation of a catalog of calibration spectra and a sensitivity matrix for all radionuclides to be radionuclide controlled in a given measurement geometry. A generally accepted solution is the simulation of elementary simulated spectra for given isotopes by the Monte Carlo method with experimental verification of their correspondence to real distributions. Verified simulated spectra can be used not only to determine the metrological parameters of equipment, but also to develop algorithms for identifying the nuclide composition of complex sources.

A two-stage algorithm for identifying and determining the partial activity of radionuclides with a composition specified in the source is proposed. At the first stage, the matrix method of processing experimental spectra is used, which is distinguished by replacing the system of linear equations by inequalities with respect to the count rates observed in selected energy intervals, taking into account the statistical error.

The system of inequalities is supplemented by the coupling equation (criterion function) with respect to the partial count rates with some weight coefficients. Solving the problem of finding extremums of the criterion function using the simplex method, we find the expected scenarios of the presence of the most significant radionuclides in the mixture and their activities. The obtained results are checked and refined at the next stage of the algorithm by reconstructing the experimental spectrum using the simulated spectra and the main parameters of the full energy peaks constituting the multiplets.

The use of the simplex method in the process of identification of complex radionuclide compounds (nuclear medicine, certification of radwaste, etc.) makes it possible to increase the capabilities of gamma-ray spectrometry based on scintillation detectors. The proposed method was tested using a gamma spectrometer based on a scintillation NaI (Tl) crystal with a size of Ø 63×63 mm for radiation monitoring of metals, where it is required to determine up to 15 radionuclides.

EXPERIMENTAL MANIFESTATIONS OF CsI:Na CRYSTAL HYGROSCOPICITY

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It is known that many scintillation materials are hygroscopic, first of all this concern the most effective of it. This circumstance significantly impairs the performance characteristics of scintillator. In practice the hygroscopic crystals are used after packing to housing that limits their application, for instance, impedes the detection of weakly penetrating radiation.

Hygroscopicity of materials is defined as: "the property of materials to absorb moisture from the air". Hygroscopicity is characteristic to substances which are well soluble in water especially for chemical compounds which form a crystal hydrate with water. CsI-based scintillator do not correspond this definition. The quantitative characteristic of hygroscopicity is an increase in the mass of the sample when stored under normal conditions. It is known that such changes are negligible for CsI-pure material as well as for CsI:Tl, $CsI:CO_3$ and even for CsI:Na. Nevertheless, the CsI:Na material is considered to be slightly hygroscopic, information on this is given in all reference publications. It seems that this term in scintillation technique implies the deterioration of the spectrometric properties of the surface layers of crystal. It is well known that CsI:Na crystals are not used for detection, for example, α-particles. This feature is associated with the formation of a dead layer (DL).

The nature of DL is somehow or other associated with the hygroscopicity of crystals. It was shown [1, 2], however, that DL is formed upon aging of CsI:Na crystals in a dry atmosphere or deep vacuum. The mechanism of DL formation is diffusive and consists of two stages. The DL itself as a full loss of detection efficiency is formed at second stage after sodium diffusion to the free surface, approximately after 6 months of aging.

Manifestation of hygroscopicity is associated with the second stage of DL formation. Adsorption of water from air by crystal surface can be observed visually. If the aged scintillator is removed from the housing and placed in a humid atmosphere, its surface very quickly, literally before our eyes, will be covered with droplets of dew. Figuratively speaking, the sample "perspire", in fact, the water on the surface is not a droplet, but a pool of saturated NaI solution. Such picture can be observed after CsI:Na aged sample removing

from dry atmosphere. It turned out that all samples became wet, despite the fact that they were placed in plastic bags for temporary storage. The explanation for such focal hygroscopicity is precisely the formation of the NaI phase on the surface of the CsI crystal. It should be noted that when the crystals are stored under normal conditions, the sweating effect is not observed.

So, the hygroscopicity of CsI:Na crystal has a focal nature and can be observed visually but at specific conditions. Formation of liquid puddles on the boundary crystal–air course a negative change in surface relief. Further transformation of NaI to $NaHCO_3$ and water puddles to a loose coating course a change in reflectivity, its uniformity and in energy resolution. To prevent these negative changes it is sufficient to wipe the crystal surface dry before removing of scintillator from dry room. Another way [3] is consisted in application of hydrophobic protective coating on the crystal surfaces.

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OPTIMIZATION OF PHYSICO-TOPOLOGICAL PARAMETERS OF DUAL ENERGY X-RAY DETECTORS APPLIED IN INSPECTION EQUIPMENT

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The optimization task for physico-topological parameters of dual energy x-ray detectors applied in security x-ray systems is solved. The standard three-layer detector design "the first scintillator layer on silicon photodiode / x-ray filter / the second scintillator layer on silicon photodiode" was considered. There were variation parameters: various scintillator materials including CsI, ZnSe, Gd_2O_2S (GOS), ceramic GOS (CGOS) along with their thicknesses; various easy processed metals and metallic alloys for x-ray filter including elements from the third, the fourth and the fifth period of the periodic table of chemical elements along with the filter thickness. As for the inspected objects and their discrimination by the effective atomic number the most important materials from the security point of view were considered. Such materials are characterized by the value of effective atomic number in the range from 6 to 9 (drugs and explosives usually concealed by organic materials of domestic items).

Tungsten anode voltage, kV	Optimal materials of detector layers	First scintillator thickness, mm	Filter thickness, mm	Second scintillator thickness, mm
320	CsI/Cu/CsI	0.5	0.8	15
160–200	GOS/Cu/CGOS	0.2	0.6	2.5
	ZnSe/Cu/CGOS	0.5		2.5
	ZnSe/Cu/ZnSe	0.5		5
120–160	GOS/Cu/CGOS	0.15	0.5	2
	ZnSe/Cu/CGOS	0.35		2
	ZnSe/Cu/ZnSe	0.35		3.5
80–120	GOS/Cu/CGOS	0.1	0.4	1.5
	ZnSe/Cu/CGOS	0.25		1.5
	ZnSe/Cu/ZnSe	0.25		2.5

To solve the multiparametric optimization problem it was applied the standard approach of maximization of the single-valued figure of merit which is equal to ratio of the value of squared signal difference to noise ratio to the value of exposure dose on inspected object [1].

The numerical calculation results of search for figure of merit maximums are presented in the table. The table data generalize and precise the parameters referred in patent [2].

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BOOK OF ABSTRACTS

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