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JOINT INSTITUTE FOR NUCLEAR RESEARCH (RUSSIA)

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ISMART 2016

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Конференция посвящена проблемам регистрации ионизирующего излучения в различных областях – от физики высоких энергий до медицинской диагностики и систем радиационной безопасности. Мультидисциплинарность конференции позволяет объединить современные достижения фундаментальных и прикладных исследований, а также новейшие технологии и инженерные решения для разработки детекторов радиации.

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International conference ISMART 2016 in Belarusian State University is an important factor in the development of scientific relations in the field of nuclear engineering. Our country will soon become a producer of nuclear power. So, the establishment of educational, scientific and industrial relations in the field of development and improvement of equipment for measurement of ionizing radiation is relevant and meets the needs of high-tech development in the country.

We welcome the participation in the conference of experts from domestic and foreign production companies. It will strengthen the links between science and industry, the creation of new high-tech products.

We are optimistic about the future of science in this field in our country. I hope that the scientific topics discussed at the conference will contribute to the progress in the creation of functional materials for experiments on a new generation of colliders such as the LHC at high luminosity and FCC at CERN, as well as their use in the field of security, environmental monitoring and diagnostic systems.

The rector of the Belarusian State University
Academician S. V. Ablameyko

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PROGRAM

26.09.2016

14.00-20.00 Registration, INP BSU, room 200

27.09.2016

Chairman: Olshewski A.G.

***Plenary Session* (rectorate)**

10.00-10.10 **Ablameiko S.V.,** Rector of BSU. Opening of the Conference

10.10-10.20 **Grinyov B.V.**, Welcome from the International Organizing Committee

10.20-10.40 **Maksimenko S.A.,** INP BSU, INP BSU. 30 years of scientific activity

10.40-11.20 Coffee Break and Registration

Detectors and materials for radiation detection-I

11.20-11.50 **Vasil'ev A.N.,** SINP MSU, Microtheory of scintillation in crystalline materials

11.50-12.20 **Gektin A.V.,** ISMA, Scintillation development and production, wishes and reality

12.20-12.50 **Vasilyev M.A.,** Baker Hughes, Demand for a new instrumentation for well logging

13.00-14.30 Lunch and Registration

Detectors for high energy physics

***Plenary Session* (rectorate)**

Chairman: Korjik M.V.

14.30-15.00 **Shwartz B.A.,** Budker Institute of Nuclear Physics, Scintillation detectors in experiments on High Energy Physics

15.00-15.20 **Kulchitskiy U.A.**, JINR, ATLAS experiment and upgrade program

15.20-15.40 **Suarez Juan,** INP BSU, CMS-Experiment results and future plans for upgrade

15.40-16.00 **Dormenev V.I.,** Giessen University, Concept and performance of electromagnetic calorimeter of the PANDA detector at FAIR (GSI, Darmstadt)

16.00-16.20 **Tamulaitis G.,** Vilnius University, Fast optical phenomena in self-activated and Ce-doped materials prospective for fast timing in radiation detectors

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

Detectors and materials for radiation detection-II
Plenary Session **(rectorate)**
Chairman: **Gektin A.V.**

16.50-17.10 **Nikl M.,** Institute of Physics AS CR, COST Action TD1401: Nanocrystalline and nanocomposite scintillators for fast timing

17.10-17.30 **Zhmurin P.N.,** ISMA, Increasing the radiation resistance threshold of the plastic scintillators based on polystyrene

17.30-17.50 **Boyaruncev A.Y.,** ISMA, Scintillation element for HEP application

17.50-18.10 **Vedda A.,** University of Milano-Bicocca, Rare-earth doped silica-based optical fibers for high energy physics detectors

18.10-18.30 **Dosovitskiy G.A.,** IREA National Research Center "Kurchatov Institute", Raw materials for novel complex oxide garnet scintillators development

16.00-18.30 ***Poster session – High energy physics and materials for radiation detection*****(INP BSU, 3rd floor)**

Galunov N.Z., ISMA, Radiation-resistant composite scintillators for registration a large flux of ionizing radiation

Zosim D.I., ISMA, Some features of a homogeneous distribution of light yield along the elongated scintillator based on CsI (Tl)

Skoroteckiy M.S., ISPM RAS, Synthesis and properties of POPOP structura lisomersandtheirtrimethylsilylderivatives

Danilenko J.A., ISMA, Application of international standards in scinitillation equipment

Le H.T.Z., INP BSU, Initial ionization distribution in active volume of ionization chamber

Podshibyakin A.V., JINR, The control system, data collection and diagnostics beam mass separator MASHA

Vasilyev I.I., JINR, The light yield of a long scintillation strip with WLS fiber embedded into the co-extruded hole

Pushak A.S., Ukrainian Academy of Printing, Luminescent and scintillation properties of $K_2BaX_4:Eu^{2+}$(X=Cl, Br)

Yemialyanchyk I.F., INP BSU, Large Hadron Collider at high luminosity: large radiation damageof scintillators and a possible way of solving the problem

Svertilov S.I., SINP MSU, Energy resolution of the flat, thin detector based on the use of $LaBr_3$:Ce crystal and PMT to be used for the light ions detection with the energy of up to 20 MeV/nucleon

Svertilov S.I., SINP MSU, Timing resolution of $LaBr_3$:Ce and $CeBr_3$ crystal scintillators in combination with different type photomultipliers, to be used for detection of cosmic radiation.

Shtitelman V. A., ISMA, Spectral distortion caused stray light and its correction

Rebrova N.V., ISMA, Crystal growth and scintillation properties of Eu^{2+} doped $RbCaCl_3$

Gavrylovets V.V., INP BSU, Influence of a crystal scintillator structure on the energy resolution of a homogeneous electromagnetic calorimeter

Mikhaylov V.A., INP BSU, Amplifier-discriminator for SiPM readout

Orsich P. O., INP BSU, Demand for radiation tolerant active materials for hadronic calorimetry at collider experiments with a high luminosity

Sytov A.I., INP BSU, A way to observe channeling and quasichanneling oscillations in a bent crystal

Drugakov V.V., INP BSU, A spectrometer system for luminosity measurement in ep scattering experiments

Kravtchuk N.P., JINR, Trekker prototype on a base of cathode stray

Belsky A., Institut Lumière Matière, Relaxed electronic states of Tl^+ and In^+ dopants in CsI scintillators

28.09.2016

Instruments and equipment for measurement of nuclear radiation and materials for radiation detection

Plenary Session **(rectorate)**

INTELUM

Chairman:	**Vasil'ev A.N.**
9.00-9.30	**Auffray E.,** CERN, 25 years of R&D on inorganic scintillator and their applications in the Crystal Clear Collaboration.
9.30-9.50	**Pauwels K.,** CERN, Crystal fibers for future calorimeters
9.50-10.10	**Petrosyan A.G.,** Institute for Physical Research NAS of Armenia, Growth of garnet and perovskite scintillators with non-isovalent minor components and related effects
10.10-10.30	**Sidletskiy O.C.,** ISMA, Engineering of YAG-based scintillators for new HEP calorimeters

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

11.10-11.30 **Korjik M.V.,** INP BSU, The choice of active materials for use in the experiments at high luminosity colliders

11.30-11.50 **Lucchini M.T.,** CERN, Comparison of single crystalline and composite scintillators for hadron calorimetry at high luminosity LHC

11.50-12.10 **Spassky D.A.,** SINP MSU, Self-trapping of charge carriers in Li_2MoO_4 and $ZnMoO_4$ cryogenic scintillators

12.10-12.30 **Tret'jak E.V.,** IPCP BSU, Optical and structural properties of $3CaO\text{-}2SiO_2$:Ce, $3CaF_2\text{-}2SiO_2$:Ce and $3Ca_xBa_{1-x}O\text{-}2SiO_2$:Ce (x=0, 0.5, 1) glasses

12.30-12.50 **Arhipov P.V.,** ISMA, Scintillation crystals of rare-earth aluminates grown in reducing environments

12.50-14.30 ***Lunch***

Instruments and equipment for measurement of nuclear radiation

Chairman: **Nikl M.**

14.30-14.50 **Singovski A.V.**, University of Minnesota, Radiation Hard Electronics for Hadron Collider Experiments. LHC Experience and Projects for HL LHC

14.50-15.10 **Kalinnikov V.A.,** JINR, Design of homogeneous electro-magnetic calorimeter with heavy crystals operating in mag-netic fields

15.10-15.30 **Taranyuk V.I.,** ISMA, Scintillation crystals growth meth-ods for laboratory research and industrial production

15.30-15.50 **Ahmadov F.I.,** Institute of Radiation Problem**,** New phoswich detector based on MAPD and LFS& p-terphenyl scintillator

15.50-16.10 **Gorbacheva T.E.,** ISMA, Light collection in composite and polycrystalline organic scintillators

16.10-16.30 **Kazuchits N.M**., BSU, Raman and photoluminescence in diamonds irradiated with swift xenon ions

16.30-17.00 ***Coffee Break***

Chairman: **Galunov N.Z.**

17.00-17.20 **Baranov V.Y.,** JINR, Research of properties undoped crystals CsI

17.20-17.40 **Pereymak V.N.,** ISMA, Improving the temporal characteristics of the plastic scintillator

17.40-18.00 **Malkov A.P.,** JSC "SSC RIAR", Monitoring systems of distribution of the starting material in the reactor target for production of radionuclides by illumination of ionizing radiation sources

18.00-18.20 **Kalinov V.S.,** Pre-irradiation annealing influence on efficiency of the near-surface color centers formation in lithium fluoride nano-crystals

18.20-18.40 **Batouritski M.A.**, INP BSU, Precision measurements RF parameters of superconducting cavities

16.00-18.30 ***Poster session – Instruments and equipment for measurement of nuclear radiation, Materials for radiation detection, Detectors and detector systems for medical diagnostics and security systems, Radiation damage of materials and detectors*** **(INP BSU, 3rd floor)**

Zhukovsky A.I., ATOMTEX, Scintillation gamma spectrometer for radiation monitoring of water and sediments

Lukashevich R.V., ATOMTEX, Calibration of scintillation block-comparators for metrological provision of measuring a dose rate of 0.1 μSv/h on the calibration dosimetric installations

Komar D.I., ATOMTEX, Using the geometry of the thermal neutron calibration unit of neutron radiation UPN-AT140, as a source of capture gamma rays with energies up to 10 MeV for the calibration of the scintillation detector blocks

Alekseichuk I.A., ATOMTEX, Intellecctual scintillation detection units for use in harsh environments

Sytova S. N., INP BSU, Basic and applied science at the portal of nuclear knowledge BelNET

Solomaha T.A., BSU, Synthesis and spectral-luminescent properties of $BaI_2:Eu^{2+,3+}$, M^+ powders ($M = Li^+, Na^+, K^+$)

Krutyak N.R., Physical Faculty MSU, Influence of fluorine doping on luminescent properties of cadmium and zinc tungstates

Nichiporchuk A.O., ATOMTEX, Imitation of bulk metals activity measures for the calibration of scintillation gamma spectrometers

Makarevich К.О., INP BSU, Applications of Monte Carlo methods in medicine

Molchanova N.I., ISMA, On the role of metrological provision of in the production process of crystals

Vasilyev D.A., Vasilyeva N.V., Prokhorov GPI RAS, Optical and scintillation properties of Ce-doped $(Pb,Gd)_3(Al,Ga)_5O_{12}$ epitaxial garnet films

Pedash V.Y., ISMA, Application of semi-transparent interpixel gaps for improvement of spatial resolution in pixilated scintillation detectors
Danilkin M.I., Vereshchagina N.Y., Lebedev PI RAS, Trapping centres formation in $Li_2B_4O_7$-based thermoluminescent materials
Velicheva E.P., JINR, Development of Geant4 optical model of LYSO crystal
Yamny K.O., The system for intrascopy of the huge objects
Onufriyev Yu.D., ISMA, LiI(Eu) based composite detector for thermal neutron registration
Onufriyev Yu.D., ISMA, Light collection in a scintillation element for HEP applications
Nepokupnaya T., ISMA, Combined detector for the registration of low-energy γ-radiation
Tarasov V.A., ISMA, On the various concepts of quality evaluation for scintillators light output measurements
Baranova M.A., JSC "SNIIP", Device of detection of inert radioactive gases olume activity
Shalamova V.Yu., JCS "SNIIP", Device of detection of vapor I-131 volume activity

29.09.2016

Plenary Session–I **(Council conference room, INP BSU)**

Detectors and detector systems for medical diagnostics and security systems; neutron detectors

Chairman:	**Dormenev V.I.**
9.00-9.30	**Kazimirov A.S.,** RPE "AtomKomplexPrylad", Experience and perspectives of scintillation spectrometry instruments for radiation safety problems at nuclear power plants, environmental control and monitoring
9.30-9.50	**Drobot S.V.,** Gosatomnadzor, Regulatory infrastructure of the Republic of Belarus in the field of radiation safety during the construction of the Belarusian nuclear power plant
9.50-10.10	**Batyunin A.V.,** Institute "Project Center ITER", Wide-ICD to measure fast neutron flux, designed for ITER
10.10-10.40	***Coffee Break (INP BSU)***
10.40-11.00	**Galunov N.Z.,** ISMA, The detection of neutrons

11.00-11.15 **Kaschuk Y.A.,** Institute "Project Center ITER", The use of fiber-optic in distributed systems of registration to ionizing radiation

11.15-11.50 **Obudovsky S.Y.,** Institute "Project Center ITER", Radiometer to monitor gpse units flux density and neutron fluence for nuclear facilities

11.30-11.45 **Kvatchadze V.G.,** Andronikashvili Physical Institute, TSU, On the possibility to use magnesium oxide for selective detector of fast neutrons

Specialized scintillators and detectors based on their

Chairman: Dosovitskiy G.A.

11.50-12.10 **Borshchev O.V.,** ISPM RAS, Nanostructured organosili-conluminophores as effective and fast spectral shifters in a wide spectral region

12.10-12.30 **Pandey I.R.,** Kyungpook National University (South Korea), Growth and Scintillation Properties of $Na_6Mo_{11}O_{36}$ single crystal

12.30-12.50 **Omelkov S.I.,** Institute of Physics, University of Tartu, CsI: A low cost scintillator for TOF-PET?

12.50-13.10 **Mokina V.M.,** INFN, Improvement of the radiopurity level of $^{116}CdWO_4$ and $ZnWO_4$ crystal scintillators by recrystallization

***Plenary Session– II* (Council conference room INP BSU)**

Detectors and detector systems for security systems and medical imaging

Chairman: Boyarincev A.Y.

9.00-9.20 **Kozhemyakin V.A.**, ATOMTEX, New developments of radiation monitoring equipment on the basis of scintillation detectors

9.20-9.40 **Pozdnyakov D.V., Kasiuk D.M.,** "ADANI", Ionizing radiation spectrum optimization for the personal inspection X-ray systems

9.40-10.00 **Svertilov S.I.,** SINP MSU, Energy resolution of $LaBr_3$:Ce, $CeBr_3$ and Ce:GAGG crystal scintillators in combination with different type photomultipliers, as well as with Si-photodiodes, to be used for detection of cosmic gamma-rays

10.00-10.20 **Bogomolov V.V., Svertilov S.I.,** SINP MSU, Scintillating spectrometer for long-term study of the sea level gamma-ray background variations caused by changes of

concentration of radioactive isotopes and particle acceleration during thunderstorms

10.20-10.40 **Fedorov A.A.,** INP BSU, GAGG:Ce scintillation detector with SiPM readout

10.40-11.20 ***Coffee Break (INP BSU)***

11.20-11.40 **Galenin E.P.,** ISMA, Peculiarities of the crystal SrI_2 by the Czochralski method

11.40-12.00 **Voronov A.P.**, "Institute for Single Crystals" NAS of Ukraine, Activated Crystals KDP group for the selective detection of neutrons

12.00-12.20 **Galunov T.Z.,** ISMA, Scintillators based on microcrystalline grains

12.20-12.40 **Nagorny S.S.,** Gran Sasso Science Institute, ZnSe scintillating bolometer with ionization readout – a new approach for particle discrimination technique

12.40-13.00 **Gritsyna V.T.,** Karazin Kharkiv National University, Luminescence properties of irradiated spinel ceramics at different temperature

13.00-14.30 ***Lunch***

14.30-18.00 ***Excursion. Options: Victory Museum or Belarus ethnovillage***

18.00-21.00 ***Conference Dinner***

30.09.2016

(Council conference room, INP BSU)

10.00-11.30 **Round table**. Chairman: Gektin A.V.
New materials, new approaches and the interaction with the industry

11.30-12.00 **Korjik M.V.,** Closing of the conference

NEW PHOSWICH DETECTOR BASED ON MAPD AND LFS & P-TERPHENYL SCINTILLATOR

Ahmadov F.[1,3], Ahmadov G.[1,2], Sadigov A.[1,3],
Sadygov Z.[1,2,4], Madatov R.[3],
Suleymanov S.[1,3], Akberov R.[1,3], Zerrouk F.[4]
[1]*National Nuclear Research Centre of MCHT, Baku, Azerbaijan*
[2]*Joint Institute for Nuclear Research, Dubna, Russia*
[3]*Institute of Radiation Problems of ANAS, Baku, Azerbaijan*
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This paper presents the results of phoswich detector which developed based on the micro pixel avalanche photodiode (MAPD) and LFS+p-terphenyl scintillators. Beta particle and gamma ray detection performance of the phoswich detector (LFS+p-terphenyl) was investigated. The energy resolution of monochromatic electron was 23% (625 keV). The detected count ratio of beta particle and gamma ray was about 37%. It was obtained that this type phoswich detector discriminates between gamma ray and beta particle due to the differences in the light decay time of scintillators.

AMPLIFIER-DISCRIMINATOR FOR SIPM READOUT

Alexeev G.D.[1], Chichin A.S.[2], Afanaciev K.G.[2], Baturitsky M.A.[2], Mikhailov V.A.[2*], Piskun A.A.[1], Tokmenin V.V.[1]
[1]*Joint Institute for Nuclear Research, Dubna, Russia,*
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The muon detection subsystem of PANDA detector will utilize the scintillation counters in the gaps between mini drift tube modules. The readout of these scintillators will be done with SiPMs. Technical require-ments for the readout electronics can't be satisfied with existing amplifiers, so specialized amplifier-discriminator was designed for this application.

An amplifier-discriminator was developed for readout of SiPM photodetectors in pulse counting mode. An amplifier-discriminator has 8 channels in one package, low power consumption and allows driving long transmission line like twisted pair. A simple amplification stage was added to an existing discriminator design which allowed to count input pulses with single photoelectron precision.

A model of SiPM was developed and the readout system was simulated in PSPICE CAD program. The resulting plot of counting rate vs pulse amplitude in p.e. units was compared to the experimental data of the performance of prototype amplifier-discriminator with MAPD-1 SiPM. There is a good correspondence between experimental and simulation data.

The developed amplifier-discriminator could be used for the readout of scintillator counters in the muon subsystem of PANDA detector. There are possible application as well in NICA and ILC detectors.

ИНТЕЛЛЕКТУАЛЬНЫЕ СЦИНТИЛЛЯЦИОННЫЕ БЛОКИ ДЕТЕКТИРОВАНИЯ ДЛЯ РАБОТЫ В ЖЕСТКИХ УСЛОВИЯХ

Алексейчук И.А., Антонов А.В., Антонов В.И.,
Барченко А.Г., Быстров Е.В., Вороньков В.Н.,
Кожемякин В.А., Лукашевич Р.В.
Научно-производственное унитарное предприятие «АТОМТЕХ»,
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Контроль радиационной обстановки на объектах ядерного цикла, таких как АЭС, хранилища отработавшего ядерного топлива и т. д., а также в районах воздействия потенциальных источников радиоактивного загрязнения диктует создание новых технических средств дозиметрического и радиометрического контроля. При этом часто возникает необходимость исследования и контроля захоронений ядерных материалов с неизвестным радионуклидным составом в жестких условиях эксплуатации. Для решения такого рода задач предприятием «АТОМТЕХ» была разработана серия блоков детектирования (БД) в защищенных корпусах.

В данной серии БД в качестве детектора применяются сцинтилляторы NaI(Tl) различного типоразмера. Варианты исполнения БД определяются исходя из поставленных задач: получение более широкого диапазона измеряемой мощности амбиентного эквивалента дозы гамма-излучения (МД) или более высокой чувствительности каждым отдельным блоком, соответственно.

Корпуса приборов разработаны специально с учетом сложных условий применения. БД могут устанавливаться в скважинах, на внешних стенах зданий, на открытой местности или погружаться в воду на глубину до 50-ти метров.

В докладе приводятся основные характеристики БД и особенности их применения.

COMBINED DETECTOR FOR THE REGISTRATION OF LOW-ENERGY γ-RADIATION

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Kovalchuk S., Nepokupnaya T., Onufriyev Yu. , Pedash V.
Institute for Scintillation Materials NAS of Ukraine, Kharkiv, Ukraine
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The basic means for detecting nuclear materials are radiation portals in the production of which scintillation plastic is widely used. The advantages of this scintillation material are large area and low cost. The main disadvantage is low scintillation efficiency in the range of low energies while many nuclear materials have the intrinsic gamma radiation in the range of low energies. In this work combined detector with the increased efficiency of the registration of low-energy γ-radiation compared to the one of the scintillation plastic was manufactured.

The base of the combined detector is scintillation plastic UPS-923A with an additional layer of the composite scintillator based on YSO:Ce or CsI:Tl granules in the optically transparent polysiloxane. The composite scintillator layer absorbs low-energy γ-radiation with the light emission with the wavelength of more than 400 nm for which plastic scintillator is a transparent material. At the same time due to the small thickness the composite scintillator does not register the radiation with the energy of more than 662 keV.

In the paper dimensions of granules, the optical medium material, concentrations of the scintillation layer components, the composite scintillator thickness were specified. It was found that the efficiency of gamma radiation registration with the energy of 59.5 keV (for ^{241}Am) with the combined detector is 4 times higher when using YSO:Ce composite scintillator and 5 times higher when using CsI:Tl composite scintillator if compared with scintillation plastic.

The use of composite scintillators as part of combined detectors has such advantages over single crystal scintillators as lower cost due to the use of single crystals with mechanical damages, as well as availability of components for the production of detectors.

THE LIGHT YIELD OF A LONG SCINTILLATION STRIP WITH WLS FIBER EMBEDDED INTO THE CO-EXTRUDED HOLE

Artikov A., Baranov V., Budagov J., Chokheli D., Davydov Yu.I., Glagolev V., Kharzheev Yu., Kolomoets V., Shalyugin A., Simonenko A., Tereshchenko V., Usubov Z., Vasiliev I.
JINR, Dubna, Russia, dagorr@gmail.com

The long scintillator counters light yield increase is a high priority task for the wide spectrum of experiments, including the Mu2e [1].

In this paper we report the light yield measurement of a 5 meter long extruded scintillation strip with a 1.2 mm Kuraray Y11 (200) MC WLS fiber embedded in the co-extruded hole as a function of the distance from the PMT photocathode. The strips with a central co-extruded hole were made of polystyrene with the 2% PTP and 0.03% POPOP dopants at ISMA (Kharkiv, Ukraine).

The light yield has been measured for strip with hole filled with an optical transparent CKTN-MED(E) resin and with no filling ("dry" strip). The technique developed in [2] was employed for the optical resin injection into the 5 m long hole. The strips were irradiated by cosmic muons and radioactive sources. In case of radioactive sources the signals from the PMT were measured with a picoammeter.

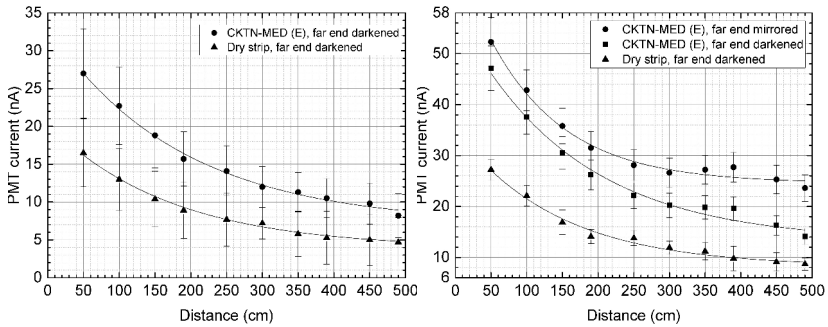

Fig. The PMT anode current in function of the distance for ^{90}Sr (left) and ^{60}Co (right) irradiation

The results of the measurements with ^{60}Co and ^{90}Sr irradiation are presented on Fig. The light yield of the strip with the filler is by factor 1.6–1.7 greater than that for the "dry" strip. Mirroring of the fiber's far end increases the light yield by a factor 1.1–1.7 comparing that of strip with darkened fiber end (right frame of Fig.).

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СЦИНТИЛЛЯЦИОННЫЕ КРИСТАЛЛЫ РЕДКОЗЕМЕЛЬНЫХ АЛЮМИНАТОВ, ВЫРАЩЕННЫЕ В ВОССТАНОВИТЕЛЬНЫХ СРЕДАХ

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Кристаллы редкоземельных алюминатов такие как YAG, YAP, LuAG, чистые и допированные редкоземельными элементами, такими как Ce, Nd, Ti, Er, Pr и др., широко используются в различных областях науки и техники, за счет сочетания теплопроводности, твердости, химической стойкости, прозрачности, высоких показатели световыхода. Однако ввиду тугоплавкости данных материалов для выращивания кристаллов из этих материалов используют преимущественно иридиевые тигли, что существенно удорожает получаемые кристаллы.

В текущей работе кристаллы чистого и допированного церием YAG, были выращены из вольфрамового тигля метом Чохральского. В качестве теплоизоляции использовались углеродные материалы. Полученные кристаллы чистого YAG имели желто-коричневый оттенок, кристаллы YAG:Ce также имели этот оттенок. Также определено влияние отжига образцов в различных условиях на оптические и сцинтилляционные свойства YAG.

Показано, что не отожженные выращенные кристаллы чистого YAG имеют фотолюминесценцию, обусловленную внутренними дефектами. Кристаллы YAG с Ce также ее имеют однако она существенно меньше люминесценциии Ce. После высокотемпературного отжига в восстановительной атмосфере (CO), окраска вызванная дефектами и люминесценция в чистом YAG пропадает, а в YAG:Ce интенсивность люминесценции Ce возрастает.

Для кристаллов чистого или допированного YAG такое поведение при высокотемпературном восстановительном отжиге не характерно, они темнеют, т. к. у них в результате насыщения кислородными вакансиями возрастает поглощение во всем оптическом лиапазоне. Наиболее вероятной причиной такого поведения является углерод, способный легко изме-нять валентность и компенсировать заряд кислородных вакансий. Угле-род попадает в расплав в процессе выращивания при взаимодействии расплава с атмосферой CO.

Оптические свойства отожженных в восстановительной среде кристаллов YAG, выращенных в восстановительной атмосфере из вольф-

рамового тигля, не хуже чем у кристаллов YAG, выращенных в слабо окислительной атмосфере из Ir тигля.

Отжиг в восстановительной среде кристаллов YAG:Ce предпочтителен, поскольку позволяет переводить Ce в трехвалентное состояние. Однако без углерода в кристалле проведение такого отжига невозможно. Поэтому наличие углерода в кристалле оказалось ключевым фактором и для выращивания кристаллов, и для их отжига в восстановительной среде.

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25 YEARS OF R&D ON INORGANIC SCINTILLATOR AND THEIR APPLICATIONS IN THE CRYSTAL CLEAR COLLABORATION

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The Crystal Clear Collaboration (CCC) has been created in 1991 in the frame of the DRDC program at CERN. Its initial goal was to identify the most suitable inorganic scintillators as candidates for an electromagnetic calorimeter at the future Large Hadron Collider LHC. The R&D carried out led to the choice of PbWO4 as material for the electromanetic calorimeter of the CMS experiment.

Since 25 years the Crystal Clear Collaboration carries out intense R&D on inorganic scintillating materials for novel ionizing radiation detectors for use in high-energy physics, medical imaging and industrial applications. Such R&D covers generic activities such as the understanding of the scintillation mechanism, to the conceptual design, test, implementation and integration of large detector systems. In this report, the main results achieved by the CCC and the current domains of activities of CCC will be presented.

PRECISION MEASUREMENTS RF PARAMETERS OF SUPERCONDUCTING CAVITIES

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The article concerns key problems of effective and accurate measurements of high Q-factor of superconducting radiofrequency (SRF) niobium resonant cavities of Tesla-type for ILC. The core outcomes of a Dubna–-Minsk research project in the part dealing with creation of measuring system for measuring of high Q-factor of single-cell 1.3 GHz SRF niobium cavities of Tesla-type are presented and discussed.

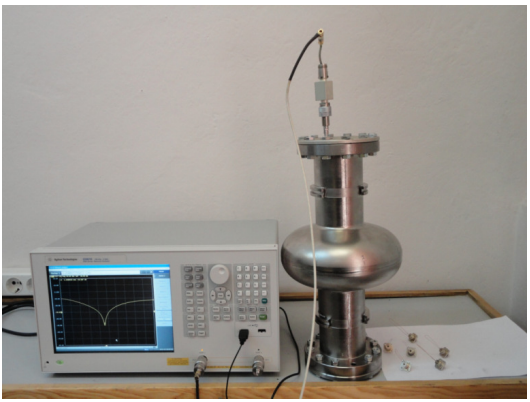

Fig. 1. The measuring scheme (stand) for "warm" measurements based on the VNA Agilent E5061B, Opt. 1E5

The automated measurement system and technique described in the article can be considered as a useful scientific instrument for measuring Q-factors of 1.3GHz SRF single-cell resonant cavities of Tesla-type (with drift tubes on both sides). The proposed technique uses direct method of measurements of Q-factor when applying a standard measurement equipment, does not require evacuating and sealing the cavity and thus the technique can be considered

both effective and practical for quality control of the cavities directly at production. In the series of "cold' experiments there have been registered the values of Q about 10^{10} which are well-consistent with the theoretical estimates. The measurement equipment and the extra UHF parts are relatively cheap so that our scientific instrument and measurement technique can be seen as an alternative to more expensive tools and measurement methods that are used for measuring Q-factor of such resonance cavities.

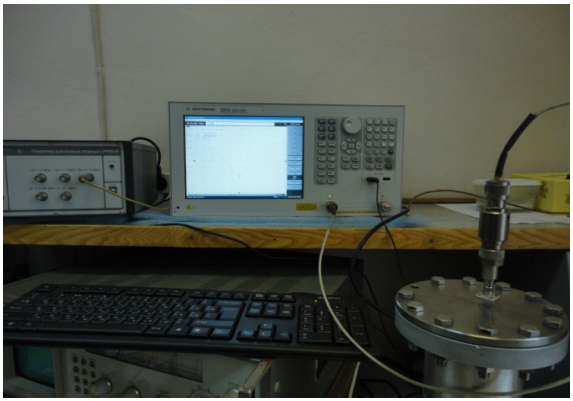

Fig. 2. The measuring scheme (stand) for "cold" measurements based on the VNA Agilent E5061B and LPFRS-01

Further improvements of measurement accuracy with the automated measurement system can be made when applying measurement techniques of transmission coefficient S_{12}. That will improve signal to noise ratio in the neighborhood of peak of AFR, and also isolation level of measurement UHF channels of the VNA. Applying a VNA with a wider dynamical range would be also preferable.

INERT RADIOACTIVE GASES VOLUMETRIC ACTIVITY MONITOR

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Monitoring of radiation factors generated by nuclear power plants is an integral part of the overall system of radiation safety. Among the wide range of radiation control tasks at nuclear power plants a special attention is paid to the dedicated measurement of volumetric activity (VA) of inert radioactive gases (IRG).

In JSC "SNIIP" it has been engineered the installation for control of volumetric activity of the nuclides ^{133}Xe, ^{85}Kr, ^{41}Ar of inert radioactive gases by beta radiation in a controlled gas atmosphere in a wide range – from $1.0 \cdot 10^3$ to $1.0 \cdot 10^{17}$ Bq/m^3.

To implement the measurement of the VA of IRG in the range from 1000 to $1.0 \cdot 10^{17}$ Bq/m^3, the installation is divided into three sub-levels: a) sensitive level – from 1000 to 10^9 Bq/m^3; b) the average level – between 10^8 and 10^{13}Bq/m^3; C) high level – from 10^{12} up to $1.0 \cdot 10^{17}$ Bq/m^3;

In sensitive detection unit 5 panels made of scintillating polystyrene are used. Application of the detector of this type allows to increase the registration efficiency and to reduce temperature dependence of the measurement results. However, this device demands highly stringent requirements to protection against external background, because the panels made of scintillating polystyrene are sensitive to γ-radiation.

Medium and high sub-levels are disposed in a single detection unit, providing measurements from 10^8 to 10^{17} Bq/m^3. The detector unit contains two silicon ion-implanted detectors, a chargeable preamplifier, the light-emit-ting diode for operation control of the amplifier chain. To protect against external gamma background the detection nodes placed in a tungsten protection.

Communications for air samples input and the trial samples input are equipped with drop-protecting appliance, and with a system of filters to exclude the ingress of aerosol fractions into the measuring volume of detectors. The volume of the measured sample is controlled with the help of a flow meter.

RELAXED ELECTRONIC STATES OF Tl^+ AND In^+ DOPANTS IN CsI SCINTILLATORS

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The problem of ns^2 centers in different matrices is again discussing in the literature. The modern DFT calculations shows strong hybridization effects between s-electrons of the dopants and the valence band electrons. Centers with the same s^2 electronic configuration, like In^+ and Tl^+ in CsI can behave in a different way depending on the position of the levels, strength of electron-phonon coupling, etc. Comparative analysis of luminescent properties of these two emission centers in CsI lattice was done using fluorescence spectroscopy methods. The position of emission bands are about the same for both activators – one UV band around 400–420 nm and two visible ones at 500 nm and 550 nm (560 for CsI:Tl). Nevertheless, the widths of indium induced bands are smaller than of thallium ones, and the excitation spectra are quite different. In case of CsI:In crystals lower energy photons (around 310 nm) excite only low energy emission band (550 nm). Increase of the excitation energy results in appearance of 490 nm emission and then 420 nm one. On the contrary, in case of CsI:Tl crystals, all the three main emission bands are excited around the lowest energy absorption band at 295nm. For higher energies the emission at 400 nm region disappears and only two visible bands (490 nm and 550 nm) are present, which is consistent with other works [1, 2].

In order to investigate the excitation mechanism of these bands we perform calculation of ground and different excited and charge states in these systems using DFT with hybrid exchange-correlation functional. It is shown that due to different hybridization of s^2 states with iodine valence band states the in case of In and Tl the excited states and charged states have quite different configuration. The excited state of indium center is localized at the dopant, whereas thallium excited state looks like Tl^0+V_K. There is also shown

that a hole captured by Tl^+ center has lower activation energy than a hole captured by In^+ center. These calculations correlate with the experimental TSL data.

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TIMING RESOLUTION OF $LaBr_3$:Ce AND $CeBr_3$ CRYSTAL SCINTILLATORS IN COMBINATION WITH DIFFERENT TYPE PHOTOMULTIPLIERS, TO BE USED FOR DETECTION OF COSMIC RADIATION

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We have studied and report here the timing resolution of different detectors of cosmic radiation, that are using modern type scintillating crystals like $LaBr_3$:Ce and $CeBr_3$.

The detector itself is based on the use of scintillating crystal and either of vacuum, or Si-type photomultipliers, that were tested with the conventional set of radioactive isotopes.

Timing resolution of detectors that was derived for different combinations of scintillating crystals and photosensors, and of detector potential use will be discussed in this talk.

SCINTILLATING SPECTROMETER FOR LONG-TERM STUDY OF THE SEA LEVEL GAMMA-RAY BACKGROUND VARIATIONS CAUSED BY CHANGES OF CONCENTRATION OF RADIOACTIVE ISOTOPES AND PARTICLE ACCELERATION DURING THUNDERSTORMS

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In this talk we present an experiment for the long-term measurements of flux and spectral variations of the sea level gamma-ray background radiation. The instrument has moderately large (80×80 mm) scintillating detector with energy resolution ~7% at 662 keV. The data are recorded in event-by-event mode with ~15 μs time resolution thus permitting detection of the terrestrial gamma-ray bursts at the moment of lightning during thunderstorms. Regular testing of ^{40}K background line position (E = 1.46 MeV) is used for calibration of the spectrometer during the whole measurements session. This set-up helps to exclude temperature variations of the signal in a long-term experiment.

The instrument design, as well as results of its long-term employment are discussed in this paper.

NANOSTRUCTURED ORGANOSILICON LUMINOPHORES AS EFFECTIVE AND FAST SPECTRAL SHIFTERS IN A WIDE SPECTRAL REGION

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Recently we have developed a new class of highly efficient luminescent materials with unique properties – nanostructured organosilicon luminophores (NOLs) [1–3]. These are branched organosilicon molecules, where two types of organic chromophores are connected to each other via silicon atoms, which brake the conjugation between them and fix them specifically in the space at 1–2 nm distance necessary for efficient Förster energy transfer [2–4]. NOLs possess several advantages: absorption in a wide optical spectral region; 5–10 times higher cross-sections the those of the best low molar weight organic luminophores; very high photoluminescence quantum yield; large pseudo Stocks shift; short luminescence lifetime down to 0.8–0.9 ns. Photoluminescence study of several new NOLs has shown the intramolecular energy transfer efficiency up to 99% and luminescence quantum yield 95– 99%.

It should be noted that combination of different chromophores in the NOL allows tuning their absorption and emission in a wide spectral region, which opens possibilities for their wide application as highly efficient spectral shifters – convertors of the emission with the energy of high frequency photons (140–400 nm) into the emission in the visible spectral range (400–700 nm) [2, 3].

We applied NOLs as spectral shifters in new highly effective plastic scintillators. Since two different luminophores are fixed properly on the nanoscale distance at the same branching molecule, the light output of the plastic scintillators is significantly increased, while their timing resolution improves. This lead to a new type of scintillating devices with nanostructured luminophores [1].

Heat treatment of specially functionalized NOLs and organosilicon oligomers having reactive vinyl and the hydride groups in solution, allowed to obtain transparent fluorescent organosiloxane scintillating composites stable over a wide temperature region [2].

NOLs are commercially available from a startup company LumInnoTech LLC. Further details can be found at www.luminnotech.com.

This work was supported by Foundation of the President of Russian Federation (project MK 6501.2015.3).

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SCINTILLATION ELEMENT FOR HEP APPLICATION

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The increase of luminosity in HEP calorimeters requires the use of radiation hard scintillation materials that can withstand doses of more than 20 Mrad. The application of scintillation plastic under high radiation doses is limited by its radiation hardness at 5 Mrad. Inorganic single crystals are a solution of the problem of scintillators selection for HEP. However, their use is limited by high cost and complexity when creating the technology for mass production of large crystals. An alternative to radiation hard single crystals are composite scintillators on their base which represent a mixture of scintillation granules in the optically transparent medium. The granules can be obtained by crushing single crystals or scintillation materials obtained by solid-phase synthesis without the crystal growth stage. Composite scintillators are the optimal solution for application in megatiles and calorimetric modules of Shashlyk type since the cost of their production is lower than the one for analogous single crystals. Also it is possible to manufacture composite scintillators of any size and shape.

In this paper a radiation hard scintillation element consisting of a composite scintillator and a light-conducting layer providing the efficient light-collection from the scintillation layer to the WLS fiber or directly to a photodetector is proposed. The scintillator of the element is oxide single crystal granules in the optically transparent polysiloxane. The proposed design allows changing the parameters of the scintillation element depending on the application by varying the composition of materials for the scintillator, light-conducting layer and light guide.

In this paper the radiation hardness of the proposed scintillation element as well as of the materials for its manufacture was tested. The test samples were irradiated with electrons with E_0 = 8.3 MeV at the room temperature at the integrated dose of 50±0.5 Mrad (500±5 kGr). After irradiation, the decrease of the light output of single crystals and composite scintillators of up to 2% and the reduction of the transparency of single crystals, quartz glass and polysiloxane in the area of 300–700 nm to 5% are observed. Radiation damage of YSO:Ce composite scintillators obtained by solid-phase synthesis are comparable to the changes of composite scintillators based on single crystals. The light output of the scintillation element calculated as regard to UPS-923A plastic scintillator before and after irradiation with 50 Mrad, made 150% and 145% respectively.

LiI(Eu) BASED COMPOSITE DETECTOR FOR THERMAL NEUTRON REGISTRATION

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Composite scintillators allow creating large area detectors with high geometrical radiation detection efficiency. To register thermal neutrons, composite scintillators based on ZnS:Ag with ^{6}Li or ^{10}B isotopes are often used. In this paper the characteristics of the composite scintillator based on LiI(Eu) granules for the thermal neutrons registration placed in an optically transparent medium were studied. Compared to composite scintillators based on ZnS:Ag with ^{6}Li or ^{10}B isotopes, the scintillator based on LiI(Eu) granules is more promising. In the first case, the formation of secondary charged particles takes place in the converter phase and the scintillation origination - in ZnS:Ag phase where the particles lose different parts of their original energy. In the second case, above mentioned processes take place within one scintillator granule with equal total loss of particles energy. For LiI(Eu) based composite scintillator there is still the problem of the scintillation light dispersion and the problem of the instability of scintillator hygroscopic disperse phase arises.

These problems have been solved in our research. The selection of the scintillator granules dimensions, of the optical medium and of the ratio of the system components was carried out using experimental and computer simulation. For the samples of the optimal composition the resolution better than 40% at 4.78 MeV was obtained. It was found that the thermal neutron detection efficiency for these samples is 70% of the efficiency of a single crystal sample of the same thickness. It was found that for these samples the registration of gamma radiation with the energy of more than 2.6 MeV takes place in the region lying below the threshold of the thermal neutrons registration.

Besides the possibility of creating large area detectors, the advantages of LiI(Eu) based composite scintillator over single crystal are the possibilities of using single crystals with mechanical defects, producing detectors of different shapes, industrial availability of all components and lower cost.

LIGHT-COLLECTION IN THE SCINTILLATION ELEMENT FOR HEP

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Composite scintillators are the basis for the production of large area detectors with high efficiency of the radiation detection. These scintillators have such advantages over single crystals as the manufacturing of detectors of different shapes, the use of both crushed single crystals and scintillators obtained by solid-phase synthesis or by sol-gel method, i.e. without the crystal growth stage, as scintillation granules, the industrial availability of all components and their low cost.

Along with the advantages one of the main problems is the non-uniformity of the light-collection on the composite scintillator area when for signal registration are used the WLS fiber or a locally placed photodetector.

Using mathematical simulation the selection of materials for the light-conducting and scintillation layers was carried out, their geometrical dimensions and shape were specified, dimensions of scintillation granules and the concentration of the scintillation layer components were calculated. In the paper the characteristics of elements based on composite scintillator of YSO:Ce granules distributed in the optically transparent polysiloxane were studied. Various materials were used in the element construction to manufacture the light-conducting layer.

The conditions ensuring the light output uniformity of the plate shaped scintillation element consisting of a composite scintillator 0.5–2 mm thickness and a light-conducting layer 2 mm thickness above it, were specified. Depending on the material of the light-conducting layer this parameter is at the level of a plastic scintillator having similar dimensions and the thickness of 4mm, or better. A scintillation element based on composite scintillator of YSO:Ce granules in the polysiloxane with the uniform light distribution at the distance of more than 30 mm from the WLS fiber or a locally placed photodetector was created.

RADIATION-RESISTANT COMPOSITE SCINTILLATORS FOR REGISTRATION A LARGE FLUX OF IONIZING RADIATION

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We have designed and studied a series of composites scintillators based on inorganic single crystalline grains (GSO:Ce, GPS:Ce and Al_2O_3:Ti) those were introduced into a transparent radiation resistant gel composition Sylgard-184 [1]. Radiation resistance of these scintillators is studied. We measure the value of the relative light output of composite scintillators before and after irradiation. The electron accelerator of the National Science Centre "Kharkov Institute of Physics and Technology" irradiates the samples by 9.2 MeV electrons at the room temperature. During irradiation, the radiation dose rate was practically uniform. We use two different dose rate namely 0.23±0.01 or 1500±5 Mrad/h. Inhomogeneity of irradiation of the samples did not exceed 5%. 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. 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 as the specific of light collection is these systems are discussed.

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CONCEPT AND PERFORMANCE OF THE ELECTROMAGNETIC CALORIMETER OF THE PANDA DETECTOR AT FAIR

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The PANDA collaboration at FAIR, Germany, will focus on undiscovered charm-meson states and glue balls in antiproton annihilations to study QCD phenomena in the non-perturbative regime. For fixed target experiments at the storage ring HESR a 4π-detector for tracking, particle ID and calorimetry is under development and construction to operate at high annihilation rates up to 20 MHz. The electromagnetic calorimeters are composed of a Target Spectrometer (EMC) based on $PbWO_4$ crystals and a shashlyk-type sampling calorimeter at the most forward region. The EMC, comprising more than 15,000 crystals, is operated at a temperature of -25·C and read-out via large-area avalanche photo-diodes or vacuum photo-triodes/tetrodes. The photo sensor signals are continuously digitized by sampling ADCs. More than 50% of the high quality PWO-II crystals are delivered and tested. The excellent performance with respect to energy, time and position information was determined over a shower energy range from 10 MeV up to 15 GeV by operating several prototype detectors. In addition, the concept of stimulated recovery has been investigated to recover radiation damage on- and off-line during the calorimeter operation. Besides the overall concept of the Target Spectrometer the response function of the shashlyk spectrometer down to photon energies even below 100 MeV will be presented.

RAW MATERIALS FOR NOVEL COMPLEX OXIDE GARNET SCINTILLATORS DEVELOPMENT

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Production of a scintillator starts with raw materials, which largely determine its properties. So, it is sensible to take into account considerations on raw materials in course of scintillator engineering. Important issues are availability, impurities content, producibility, price. Most of classic and new inorganic scintillators, such as YAG, BGO, PWO, LSO, GGAG, etc., are complex oxides, and composition is another major issue for them, as compositional changes may induce defects or influence formation of the desired phase. Ceramic scintillators are of rising interest for various applications, among which medical imaging is one of the largest. Nanocrystalline powders are widely used for production of such materials, so raw materials microstructure becomes of importance. These subjects will be covered in the talk from the point of view of chemical technology, as it is applied to scintillator development.

Particularly, raw material composition is an issue for novel highly efficient scintillating material GGAG:Ce with high potential for medical imaging and other applications. As scintillator production in a form of single crystal or transparent ceramic is a costly and time consuming process, there is an interest in a more rapid way to perform experiments during scintillators development. Synthesized powders, as an intermediate stage between raw materials and crystal/ceramics, are good objects for express studies of composition influence on scintillation properties. Such studies were performed for $Gd_3Ga_3A_2O_{12}$:Ce material. Powders were prepared by a wet chemical route and calcined at temperatures up to 1600 °C. Garnet phase and uniform microstructure with micron-sized grains were obtained. Powder scintillation properties depending on microstructure and composition were studied and compared to other forms of GGAG scintillator.

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A SPECTROMETER SYSTEM FOR LUMINOSITY MEASUREMENT IN *ep* SCATTERING EXPERIMENTS

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Precise luminosity measurement is essential for determination of cross-sections associated with physical processes. At ZEUS experiment at HERA collider the luminosity was measured using photons from the bremsstrahlung reaction, $ep \rightarrow ep\gamma$. Produced photons followed the direction of the colliding beam electrons and were detected about 100 m downstream using two independent luminosity monitors. Their layout relative to the ZEUS central detector is shown in Fig.

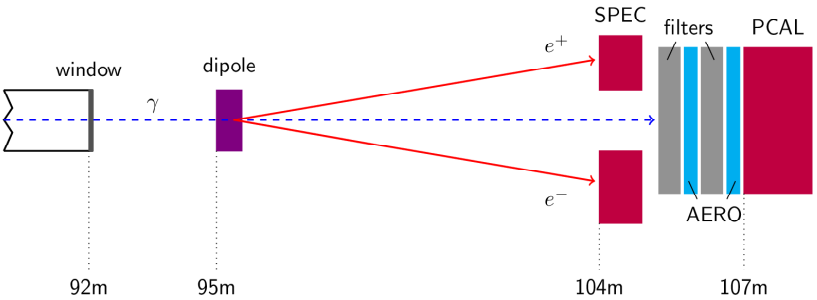

Fig. The layout of the ZEUS luminosity system

At Z = 92 m, photons from the interaction point exited the HERA vacuum system; approximately 9% of photons converted into e^+e^- pairs in the exit window. Converted pairs were detected using monitor SPEC [1]. It consisted of a dipole magnet and a pair of tungsten–scintillator sandwich calorimeters located about 10 cm above and below the beam axis. Photons which did not convert in the exit window were detected using monitor PCAL [2], a radiation hard lead-scintillator sandwich calorimeter.

The main two challenges for luminosity measurements at ZEUS experiment were high synchrotron radiation level and large event pile-up. The SPEC design significantly reduced the impact of these problems on the measurement. The problem of radiation damage in the calorimeters was significantly reduced by positioning them away of the synchrotron radiation plane. When back-scattered synchrotron radiation started becoming a

problem, improved shielding and frequent calibrations addressed the issue. The solution of the pile-up problem was achieved by reducing the event rate by looking at photons which converted in the exit window. The rate was further lowered by acceptance requirements in calorimeters.

Monitor SPEC provided a robust luminosity determination with a systematic uncertainty of 1.8% [3]. The measurement is in good agreement with the result obtained using PCAL. This method of luminosity measurement is planned to be used at the future EIC collider [4].

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LARGE HADRON COLLIDER AT HIGH LUMINOSITY: SCINTILLATORS RADIATION DAMAGE EXCESS AND A POSSIBLE WAY OF SOLVING THE PROBLEM

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Scintillators of CMS endcap hadron calorimeter are degrading faster than it was predicted at design time. If nothing will be done, the calorimeter will not even withstand the expected term of operation at current luminosity, not speaking about the High Luminosity mode.

The influence of irradiation rate is not negligible. At smaller dose rate the scintillators degrade faster. It wasn't taken into consideration at design time – scintillators were tested at big irradiation rate to shorten the test time.

We've produced scintillator elements with the same design and same material (SCSN-81) as in actual CMS endcap calorimeter. We've irradiated them at Sosny irradiation facility (γ-source ^{60}Co) at different dose rates and measured the degradation.

We've made the graph "light yield versus dose rate", which explanes the contradiction between expected and real radiation damage of plastic scintillator.

We have tested a method of improving of calorimeter radiation hardness – additional segmentation of tiles. We used the same scintillating material.

We have produced and irradianed tile segments. Measurements shown that the calorimeter of this configuration will withstand the whole term of operation in the mode of High Luminocity (3000 $fbarn^{-1}$).

OPTICAL AND STRUCTURAL PROPERTIES OF $3CaO\text{-}2SiO_2$:Ce, $3CaF_2\text{-}2SiO_2$:Ce AND $3Ca_xBa_{1-x}O\text{-}2SiO_2$:Ce (x=0, 0.5, 1) GLASSES

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At present time, a lot of research is focused on the study of luminescent glasses. Glasses have several properties that make them desirable candidate materials for scintillator applications. They are mechanically robust and easier to synthesize in large volumes than single crystals. Glasses do not cleave, and may be cut and polished with relative ease. The glass production routes allow a great compositional flexibility and may be used to produce compounds that do not melt congruently. More significantly, glass-ceramics production methods are typically cheaper than crystal growth methods, or than hot pressing routes used for polycrystalline ceramics.

In our work we focused on the study of the luminescent (photo – PL, radio – RL, and thermally stimulated – TSL) properties of $3CaO\text{-}2SiO_2$:Ce, $3CaF_2\text{-}2SiO_2$:Ce and $3Ca_xBa_{1-x}O\text{-}2SiO_2$:Ce (x=0, 0.5, 1) glasses.

RL spectra of all samples feature an unresolved doublet corresponding to the 5d-4f ($^2F_{5/2}$ and 5d-$^2F_{7/2}$) radiative transitions of Ce^{3+}. Increasing the Ce^{3+} concentration in the $3CaO\text{-}2SiO_2$:Ce and $3CaF_2\text{-}2SiO_2$:Ce samples from 0.05% to 1% leads to an emission red shift from ~380 nm to ~410 nm. In the $3Ca_xBa_{1-x}O\text{-}2SiO_2$:Ce (x=0, 0.5, 1) samples, increasing the Ba^{2+}content also leads to an emission red shift from 410 nm to 440 nm. Moreover, no significant scintillation efficiency increase is noticed by increasing Ba^{2+} concentration. The RL signals of all glasses are significantly weaker with respect to a $Bi_4Ge_3O_{12}$ (BGO) crystal measured as reference.

PL emission spectra, excited both at 300 and 360 nm, display different bands, occurring at slightly longer wavelengths with respect to RL ones. Such spectral differences depending on excitation source and wavelength call for the presence of at least two kinds of different sites occupied by Ce^{3+} ions and characterized by a different crystal field. Indeed, Raman measurements evidenced the presence of vibrations compatible with the presence of orthosilicate and pyrosilicate clusters. Re-absorption of the emitted light

contributes as well to spectral modifications observed by Ce concentration increase both in RL and PL.

Finally, TSL properties were also investigated. In all cases the glow curves featured very broad peaks, in accordance with the presence of continuous distributions of trap levels as expected in amorphous structures. Especially at low temperature weak signals were detected.

The weakness of the signals detected under ionizing radiation excitation, in RL and TSL measurements, despite a relatively strong PL emission, suggests the presence of non-radiative recombination channels in the glass network.

The application perspectives of the glasses as wavelength shifters in combination with UV emitting scintillators will be discussed.

GAGG:Ce SCINTILLATION DETECTOR WITH SIPM READOUT

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Gadolinium-aluminum-gallium garnet $Gd_3Al_2Ga_3O_{12}$:Ce (GAGG:Ce) is a novel scintillation crystal having a garnet structure like well-known yttrium-aluminum garnet with well-developed growing technology, $Y_3Al_5O_{12}$:Ce (YAG:Ce), which is used though mainly for x-ray and electron counting due to its low effective atomic number and density.

In the same time, GAGG:Ce possesses far larger effective atomic number of 51 and density 6.7 g/cm^3. This makes GAGG:Ce stopping power to gamma-quanta comparable or even exceeding that of CsI(Tl) or CsI(Na). Its light yield amounts to about 40,000–50,000 photons/MeV, which also approaches that of iodides mentioned above. Finally, due to presence of gadolinium, GAGG:Ce can also be used for neutron detection by gamma-radiation accompanying neutron capture.

Silicon Photomultipliers (SiPMs) are yet another example of innovations in radiation detection techniques. Currently available with dimensions up to 6×6 mm^2, SiPM with its intrinsic gain comparable with that of conventional vacuum PMT is the only solid-state photo detector able to detect scintillation light at the single photon level.

Here we report on our very preliminary efforts to estimate potentiality of GAGG:Ce with SiPM readout for conventional tasks of ionizing radiation detection. Although GAGG:Ce production technology is still under development and perfecting (some care still has to be paid to afterglow and intrinsic energy resolution), results obtained by us to date with SiPM readout are optimistic ones. In particular, energy resolution of ~12% FWHM @ 662 keV and energy noise equivalent < 30 keV were obtained with relatively large (~2 cm^3) GAGG:Ce sample attached to a 6×6 mm^2 SensL SiPM.

SCINTILLATORS BASED ON MICROCRYSTALLINE GRAINS

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New types of scintillators, namely the materials based on single crystal grains are investigated. It is composite scintillator when grains are introduce in gel-composition, and polycrystals obtained by hot pressure of the grains. Crystalline grains were obtained by grinding single crystals. The fractions of grains with required sizes were selected using the set of calibrated sieves. The samples of organic polycrystals were prepared by hot pressing of grains at pressure about 30 MPa. Such a low pressure ensures that organic grains does not fissure during the process of polycrystal preparation.

For composite scintillators we showed that such a material can be created both based on organic and inorganic grains. In the former case, efficient fast neutron detectors can be created, with selection of neutron events in the presence of background gamma-radiation, which is close to organic single crystals one. These materials can be used as selective alpha-particle or beta-particle detectors as well. In the latter case (when the grains of inorganic crystals are used), efficient detectors of thermal neutrons could be developed. Variation of the grain size allows substantial reduction of the effects of background radiation. Technology of composite scintillators production has no limitations on area and shape of the input window. Separate fragments of the scintillator can be linked together, creating endless planes. A possibility to use a base material with high radiation resistance, as well as possibility to use any scintillation material to produce the grains allows thinking about possible application of such technological approach not only for radioecological applications, but also for high-energy physics.

For a thin polycrystal stilbene, we obtain the technical light output higher than for single crystals. These polycrystals are good to detect short-range radiations. The possible applications of organic polycrystal scintillators are discussed.

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SCINTILLATION DEVELOPMENT AND PRODUCTION, WISHES AND REALITY

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A lot of new scintillation materials were invented and partly developed during last decade. But main part of them still is not available due to different reasons. It relates both to halide and oxide materials.

This review is directed to the analysis of such status of new scintilators and potential ability to resolve the problem. Such criteria of scintillation selection like application pecificy, key properties, main and additional parameters, correspondence to the light receiver and so on will be discussed.

The main aspect of this review relates to the balance between engineering wishes and reality. Technological pile ups are dictated by limits for the crystal growth, ingot size, yield and uniformity, the cost of the raw material and price. It will be shown that these pragmatic issues limit the transfer of many new scintillators to the practice. We will try to show the best options available now.

LIGHT COLLECTION IN COMPOSITE AND POLYCRYSTALLINE ORGANIC SCINTILLATORS

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Characteristics of scintillation detectors based on composite and polycrystalline organic scintillators on the one hand depend largely on the conditions of light propagation. On the other hand, a large area of the grain surface and consequently a significantly larger number of defects in comparison to single crystal influences the luminescence spectral characteristics and quantum yield. Thus, accurate determination of the absolute light output requires separation of these effects.

In this work light transport in polycrystalline scintillators based on stilbene, anthracene, and doped *n*-terphenyl was simulated using a discrete model. The sample volume was divided into cells. Each cell contained the dispersed phase particle of predetermined shape. Experimental characteristics were obtained for samples with a diameter of 30 mm and a thickness of 5 mm with various types of reflectors when irradiated by gamma quanta and conversion electrons.

The measured technical light output of polycrystalline samples was lower than that of single crystal. This difference increased in the case of excitation with conversion electrons. These patterns were observed for samples with and without a reflector. This is due to increase of the average path length of light to the exit surface both in the case of transition from single crystal to polycrystalline sample and in the case of transition from the volume excitation to a local one, remote from the output window.

The calculated light-collection efficiencies repeated experimental patterns. This indicates that the technical light output in considered detectors depends largely on the light-collection conditions. Absolute light yields calculated from experimental data were close for identical materials.

LUMINESCENCE PROPERTIES OF IRRADIATED SPINEL CERAMICS AT DIFFERENT TEMPERATURE

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The transparent magnesium aluminates spinel ($MgAl_2O_4$) ceramics possesses unique thermal, optical and mechanical properties to have different technological applications. The specific spinel structure, which includes high concentration of locally charged anti-site defects, experience at ionizing irradiation the charge rearrangement and storage of energy in the material. At the heating of irradiated material the release of charges leads to thermo luminescence (TSL), or illumination with light causes the elaboration of charges and leads to optically stimulated luminescence (OSL). Both phenomena are considering spinel as dosimetric material [1]. Spinel ceramics with LiF as a sintering aid and CeO as the dopant was prepared by the hot-pressed technique demonstrate a prospective scintillating properties [2]. In this paper we investigate luminescence properties of spinel ceramics at different temperatures and irradiated to gamma rays and high energy electrons.

The spectra of the stationary radio-luminescence (RL) of spinel crystals and ceramics demonstrate three bands: at 253, 520, and 688 nm. The last two bands are attributed to luminescence of impurity ions Mn^{2+} and Cr^{3+}, respectively. The first one is indentified with electron-hole recombination luminescence on the intrinsic crystal defects. Investigation of intensity of each band in dependence on the temperature of samples show the different temperature intervals where given band is observed. The UV-band has maximal intensity near room temperature and at temperature higher 400 K it practically demises. The intensity of Cr^{3+} luminescence is growing up from room temperature heaving maximum at about 450K. Finally, emission of Mn^{2+} ions starts to grow at 450 K having maximum at 600K. The practical meaning of this result consists in possibility to obtain emission in different spectral range under ionizing irradiation from the same sample by variation of its temperature.

To demonstrate the sensitivity of (RL) to preliminary irradiation of spinel we investigated ceramics irradiated with 16 MeV electrons to different fluences and subsequent annealed to given temperature measuring RL at room

temperature. Irradiation with electrons up to fluences of $4.2 \cdot 10^{16}$, $1.1 \cdot 10^{17}$ and $3.3 \cdot 10^{17}$ el/cm^2 makes the rearrangement of electronic subsystem of crystals and formation of optical absorption centers at cations and anions vacancies. No systematic dependences of RL intensity on the electron fluences was detected, also the change of RL for samples subjected to different annealing temperatures demonstrates the same decrease of all band in samples annealed to temperature about 400 K and maximal intensity of all RL bands was registered in samples annealed to 600 K.

TSL measurements of gamma-irradiated spinel ceramics demonstrate two maxima at 340 and 530 K, which is in accordance with temperature dependence of stationary RL. The first glow peak emits predominantly in UV range, but spectra of the second one consist of bands related to emission of impurity ions.

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APPLICATION OF INTERNATIONAL STANDARDS IN SCINITILLATION EQUIPMENT

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In the frameworks of Technical Committee of Ukraine 99 Institute for Scintillation Materials NAS of Ukraine actively participates in the work of IEC Technical committee (TC) 45 “Nuclear instrumentation”.

The paperwork of IEC SC 45B “Radiation protection instrumentation”, subcommittee of TC45, consists of development of the standards for ionizing radiation control methods, which enable detecting radiation background abnormalities in a timely manner; revealing and identifying radioactive radiation sources; preventing non-authorized distribution of nuclear materials and radioactive substances.

TC 99 actively participates in the activity of working groups IEC TC 45, developing new projects of international standards and review all projects developed by groups in IEC TC 45.

The first developed standard was IEC 62372:2006 "Nuclear instrumentation – Housed scintillators – Measurement methods of light output and intrinsic resolution" which was devoted to the measurements of the main quality parameters of scintillators and their products, i.e. "intrinsic resolution and light output" where absolute method intended for the measurement of housed scintillator’s technical light output on the basis of any scintillation material was proposed.

The was another very essential standard for scintillation instrumentation IEC 60462:2010 "Nuclear instrumentation – Photomultiplier tubes for scintillation counting – Test procedures", which has had a big impact both for manufacturers of photomultiplier and for the customers, since it allows to have the same approach to the determination of photomultiplier’s characteristics.

The purpose of IEC 60412:2014 **"**Nuclear instrumentation – Scintillation detectors – Nomenclature (identification) – Standard dimensions of scintillators**"** was to standardize the nomenclature of scintillation detectors which contained the maximum quantity of the properties, as well to standardize scintillator’s dimensions in order to facilitate interchangeability of the scintillators without a housing, and to compare the measurements to the housed scintillator.

Standardization of the indications within scintillation detector’s nomenclature is aimed to achieve the optimum degree of regulation by establishing

provisions for the general and multiple applications of scintillation detectors and for the unity in the measurements of the main scintillation parameters for scintillation instrumentation tasks. It allows reducing the timing and costs due to application of already developed indication charts, which significantly simplifies the search while ordering the products and makes it easy to classify the products.

As an example of the company which uses this standard, Scionix (the Netherlands) can be named which has been extensively using developed nomenclature. In our opinion, more and more companies producing scintillation products will use these indications to designate their scintillation products.

Introduction of the international standards is becoming a necessity nowadays. Not only do they establish the image of the company, but they also serve as a pass to the world market removing the trade barriers to settle profitable agreements and to enable the free movement of the goods all over the world.

ABOUT VARIOUS CONCEPTS OF QUALITY EVALUATION FOR SCINTILLATORS LIGHT OUTPUT MEASUREMENTS

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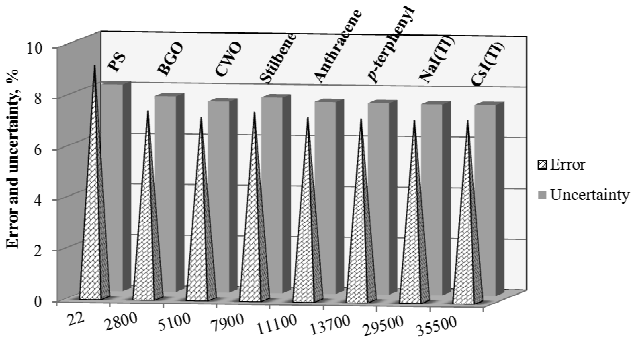
The measurement results quality evaluation of various units is made now with using «uncertainty concept» in accordance with international recommendation GUM (Guide to the Expression of Uncertainty in Measurement). However, many normative documents are oriented to traditional approach based on «error concept».

It is absent contrasting between error and uncertainty in GUM. It is indicated there, that measurement uncertainty can by perceived as possible error measure, because we can't know error exactly. For this reason measurement uncertainty occurs. GUM offers to different error concept as measure model, approximate to reality, and measurement uncertainty as possible inaccuracies measure of experimental results.



	22	2800	5100	7900	11100	13700	29500	35500
Error	9,17	7,42	7,18	7,41	7,22	7,20	7,17	7,17
Uncertainty	8,15	7,71	7,53	7,71	7,56	7,54	7,52	7,52

Fig. Error and uncertainty of scintillators light output measurement

We investigated different scintillators with light output (relative to working standards) from 20 photons/MeV to 35000 photons/MeV: cylindrical NaI(Tl), CsI(Tl), CWO, BGO, *p*-terphenyl, anthracene, stilbene and polystyrene strips. Estimation results are shown in Fig. Errors estimation are in the interval from 9.2 % to 7.2 %, uncertainty from 8.2 % to 7.5 %.

The conclusion is made that logical conflict for joint using of «error concept» and «uncertainty concept» is absent.

INFLUENCE OF A CRYSTAL SCINTILLATOR STRUCTURE ON THE ENERGY RESOLUTION OF A HOMOGENEOUS ELECTROMAGNETIC CALORIMETER

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It was predicted and experimentally observed in 1980-th [1–3] that both electron-positron pair production (PP) by gamma-quanta and gamma-quanta emission from electrons and positrons are strongly enhanced in oriented crystals at the energies exceeding tens of GeV. Scintillating crystals are widely used in the electromagnetic calorimeters, e.g. the electromagnetic calorimeter ECAL of Compact Muon Solenoid (CMS) at LHC is made of PWO crystals. In spite of this, the influence of the crystal structure on the process of electron, positron and gamma-quanta energy measurements was neither analyzed, nor taken into consideration in the determination of both the measured energy value and energy resolution. We report the first results of simulations of the electromagnetic shower development accelerated by the processes described in [1–3] in the PWO crystals manufactured for the ECAL CMS.

To estimate the maximum PWO crystal structure influence on the energy deposition, the GEANT4 simulation of electromagnetic shower development in a structureless PWO *standard* sample was used as a benchmark. Then, the characteristics of both $e^{\pm}$ PP and γ-quantum emission in the PWO crystal have been evaluated by the method [4, 5] for various γ and $e^{\pm}$ energies. The obtained PP probabilities and $e^{\pm}$ energy loss lengths, increased due to the influence of the PWO crystal structure, have been introduced into the GEANT4 simulations through the increase of the corresponding values for the structureless PWO. These simulations demonstrate that the maximum of the energy deposition by both $e^{\pm}$ and γ with the initial energy of several hundred GeV is shifted by 2–3 radiation lengths while the longitudinal energy leakage is decreased by about 1%.

These estimates represent themselves the maximum effect of the PP and radiation enhancement [1–3] reached at submilliradian angles of $e^{\pm}$, γ incidence w.r.t. PWO main crystal axes. Most of $e^{\pm}$ and γ hit the PWO crystals in CMS at considerably larger angles, inducing the less, however also considerable electromagnetic shower acceleration [1–3], strongly dependent on the

angle between particles' incidence directions and a crystal axis. Considerable spread of $e^{\pm}$, γ incidence directions makes the latter to be a source of additional energy measurement uncertainty in the existing electromagnetic calorimeters. However in future detectors, intentionally designed to make the direction of $e^{\pm}$, γ incidence to be coordinated with that of main axes of scintillator crystal at the milliradian level, the same effects of the PP and radiation enhancement [1–3] will be able to provide a considerable decrease of the absorption length of electromagnetic showers induced by all the $e^{\pm}$, γ of arbitrarily high energies.

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ENERGY RESOLUTION OF THE FLAT THIN DETECTOR BASED ON THE USE OF $LaBr_3$:Ce CRYSTAL AND OF VACUUM TYPE PHOTOMULTIPLIER TO BE USED FOR THE LIGHT IONS DETECTION WITH THE ENERGY OF UP TO 20 MeV/NUCLEON

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We report on the performance of the flat shape, thin frontal wall scintillating crystal detector of the light ions with energies up to 20 MeV per nucleon.

The detector that is based on the use of $LaBr_3$:Ce crystal and of the vacuum type photomultiplier was exposed to the tandem van-der-Graaf accelerator beam of protons and ions of ^{4}He, after being calibrated in laboratory with the use of conventional set of radioactive isotopes.

Energy resolution of the detector to the light ions as derived and of detector potential use will be discussed in this talk.

DESIGN OF HOMOGENEOUS ELECTROMAGNETIC CALORIMETER WITH HEAVY CRYSTALS OPERATING IN MAGNETIC FIELDS

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In physical experiments the electromagnetic calorimeters (ECAL) are used to measure the deposited energy and particle identification. Homogeneous segmented ECALs are universal, as they are able to provide the necessary length of interaction and compactness, using high density crystals, having a minimum value of radiation length. However, the energy resolution of homogeneous segmented ECAL may deteriorate, because of the fluctuations caused by loss of the electromagnetic shower in the active (scintillator) and absorption (reflective wrapper) layers of the optical medium. In addition, when one uses crystals with a high index of refraction a significant part of emitted photons falls into the "optical trap" due to total internal reflection from the polished surfaces of the crystal, and therefore, more than 50% of the light doesn't reach the photo-detector.

It should be noted that for homogeneous segmented ECAL, located in a magnetic field, the electromagnetic showers can be developed in various directions relatively to crystal axis, so they not paraxial anymore. In turn the distance from the crossing point of electron tracks in the crystal to the photo-detector also varies and so does the light yield due to varying light losses. This raises the non-uniformity of light collection of the scintillation photons along the crystal length, which degrades the energy resolution and the accuracy of the measurement of the deposited energy in the calorimeter. Thus, for homogeneous segmented ECAL, located in a magnetic field, the accuracy of measurement of energy deposited and energy resolution is influenced by: 1) electromagnetic shower losses in construction materials (reflective wrapping etc.) and leakage outside the material of the scintillator during passage of high energy particles through alternating layers of the calorimeter; 2) scintillation photons losses in calorimeter cell, depending on the track location in the crystal; 3) dependence of the deposited energy in the cell on the angle between particle track and cell axis (the angular energy dependence).

Therefore, the aim of this work was to study the processes which affect the accuracy of measuring the energy deposited in the segmented ECAL by passing 105 MeV electron beam through the cells, and the development of

methods and algorithms to improve the accuracy of determination of the energy during measurements and data handling.

The processes affecting on light collection of emission of photons in the crystal – the self-absorption of light in the scintillator; losses associated with the reflection of light on crystal surfaces – depending on the position of the particle track in the crystal were investigated. The techniques of the reducing of light collection of light yield non-uniformity, consisting in optimization of crystals wrapping by the reflective materials (tape type, thickness) were developed. It was experimentally found the best results in terms of energy resolution can be obtained for the combined-type wrapping: the lateral surface of the crystal first wrapped with two layers of Teflon, and then a layer of ESR tape outside; end surface of the crystal is covered by the mirror-type reflector.

Algorithm of measured energy correction for light yield non-uniformity and angular effects for non-paraxial electromagnetic showers in the crystal ECAL based on spatial track reconstruction is proposed and successfully tested with prototype LYSO crystal matrix. From the obtained results it was found that measurement error of energy deposited by cosmic muons at an angle of 20 degrees was approximately 6.7 %, which agrees well with the results obtained in the calorimeter prototype test at Tohoku.

DEVELOPMENT OF GEANT4 OPTICAL MODEL OF LYSO CRYSTAL

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Geant4 simulation is an important task when creating the electromagnetic calorimeters. In such simulations many design parameters can be varied much more easily than in measurements. Geant4 simulation includes the following tasks: determining the expected parameters of the calorimeter using different types of crystals and wrappers; determination of the optimal structure and geometry of the calorimeter.

Optical photons are primary information carriers in any scintillation detectors: the scintillation process, the transport of the scintillation photons through the crystal towards the photo-detector and the conversion of these photons into electronic signals all have a major influence on the calorimeter performance. Thus, for many experiments, for example COMET, where requires high energy resolution and accuracy of energy measurement, the optical model of actual crystal should to be taken into account in Geant4 simulation of electromagnetic calorimeters to obtain accurate results.

A comparison of simulations and measurements of LYSO crystals shows that the optical models of Geant4 enable accurate prediction of the spatial and energy resolutions of such scintillation detectors, provided that all necessary input parameters are known with sufficient accuracy. To create the optical model of actual scintillator some required optical parameters as a function of wavelength or energy was obtained within SLitrani package. Also experimental measurements of some optical parameters (light output, the loss along the length of the crystal, energy resolution of the crystals, time decay, emission spectrum) were carried out.

In the first stage, the optical model of actual scintillator was developed using SLitrani simulation and then after verification, it was included in the Geant4 simulation.

A validation of Geant4 optical models was performed by simulation of energy spectra of LYSO crystals and comparing the predicted spatial and energy resolution to experimental spectra obtained under the same conditions. From the comparison of results simulation and measurements it was found that the optical model describes well the optical processes of the actual scintillator and can be used for Geant4 simulations.

Geant4 simulation of the optimal structure and geometry of the calorimeter were made, the energy resolution of 4.8 % for LYSO crystal was obtained.

As results in this work, optical Geant4 simulation require accurate knowledge of a relatively large number of input parameters. Not all of these parameters may be readily available. This work demonstrates how the required optical parameters can be determined such that accurate simulations become possible.

IONIZING RADIATION SPECTRUM OPTIMIZATION FOR THE PERSONAL INSPECTION X-RAY SYSTEMS

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Expanding application of personal inspection X-ray scanners to detect restricted or prohibited objects in/on the human body sets problem of their parameters optimization. Image quality and dose during inspection are the most significant among such parameters [1, 2]. Mathematically this is multi-objective multi-parameter optimization problem. In general, the main parameters are determined by the spectrum of the detected X-rays, which depends on the material of anode target, accelerating voltage, composition and thickness of additional filter.

Some optimization parameters have narrow range of allowable variation and can be set a priori. For example, tungsten is widely used for anode target having the highest operational performance and very large radiation output. Also, the set of materials for additional filtration is highly constrained. In particular, only aluminum and copper are widely applied as filtration materials in personal inspection x-ray systems for the reasons connected with the manufacturability. Brass $Cu_{0.63}Zn_{0.37}$ was considered as a promising filtration material which is more technologically suitable and at the same time having comparable attenuation properties like copper.

Thus, the aim of this investigation is to define brass filter thickness at which the optimal spectrum is formed using x-ray source with tungsten anode target. The quality of image acquired was estimated with relative contrast of test object to the background of the water phantom. The dose was evaluated assuming complete absorption of scattered ionizing radiation inside phantom. This problem was solved with mathematical simulation in the framework of phenomenological approach [1, 2] taking into account angle distribution of photons emitted and geometrical configuration of inspection system. Additionally, the solution of digital detector signal profiling in the region of inspection interest was obtained.

As a result optimal values of brass filter thickness and anode voltage for personal inspection x-ray scanner model are obtained. Also the profile of filter thickness required for desirable digital x-ray detector signal profile was evaluated.

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ОПЫТ И ПЕРСПЕКТИВЫ ПРИМЕНЕНИЯ ПРИБОРОВ СЦИНТИЛЛЯЦИОННОЙ СПЕКТРОМЕТРИИ ДЛЯ ЗАДАЧ РАДИАЦИОННОЙ БЕЗОПАСНОСТИ НА АЭС, ЭКОЛОГИЧЕСКОГО КОНТРОЛЯ И МОНИТОРИНГА

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Исходя из опыта эксплуатации спектрометрических систем собственной разработки оценивается достаточность контроля барьеров безопасности АЭС и делаются выводы о возможных путях улучшения состояния дел в области аппаратного обеспечения радиационного контроля. Представлены основные характеристики гамма, бета-спектрометров, спектрометров излучения человека, спектрометрических комплексов для АЭС.

Для изготовления большинства приборов преимущественно используются сцинтилляционные детекторы β- и γ-излучения, среди которых:

– Лабораторные спектрометры энергии β- и γ-излучения.
– Спектрометры излучения человека серии «СИЧ-АКП».
– Передвижные γ-спектрометрические установки для:
  - определения активности и радиоизотопного состава твердых радиоактивных отходов (ТРО) первой и второй групп без проведения пробоотбора;
  - поиска радиоактивных источников и определения радиоактивного загрязнения территорий в зонах аварий (полевая спектрометрия);
  - определения состава радионуклидов в сухих и заполненных водой скважинах.
– Устройство детектирования типа УДЖГ для измерения объемной активности γ-излучающих нуклидов в жидкости технологических контуров АЭС.
– Программно-технический комплекс определения протечек в парогенераторах по активности ^{16}N в остром паре «Азот-16-ПГ».
– Спектрометрический комплекс контроля активности теплоносителя первого контура СТПК-01 на основе полупроводникового детектора.

Рассмотрены возможности и перспективы использования приборов сцинтилляционной спектрометрии для решения широкого круга вопросов радиационного контроля техногенных и естественных радионуклидов в окружающей среде. Также описаны разработки для систем радиационного контроля (СРК) АЭС.

RAMAN AND PHOTOLUMINESCENCE IN DIAMONDS IRRADIATED WITH SWIFT XENON IONS

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Synthetic diamonds of type Ib irradiated with 167 MeV Xe ions were studied using Raman spectroscopy and photoluminescence (PL) techniques. The samples were irradiated at the IC-100 FLNR JINR cyclotron (Dubna, Russia) with fluences ranging from 10^{10} to $6.2 \cdot 10^{12}$ cm^{-2}. Raman and PL spectra were registered in backscattering mode using "Nanofinder High End" (LOTIS TII, Tokyo Instruments) confocal spectrometer. The measurements were performed with excitation wavelength 532 nm at room temperature in a Raman shift range of 50–6000 cm^{-1}. The spectra were measured across a thickness of the irradiated layer with spatial resolution about 1 micron.

Main aim of this work was to study the radiation damage/impurity profiles in the irradiated material and comparison with those predicted by SRIM-2000 code calculation.

Raman spectra of structurally perfect diamond contain single narrow (~1.6 cm^{-1}) line due to light scattering by crystal lattice vibrations peaked at 1332 cm^{-1} [1]. In irradiated samples additional lines, associated with both Raman scattering and photoluminescence are registered. In particular, the PL spectra of irradiated diamond have narrow lines ascribed to point defects: 575, 638 nm (NV^0, NV^- centers [2]) and 743 nm (neutral vacancy [2]). Raman scattering demonstrates a narrow line at 1635 $см^{-1}$ associated with interstitial carbon atoms [2].

As was found the intensity of 1332 cm^{-1} line decreases and its width increases from the surface to a depth of 8.4 microns in the irradiated layer while from 8.4 to 11 microns the line width and intensity of 1332 cm^{-1} are restored to the values corresponding to the non-irradiated diamond. Position of this line is 1332.15 cm^{-1} and is not changing along the ion path. Characteristic depth of 11 microns is very close to calculated ion projected range 10.67 microns. It should be noted the inhomogeneous (low frequency) broadening of that line is due to nonuniform distributions of defects and associated stress in the irradiated region.

Luminescence intensity of all centers is gradually reduced along the ion path. Nevertheless the 743 nm PL line and Raman line 1635 $см^{-1}$ are detect-

able up to 11 microns while the lines of NV center disappear at depth about 9 microns.

The ability to register both vacancy luminescence and interstitial Raman lines along whole ion range allows using them as markers of damaged area, while non monotonic behavior of main Raman line could be used for monitoring of stress in the irradiated layer.

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ИСПОЛЬЗОВАНИЕ ГЕОМЕТРИИ ТЕПЛОВЫХ НЕЙТРОНОВ ПОВЕРОЧНОЙ УСТАНОВКИ НЕЙТРОННОГО ИЗЛУЧЕНИЯ УПН-АТ140 КАК ИСТОЧНИКА ЗАХВАТНОГО ГАММА-ИЗЛУЧЕНИЯ С ЭНЕРГИЯМИ ДО 10 МЭВ ДЛЯ КАЛИБРОВКИ СЦИНЦИЛЛЯЦИОННЫХ БЛОКОВ ДЕТЕКТИРОВАНИЯ

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Развитие и распространение техногенных источников высокоэнергетического гамма-излучения, таких как линейные ускорители электронов, приводит к появлению ряда прикладных задач радиационной защиты, в которых спектрометрические и дозиметрические измерительные приборы используются в полях фотонных источников в диапазоне энергий от 4 до 10 МэВ.

Для метрологического обеспечения измерений необходимо знание отклика средств измерений в пределах измеряемого энергетического диапазона. Кроме того, расширение энергетического диапазона измерений мощности дозы гамма-излучения до 7 МэВ диктуется и требованиями международных стандартов [1].

Таким образом, существует практическая необходимость калибровки спектрометрических и дозиметрических приборов в диапазоне энергий гамма-излучения до 7 МэВ и до 10 МэВ. Для корректной калибровки необходимо наличие в эталонном спектре излучения одиночных линий с известной энергией. При калибровке до 3 МэВ эту проблему можно решить при помощи набора радионуклидных гамма-источников (таких как Cd-109, Am-241, Co-57, Cs-137, Co-60, Ra-226 и др.)

Гамма-кванты с энергиями более 3 МэВ могут быть получены в результате радиационного захвата нейтрона ядром мишени, т. е. ядерной реакции. Сечение реакции радиационного захвата нейтронов ядрами мишени увеличивается с уменьшением энергии нейтронов. Быстрые нейтроны от радионуклидных источников нейтронов могут быть замедлены до тепловых энергий при помощи водородосодержащих замедлителей (полиэтилен, парафин, вода) и направлены на мишень. Таким образом, простейший источник мгновенного захватного гамма-излучения

должен состоять из источника быстрых нейтронов, замедлителя нейтронов и облучаемой тепловыми нейтронами мишени. При проектировании такого источника необходимо учитывать, что в спектре гамма-излучения будут присутствовать характеристические линии захватного излучения от материалов замедлителя, от конструкционных материалов, от биологической защиты источника, стен помещения и воздуха. Такие гамма-линии могут накладываться на эталонные линии от мишени и ухудшать "качество" излучения. Поэтому материалы необходимо подбирать с наименьшими значениями сечения радиационного захвата нейтронов и с характеристическими линиями, значительно отличающимися по энергии от линий мишени.

Так как энергия гамма-излучения при радиационном захвате соответствует переходам между энергетическими уровнями ядра мишени, то каждый материал будет обладать своим уникальным набором энергетических линий [2]. Для калибровки спектрометров необходимо, чтобы материал мишени имел набор одиночных линий в широком диапазоне энергий с достаточно большими сечениями захвата нейтронов. Для калибровки по энергии до 7 МэВ в качестве мишени можно использовать титан, а по энергии до 10 МэВ – никель [3, 4].

К настоящему времени известны примеры построения источника захватного гамма-излучения на основе Cf-252 и Am-Be-источников нейтронного излучения [5, 6].

Целью данного исследования является изучение при помощи моделирования методами Монте-Карло возможности использования стандартного коллиматора тепловых нейтронов установки поверочной нейтронного излучения УПН-АТ140 (геометрия УКПН) с 238Pu-Be источником нейтронов (типа ИБН-8-6), как источника гамма-излучения в диапазоне энергий до 9 МэВ для поверки и калибровки спектрометров и дозиметров гамма-излучения в расширенном диапазоне энергий.

Преимущество метода Монте-Карло перед другими методами определяется возможностью рассмотрения частиц в сколь угодно сложных по геометрическим условиям и по составу средах без необходимости использования существенных упрощений в вычислительном алгоритме.

Монте-Карло моделирование проводилось с помощью кода MCNP (версия MCNP 4b) [7]. Данный код позволяет получить хорошую сходимость с экспериментальными данными. Была разработана подробная модель коллиматора тепловых нейтронов установки поверочной нейтронного излучения УПН-АТ140, 238Pu-Be-источника нейтронов и помещения.

В ходе работы при помощи моделирования методами Монте-Карло определены энергетические распределения плотности потока фотонов

для мишени из титана и из никеля, а также без мишени. Проведена оценка мощности кермы при различных вариантах мишеней и фильтрации рассеянного гамма-излучения.

Получены экспериментальные спектры захватного гамма-излучения, для спектрометрических блоков детектирования БДКГ-11М NaI(Tl) 63×63мм и БДКГ-19М NaI(Tl) 63×160мм с расширенным энергетическим диапазоном до 10 МэВ.

Данные, сформированные в результате моделирования и экспериментов, будут использованы при выборе оптимальной геометрии фильтрации гамма-излучения и нейтронов.

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THE CHOICE OF ACTIVE MATERIALS FOR USE IN THE EXPERIMENTS AT HIGH LUMINOSITY COLLIDERS

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Further physic programs at the LHC accelerator will require an increase of the luminosity up to 300 fb^{-1} per year from 2023 with an integrated luminosity of 3000 fb^{-1} by 2023 to 2033. At such luminosities, charged hadrons with fluence higher than 10^{14} p/cm^2 per year in a large pseudo-rapidity region of the detectors will have a non-negligible influence on the radiation damage of materials. Even stronger damage effects are expected at Future Circular Collider (FCC) experimental facilities. Moreover, with the increasing activetion of the experimental setups, it will become more difficult to periodically replace and maintain the detector elements for radioprotection issues for the personnel. Therefore for the selection of the materials for new detectors in such high radiation environment, a more reliable assessment of the risks of detector failures due to high radiation environment is required. Such assessment can be made through the consideration of the radiation damage effects occurred in the chosen components of the detector.

For last six years we carry on systematic study the damage effects under high-energy protons. The unique possibility to irradiate the crystal samples with 24 GeV protons of the PS accelerator with the 10^9 p/cm^2s flux with fluence up to 10^{14} p/cm^2 contributed to the progress in this research.

Recently, to the elation of many researchers, it has been established that the damage effects at 150 MeV protons is similar to the effects measured after the irradiation with 24 GeV protons. It is well known [21] that the cross-section σ_f of the heavy nucleus fission under protons strongly depends on the energy of the incidental particle. For instance, for a ^{208}Pb nucleus, it shows a fast growth from 10^{-7} to 0.1 b in the incident particle energy range from 20 to 90MeV followed by an increase up to 1bn at the energy of 1GeV. Smooth behavior of the σ_f energy dependence in the range above 100 MeV allows extrapolating this behavior to the range of a few tens of GeV. Thus, the effect of the irradiation under 150 MeV protons will be the same than 24 GeV for the same order of fluence but smaller in magnitude because σ_f(150 MeV)< σ_f(24 GeV). The observed identity of the damage effects under low energy protons considerably simplifies the investigations of the effect of hadron damage. Several accelerating facilities, having relatively cheaper proton

machines with energy in the range 150–200 MeV became suitable for routine measurements of the damage effects.

We give a review of the last results of the radiation damage effects in scintillation materials used in high energy physics experiments, that are caused by high energy hadrons, the main contributors to the irradiation environment at experimental facilities of forthcoming High Luminosity LHC and future FCC.

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IONIZING RADIATION SOURCES-BASED SYSTEMS TO CONTROL THE STARTING MATERIAL DISTRIBUTION IN REACTOR TARGETS FOR RADIONUCLIDES ACCUMULATION

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One of the areas where nuclear research reactors (RRs) are used is the accumulation of radionuclides for medicine, science and industry. As a result of the nonuniform distribution of the starting material, a target may leak due to localized overheating, that is unacceptable.

JSC "SSC RIAR" operates six research reactors and has equipment to control the starting material distribution in radionuclides accumulating targets of various geometry: flat, cylindrical, ring. All nondestructive testing techniques are based on the method of targets exposing to emission from purposely-made sources and recording its attenuation. Depending on the target thickness, an appropriate emission source is selected: generally, ^{55}Fe is selected for thin targets and ^{133}Ba is selected for thicker ones.

The ^{55}Fe-based source shows continuous emission in the range of 30–220 keV and is made as an X-ray tube. The radiant energy being low, this source is acceptable to work with thin materials (up to 0.6–0.7 g/cm^2). The ^{133}Ba source shows a characteristic radiation line of 356 keV and allows exposing the materials with the surface density more than 1 g/cm^2. All unique design sources were developed and manufactured in JSC "SSC RIAR". The material for the sources was also accumulated in the RIAR's reactors.

The paper presents some options of the implemented measurement equipment. All devices are equipped with a purposely-made emission source, scintillation or semiconductor detector, mechanism to move a target along the predetermined path in relation to the source collimator as well as specialized software to operate the target movement mechanism and for mathematical processing of emission spectra.

A device to determine the uniform distribution of the starting material in a target, which accumulates transuranium elements (TUEs), is designed to control cylindrical targets. The specific feature of these targets is that the core contains radioactive nuclides (Pu, Cm and Am heavy isotopes). Therefore, measurements can be taken in the hot cell only.

Devices to measure the uranium distribution in the rod-type (UIRUM-S) and ring-type (UIRUM-K) targets are designed to control targets for ^{99}Mo accumulation. The emission source is based on ^{55}Fe.

A device to control surface density of the uranium cores is designed to control flat samples up to 10-mm thick using gamma emission from the ^{133}Ba source.

СИСТЕМА УПРАВЛЕНИЯ, СБОРА ДАННЫХ И ДИАГНОСТИКА ПУЧКА МАСС СЕПАРАТОРА MASHA

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Описаны системы управления, сбора данных и диагностики пучка экспериментальной физической установки “MASHA”, разработанной для прямой идентификации по массе сверхтяжелых элементов в ходе их синтеза на пучках ускоренных тяжелых ионов.

Система управления установки MASHA разделяется на три логические части:

- Управление масс-спектрометром;
- Управление ЭЦР источником ионов;
- Управление горячей ловушкой и мишенным устройством.

При построении аппаратной архитектуры системы управления были задействованы логические контроллеры Smartbox, предназначенные для создания модульных масштабируемых распределенных систем автоматизации промышленных и научно-исследовательских установок, разработанные в ЛЯР ОИЯИ. Помимо этого, в системе присутствует большое количество устройств с цифровыми интерфейсами RS-232/485. Управление производится с помощью компьютерной программы разработанной на LabVIEW.

Развитие системы управления ведется в направлении повышения гибкости и общего упрощения. Предполагается, что основной системой, увязывающей различные исполнительные устройства и датчики в масс сепараторе MASHA, станет сетевая магистраль CAN, в которой находятся контроллеры WAGO 750-837, обрабатывающие данные на шине CAN согласно протокола CANopen. Протокол CanOpen позволяет соединять несколько сетей CAN и компьютерную сеть посредством различных шлюзов. Проверка входных данных с датчиков и установка параметров на исполнительные устройства в реальном времени

производятся в программном блоке контроллера WAGO 750-837, а конфигурирование, мониторинг и управление производится через Ethernet-шлюз в компьютерной сети в программе разработанной на Lab-view.

Мониторинг параметров пучка и сбор данных о свойствах продуктов реакций производятся через различные цифровые и аналоговые модули, объединенные в стандарте PXI. Так система сбора данных состоит из высокоскоростных АЦП XIA PIXIE 16, синхронизованных посредством шины синхронизации PXI. Сохранение данных производится по мере заполнения внутренней памяти каждого из цифровых модулей, выполняется по шине PXI и контролируется непосредственно из встроенной операционной системы Windows. В процессе сохранения данных добавляется информация о параметрах пучка, получаемая по сети Ethernet.

INFLUENCE OF FLUORINE DOPING ON LUMINESCENT PROPERTIES OF CADMIUM AND ZINC TUNGSTATES

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Tungstates single crystals are interesting as effective converters of the high-energy radiation to the visible light. New tasks arising in different areas of science and technology, for example, the registration of rare events in the physics of elementary particles, require the improvement of optical and luminescent properties of tungstates by doping and co-doping.

Previously it was shown that the fluorine doping of $PbWO_4$ crystals leads to the increase of lattice constants, decrease of the oxygen vacancies concentration, formation of WO_3F centers and improvement of radiation hardness [1, 2]. Also co-doping with univalent metals and fluorine ions improves the transparency and scintillation yield of $ZnWO_4$ [3]. In the present paper we have studied the influence of fluorine doping on the optical and luminescent properties of $ZnWO_4$ and $CdWO_4$ crystals. It was demonstrated that fluorine doping does not modify the spectral composition of luminescence, but leads to decrease of emission intensity at the intraband excitation. The effect is connected with decrease of the energy transfer efficiency of separated e-h pairs to the intrinsic luminescent centers.

All investigated $ZnWO_4$ and $CdWO_4$ single crystals were grown using Czochralski method. Measurements were performed at the SUPERLUMI station (DESY) and at the laboratory set-up.

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ATLAS EXPERIMENT AND UPGRADE PROGRAM

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Run-I at the LHC was very successful with the discovery of a new boson with properties compatible with those of the Higgs boson predicted by Standard Model. Precise measurements of the boson properties, and the discovery of physics beyond the Standard Model, are primary goals of the restarted in 2015 LHC running at 13 TeV collision energy and all future running at the LHC. Meanwhile, plans are actively advancing for a series of upgrades of the accelerator, culminating roughly ten years from now in the high-luminosity LHC (HL-LHC) project, delivering of the order of five times the LHC nominal instantaneous luminosity along with luminosity levelling. The ultimate goal is to extend the dataset from about few hundred fb^{-1} expected for LHC running to 3000 fb^{-1} by around 2035 for ATLAS experiment. In parallel, the experiments need to be keep lockstep with the accelerator to accommodate running beyond the nominal luminosity. Along with maintenance and consolidation of the detector in the past few years, ATLAS has added inner b-layer to its tracking system. The challenge of coping with the HL-LHC instantaneous and integrated luminosity, along with the associated radiation levels requires further major changes to the ATLAS detector. The designs are developing rapidly for a new all-silicon tracker, significant upgrades of the calorimeter and muon systems, as well as improved triggers and data acquisition. ATLAS is also examining potential benefits of extensions to larger pseudorapidity, particularly in tracking and muon systems. This report summarizes various improvements to the ATLAS detector required to cope with the anticipated evolution of the LHC luminosity.

ON THE POSSIBILITY TO USE MAGNESIUM OXIDE FOR SELECTIVE DETECTOR OF FAST NEUTRONS

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In the field of luminescent dosimetry the most complex and unsolved problem is the selective detection of fast neutron fluxes. One of the reasons of this problem is the fact that all real neutron sources have either gamma-radiation (γ) background or background radiation of charged particles. This significantly complicates the dosimetry of fast neutrons. Some approach for solution of this problem for neutron fluences in the range of 10^{16}–10^{18} n/cm^2 on the basis of MgO is discussed in [1, 2]. However, the sensitivity of detectors based on nominally pure MgO is rather low, especially, at fluences lower than 10^{16} n/cm^2, making it difficult to use them in practice. The possible way of increasing the sensitivity is the introduction of impurities (doping). In particular, in case of reactor irradiation in mixed n, γ field (IBR-2) at comparatively weak fluences (< $1\cdot10^{16}$ n/cm^2) the impurity of Mn^{2+} in MgO increases the intensity of luminescence of irradiated crystals, so the slope of dosimetric curve is becoming considerably steeper in the range 10^{13}–10^{16} n/cm^2 than in case of samples without impurities.

In this paper we present the results of investigation of perature thermoluminescence (TSL) in the high tem range 300–775 K in MgO-LiF ceramics after irradiation in reactor IBR-2 (Dubna). Most intense glow peaks at maxima of 456, 556 and 693 K was observed for samples irradiated with low fluences of neutrons ($4.1\cdot10^{14}$ n/cm^2). At the increasing of fluence the TSL peaks at 556 и 693 K demise, intensity of 456 K peak decreases, but there appears new peak at 612 K. To clarify the role of influence of accompanied γ irradiation on the resulting TSL curves we provided measurements of TSL curves irradiated from ^{60}Co source. The glow curves of γ-irradiated samples are similar to that of irradiated in reactor at low fluences except peak at 612 K, which can be served as dosimetric characteristic for detection of neutrons.

The new information was obtained from the measurements one of the same sample by using two independent methods (EPR and optical spectroscopy) [3]. Finally we obtained the correlated data on the dependences of TSL intensity peak and concentration of F-type centers on the neutron fluence in

the range of $2.0 \cdot 10^{14}$–$1.0 \cdot 10^{17}$ n/cm^2. Therefore, we show the possibility for creation of the combined Optic-EPR-TSL detector on the basis of MgO-LiF that provide the high reliability of results. At least, it is obvious that the ceramic samples of this composition are very prospective for dosimetric purposes.

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INITIAL IONIZATION DISTRIBUTION IN ACTIVE VOLUME OF IONIZATION CHAMBER

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Spatial distribution of ion pairs in the sensitive volume of the fission ionization chamber is under consideration in a few papers. They present various formulas for this quantity having different, sometimes unphysical, behavior near and far from the fissile material surface.

Correct expressions for the ionization density *N(r, z)* inside workspace of cylindrical fission chamber have been derived. When the layer of fissile material is put on the internal electrode of the chamber, simple physical consideration of the ionization mechanism in the gas gives us the following expression:

$$N(r,z) = \frac{N_0 R_a}{2\pi}\int_{-\theta_{1\max}(r)}^{\theta_{1\max}(r)}\int_{z_{\min}}^{z_{\max}} X(r')H(l-r')\frac{\left[r\cos(\theta')-R_a\right]dz'd\theta'}{\left(r^2+{R_a}^2-2rR\cos(\theta')+(z-z')^2\right)^{3/2}}.$$

In another case, when the layer of fissile material is put on the external electrode the spatial distribution of ion pairs can be written in the form:

$$N(r,z) = \frac{N_0 R}{2\pi}\int_{-\theta_{2\max}(r)}^{\theta_{2\max}(r)}\int_{z_{\min}}^{z_{\max}} X(r')H(l-r')\frac{\left[R-r\cos(\theta')\right]dz'd\theta'}{\left(r^2+R^2-2rR\cos(\theta')+(z-z')^2\right)^{3/2}}.$$

where N_0 is the surface density of the fission fragments, z is a coordinate along the chamber. (R_a,θ',z') is a cylindrical coordinate of the fissile material surfaceelement, r is a radial distance of the point of interest inside the workspace. R and R_a is cathode and anode radius. r' is the length of fragment trajectory in chamber workspace. $X(r')$ is the average number of ion pairs created by a fission products per unit of length traveled in the gas (linear ionization density along the trajectory).

$$\theta_{1\max}(r) = \arccos\left(\frac{R_a}{r}\right);\ \theta_{2\max}(r) = \arccos\left(\frac{R_a}{R}\right)+\arccos\left(\frac{R_a}{r}\right).$$

The integration in (1) and (2) is performed over the part of the layer surface, that can be seen from the point $\vec{r} = (r, \theta, z)$ of interest inside the workspace. *H(l-r')* is Heaviside function which reflects the fact that integration in (1) and (2) is performed also under condition that the length of fragment trajectory is restricted by the minimal value which is the length of mean free path *l* of the fission fragments.

Formulas (1) and (2) give the correct behavior of the spatial distribution of the ionization density in any point in the sensitive volume of the cylindrical fission chamber.

COMPARISON OF SINGLE CRYSTALLINE AND COMPOSITE SCINTILLATORS FOR HADRON CALORIMETRY AT HIGH LUMINOSITY LHC

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Further physical programs at the LHC will require a significant increase of the accelerator luminosity throughout the High Luminosity phase of LHC. During this period, charged hadrons with fluences higher than 10^{14} p/cm^2 per year in the largest pseudo-rapidity regions of the detectors will have a non-negligible influence on the radiation damage of materials. Moreover, with the increasing activation of the experimental equipment, it will become more difficult to periodically replace and maintain the detector components. Therefore, the selection of materials for new detectors to be used at the upgrade of experimental setup requires a more reliable assessment of the risks of detector failures due to severe radiation damage. During last few years we performed systematic studies of the damage effects in inorganic scintillation materials. The results obtained confirmed that $Y_3Al_5O_{12}$:Ce (YAG:Ce) crystal has a very low optical transmission damage after irradiation with 24 GeV protons up to the fluence of 5×10^{14}p/cm^2.

In addition to the single crystalline option we developed and tested a composite scintillation material consisting of YAG:Ce grains compacted by gluing (Sylgard-184) in a translucent body with density up to 65% of the single crystal, i.e. around 3 g/cm^3. As all the components of the composite module are selected to be radiation hard, such technology can be considered a suitable option to replace plastic scintillators in the region of the detector where high radiation hardness is required.

In this study, we report the results of a comparative tests of the YAG:Ce single crystals and YAG:Ce/quartz composite modules scintillation properties and radiation tolerance.

КАЛИБРОВКА СЦИНТИЛЛЯЦИОННЫХ БЛОКОВ-КОМПАРАТОРОВ ДЛЯ МЕТРОЛОГИЧЕСКОГО ОБЕСПЕЧЕНИЯ ИЗМЕРЕНИЙ МОЩНОСТИ ДОЗЫ ОТ 0,1 МКЗВ/Ч НА ПОВЕРОЧНЫХ ДОЗИМЕТРИЧЕСКИХ УСТАНОВКАХ

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Аттестация и поверка дозиметрических установок с типовым коллиматором фотонного излучения в настоящее время осуществляется с использованием ионизационных камер из состава государственных эталонов, нижняя граница измерения которых соответствует десяткам мкЗв/ч. Обеспечение диапазона мощностей доз от 0,1 мкЗв/ч на поверочных дозиметрических установках продиктовано необходимостью расширения диапазона калибровки высокочувствительных дозиметров радиационной защиты. Для решения этой задачи в УП «АТОТМЕХ» были разработаны блоки-компараторы фотонного излучения на базе серийно выпускаемых сцинтилляционных блоков детектирования.

Для создания блоков-компараторов использовался спектрометрический метод дозиметрии на основе преобразования измеренного аппаратурного спектра. В основу метода положено вычисление мощности дозы с помощью оператора преобразования «спектр–доза», при этом полная мощность дозы находится с использованием функции G(E) без применения восстановления спектра из измеренного амплитудного распределения фотонного излучения.

Использование специально отобранных детекторов с высокой стабильностью измерительного тракта и лучшим разрешением, а также применение описанного выше подхода с использованием оператора преобразования позволяют использовать блоки детектирования в метрологии фотонного излучения с целью поверки рабочих эталонов и средств измерений с погрешностью не более 5–7 % с использованием источников фотонного излучения низкой интенсивности в интервале энергий 5–3000 кэВ.

Для подтверждения метрологических характеристик блоков-компараторов были проведены исследования основных харак-

теристик, а также калибровка блоков-компараторов во ФГУП «ВНИИМ им Д.И. Менделеева» на государственных вторичных эталонах РФ.

В докладе представлены блоки-компараторы фотонного излучения с основными метрологическими характеристиками, результаты исследований этих характеристик, а также возможности применения данных компараторов.

APPLICATIONS OF MONTE CARLO METHODS IN MEDICINE

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Different problems in medicine connected with interaction of radiation with matter are successfully solved using the Monte Carlo method because this method is very realistically reproduces real interaction of particles with matter. Examples of such applications of the Monte Carlo method in medicine are the following:

- External and internal radiation dosimetry (e.g., estimation of radiation doses to patients from X-ray irradiation during fluorography or from brachytherapy);
- Development of medical equipment (e.g., obtaining trajectories of gamma rays emitted from radiopharmaceuticals in PET and SPECT, assessment of an X-ray tube spectra);
- Treatment planning (e.g., predicting the dose distribution in a procedure of radiotherapy);
- Imaging correction (e.g., quantifying and correcting photon scattering that usually produces blurring of the image and loss of contrast in nuclear medicine imaging procedures).

The work is mostly devoted to Monte Carlo modelling of different X-ray procedures with the aim of estimating doses to patients. Such simulations require "source-phantom-detector" assembly and allow obtaining the absorbed energy distribution within the human body. Thus, one has an opportunity to calculate the equivalent doses to organs and tissues and then estimate the effective dose on the basis of received information.

In this work the model of X-ray unit was developed taking into account various parameters of an X-ray examination procedure (high voltage, total beam filtration, X-ray unit spectrum, radiation field, focus-surface distance, X-ray tube radiation yield, collimator characteristics, etc.). A tungsten anode spectral model using interpolating polynomials (TASMIP [1]) was applied to generate the X-ray spectra of the unit. Reference male and female voxel phantoms that are recommended by ICRP for dosimetry calculations [2] were adapted to the Monte Carlo N-Particle Transport Code (MCNP [3]) and optimized for modelling X-ray irradiation. Positioning of the X-ray source relative to the patent was modeled in compliance with the corresponding exami-

nation protocols. All calculations of the effective dose were performed in line with the ICRP Publication 103 [4].

The simulations were carried out for dental X-ray examinations and for the most frequent X-ray procedures. Computations were performed both for constant value of X-ray tube voltage with different total beam filtration and different high voltage values with constant filtration. The results revealed a rather clear dependence of these coefficients on the high voltage and total beam filtration. The ignoring of these relationships in evaluating the dose leads to a marked increase in uncertainties of dose assessments. The results obtained can be used in practically public health services for development of optimal exposure conditions of patients.

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IMPROVEMENT OF THE RADIOPURITY LEVEL OF $^{116}CdWO_4$ AND $ZnWO_4$ CRYSTAL SCINTILLATORS BY RECRYSTALLIZATION

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Radioactive contamination is one of the most crucial characteristics of crystal scintillators for low counting experiments. Cadmium tungstate and zinc tungstate crystal scintillators are promising detectors to search for double beta decay, dark matter, and to investigate rare alpha and beta decays. The radioactive contamination by thorium (^{228}Th) as well as by alpha active uranium, thorium, and their daughters in a cadmium tungstate crystal enriched in ^{116}Cd ($^{116}CdWO_4$) was reduced by factors of 10 and 3, respectively, using recrystallization; levels of 0.01 mBq kg^{-1} and 1.6 mBq kg^{-1}, respectively, were achieved. This finding, as well as the much higher concentration of potassium, radium and thorium in the remaining material after the crystal growing process, indicates strong segregation of the radionuclides in the $CdWO_4$ crystal growing process. This property can be used to produce highly radiopure $CdWO_4$ crystal scintillators for double beta decay experiments. A possible higher concentration of radioactive elements (^{228}Th and α active radionuclides of uranium, thorium and their daughters, in general) in a thin ($\approx$ 0.4 mm) surface layer was not observed in the $ZnWO_4$ crystal. Therefore the concentration of uranium and thorium and their daughters in a thin surface layer of the enriched $^{116}CdWO_4$ crystal scintillator reported in [1] was most probably not due to the growing process but to the diffusion of radioactive elements into the crystal during the annealing process in the ceramic oven.

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НОВЫЕ РАЗРАБОТКИ АППАРАТУРЫ РАДИАЦИОННОГО КОНТРОЛЯ НА ОСНОВЕ СЦИНТИЛЛЯЦИОННЫХ ДЕТЕКТОРОВ

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Научно-производственное унитарное предприятие «АТОМТЕХ» разрабатывает и выпускает широкую номенклатуру продукции ядерного приборостроения, основанную на использовании разнообразных детектирующих элементах, в т.ч. и сцинтилляционных детекторов. Значительный упор делается на создание интеллектуальных блоков детектирования с высокими техническими характеристиками дозиметрического, радиометрического и спектрометрического назначения. Их промышленное освоение создаёт радикальные предпосылки как для создания новых типов средств измерения ионизирующих излучений, так и для оперативного расширения возможностей выпускаемой продукции.

За два года, прошедшие после конференции «ИСМАРТ-2014» благодаря принятому подходу создан ряд новых и модифицированных видов приборов и аппаратуры, привлекательных с точки зрения их функционального назначения, сферы применениями метрологических параметров.

В докладе рассматриваются соответствующие решения с использованием линейки сцинтилляционных блоков детектирования, созданных в указанный период времени как по инициативе предприятия, так и по предложениям потребителей ядерно-измерительной аппаратуры и приборов радиационного контроля.

ZnSe SCINTILLATING BOLOMETER WITH IONIZATION READOUT – A NEW APPROACH FOR PARTICLE DISCRIMINATION TECHNIQUE

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The registration of elusive particles requires the use of new high quality detectors with enhanced characteristics. Scintillating bolometers are among the most promising detectors used in rare event physics, what have clearly demonstrated by the excellent background rejection capabilities that arise from the simultaneous, independent, double readout of heat and scintillation light.

The main goal of CUPID-0 experiment is to search for neutrinoless double beta decay of ^{82}Se isotope with ZnSe crystals that work as scintillating bolometers. At the same time, the ZnSe is also wide band gap semiconductor material (2.8 eV at room temperature). According to the published data the electron mobility in ZnSe is about 530 $cm^2/V{\cdot}s$ with a concentration of free carriers $n_0 \sim 10^{17\text{-}18}$ cm^{-3} at 300 K. Going down to the lower temperature drastically increases the electron mobility up to 12 000 $cm^2/V{\cdot}s$ at 60 K. Based on these preliminary data, it looks possible to collect even tiny charges induced by single particle interaction.

The present report relates to results on the development and study of semiconductor detectors based on ZnSe crystals in order to develop of triple read-out detector – heat, light and ionization channels. Such experimental technique, as we expect, will allow getting more information about interacting particle and helps to reduce the radioactive background to virtually "zero" level. Additionally, these investigations will help to understand energy distribution into scintillating crystals.

COST ACTION TD1401: NANOCRYSTALLINE AND NANOCOMPOSITE SCINTILLATORS FOR FAST TIMING

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Fast and efficient scintillators are required by a number of applications, namely in high energy physics and medical imaging (Positron Emission Tomography – PET) where so call time-of-light (TOF) techniques are used and timing coincidence resolution (TCR) is of critical importance. Using one of the most advanced single crystal scintillators today, LYSO:Ce,Ca, TCR value below 200 ps has been demonstrated, but it seems improbable to reach values below 100 ps using single crystal scintillators of this kind. The goal of COST FAST project is to seek the concept(s) to advance TCR up to by one order of magnitude, down to 10 ps which would give an unprecedented improvement in the applications using TOF techniques, e.g. a direct image reconstruction could be used in TOF-PET imaging.

To advance the value of TCR one needs to register sufficiently high number of scintillation photons in the time scale of about 100 ps after the absorption of high energy photon (particle) by the scintillator. To achieve it, scintillator should posses high light yield, as short as possible decay time and rising components in scintillation response should be diminished to a maximum extent. In COST FAST TD1401 project it is Work Package 2 which searches for materials of such potentionality. Wide band gap semiconductors with direct gap as ZnO, GaN, but also e.g. PbI_2, CdSe or $CsPbX_3$ (X = Cl,Br) [1–3] could be particularly useful for this concept as their luminescence is based on Wannier exciton the radiative lifetime of which is below 1 ns and theoretical light yield could exceed 100 000 phot/MeV due to smaller value of band gap compared e.g. to above mentioned LYSO. If these materials are prepared in a nanocrystalline form and quantum size effect can take place, the radiative lifetime can be shortened further down to tens of picoseconds [3]. However, small Stokes shift, which is a consequence of Wannier exciton nature, practically disable to use these materials in a bulk form due to huge reabsorption losess [4]. Moreover, due to the fact that such excitation is not localized, nonradiative quenching e.g. at the surface or interface of these materials becomes a critical problem. Using these materials in a powder extremely fast scintillation response has been demonstrated with the dominant component well below 1 ns [1]. The powder form, however, is unsuitable for practical applications and

the transparent composite materials, in which the scintillation nanophase is embedded in an optically transparent host, became intensively studied [5]. Recently, ZnO:Ga nanocrystals in a polystyrene matrix have shown very promising timing chracteristics demonstrating superfast energy transfer from polystyren host to ZnO:Ga nanocrystalline phase which migh pave the way to such superfast composite scintillators. The results and such a concept will be further discussed in the presentation.

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ИМИТАЦИЯ ОБЪЕМНЫХ МЕР АКТИВНОСТИ МЕТАЛЛОВ ДЛЯ КАЛИБРОВКИ СЦИНТИЛЛЯЦИОННЫХ ГАММА-СПЕКТРОМЕТРОВ

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Радиационный контроль выплавляемого металла должен обеспечивать получение информации о наличии или отсутствии радионуклидов техногенного или природного происхождения в пробах металла. Использование сцинтилляционных спектрометров гамма-излучения с детектором NaI(Tl) позволяет осуществлять идентификацию и измерение удельной активности контролирумых радионуклидов в представительных пробах плавки металла.

Для градуировки и калибровки гамма-спектрометров требуется наличие функции отклика спектрометра к таким радионуклидам, как ^{137}Cs, ^{134}Cs, ^{152}Eu, ^{154}Eu, ^{60}Co, ^{54}Mn, ^{232}Th, ^{226}Ra, ^{65}Zn, ^{125}Sb+^{125m}Te, ^{106}Ru+^{106}Rh, ^{94}Nb, ^{110m}Ag, ^{233}U, ^{234}U, ^{235}U и ^{238}U, представляющей собой аппаратурные спектры в используемой геометрии измерения. Для их получения используются объёмные меры активности металлов, подобные по размерам и составу материала. Вместе с тем, изготовление мер активности является дорогостоящим, а с отдельными радионуклидами затруднительным. Для решения задачи в данном случае использовано моделирование методом Монте-Карло.

Для получения функций отклика спектрометра с использованием мер активности на основе недоступных радионуклидов, а также для подтверждения правильности результатов Монте-Карло моделирования с такими радионуклидами, как ^{152}Eu, ^{154}Eu, ^{232}Th, ^{226}Ra, ^{94}Nb, ^{125}Sb+^{125m}Te и т.д., имеющих несколько высокоинтенсивных линий гамма-излучения с энергиями в диапазоне от 50 до 3000 кэВ, предлагается использовать имитанты в виде набора рассеивателей (металлических дисков различной толщины) и точечных источников типа ОСГИ.

Использование комбинаций точечных источников гамма-излучения и рассеивателей позволяет сформировать необходимый отклик в фотопике и области пика комптоновского рассеяния, и в итоге получить амплитудное распределение, эквивалентное результатам взаимодействия излучения в объемном источнике с равномерно распределённым по объему радионуклидом.

Полученные экспериментальные и теоретические функции отклика спектрометра на излучение контролируемых радионуклидов показали хорошее соответствие разработанной модели реальному образцу и подтвердили правильность результатов Монте-Карло-моделирования для ряда радионуклидов, а также показали обоснованность методического подхода в процессе имитирования мер активности.

WIDE-RANGE FISSION CHAMBERS FOR ITER NEUTRON FLUX MONITOR

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The paper describes the wide-range fission chambers (FC) developed to measure total neutron flux in ITER. ITER is International Thermonuclear Experimental Reactor being built at the moment in France and designed to demonstrate the feasibility of fusion power engineering in future.

ITER neutron diagnostic has to provide measurement of fusion power in the range from 1.0 kW up to 1.5 GW. That corresponds to the total neutron yield range from 3×10^{14} up to 5×10^{20} n/s. It's necessary to carry out measurements with temporal resolution 1 ms to control the processes taking place in fusion plasma. The French nuclear regulator prescribes to detect the absolute value of the total neutron flux at any given time with accuracy less than 10%.

In order to ensure these requirements we are developed multi-detector neutron flux monitor system with FC. The simulation of neutron fields at the FCs location was carried out to determine the radiation and thermal loads. The result of calculation confirmed that application of wide-range FC with U-235 and U-238 radiators is the optimal solution to cover the full ITER dynamic range.

The required dynamic range (6 orders) is provided both by using FC with different sensitivities, and by operating in the count-rate, Campbell and current mode. We designed two types of 3-sectional FC: with high-purity U-238 (the state standard sample of the isotopic composition of uranium GSO 7516-99) and U-235 enriched to 90%. Product is assigned a name KNT 30-8 and KNT 30-5 respectively.

FC tightness is determined by the helium leak rate and is less than 1.3×10^{-10}W. Quality manufacturing provides a mean time to failure at least 75 000 hours at the temperature 100°C. The assigned life of KNT 30-5 and KNT 30-8 FC is 20 years.

FC KNT 30-8 features:

1. Pulse sensitivity to detect 14,8 MeV neutrons: section 1 – 1×10^{-3} cm^2; section 2 – 1×10^{-4} cm^2; section 3 – 1×10^{-5} cm^2;
2. Current sensitivity to detect 14,8 MeV neutrons: section 1 – 2×10^{-16} A·cm^2; section 2 – 2×10^{-17} A·cm^2; section 3 – 2×10^{-18} A·cm^2;
3. Charge collection time – 1×10^{-7} s;

4. Charge in pulse – 2×10^{-13} C;
5. Slope of count-rate curve – less 0.1 %/V;
6. Slope of U-A curve – less 0.05 %/V;
7. FC KNT 30-5 pulse sensitivity to detect thermal neutrons: section 1 – 5×10^{-2} cm^2; section 2 – 1×10^{-2} cm^2; section 3 – 2×10^{-3} cm^2.

Factory acceptance tests of FC KNT 30-8 were performed in JSC "TRINITI" Neutronic Laboratory with several neutron generators: ING 07T (E_n=14.5 MeV; $Y_n=10^9$ n/s), ING 07D (E_n=2.5 MeV; $Y_n=10^7$ n/s) and NG-24M (E_n=14.7 MeV; $Y_n=5\times10^{10}$ n/s).

Factory acceptance tests of FC KNT 30-5 were performed by a comparison method according to the Russia Standard GOST 8.031-82.

Factory acceptance tests of FC KNT are planned to be completed in Nov. 2016. According to the test program FC KNT are applicable for the use in the ITER experimental reactor, as well as in nuclear power plants. Finally the wide-range FC KNT will be included in a JSC "NIITFA" catalogue of commercial available products.

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NEUTRON FLUX MONITOR FOR RUSSIAN STATE PRIMARY SPECIAL STANDARD WITH 14 MEV NEUTRON SOURCE

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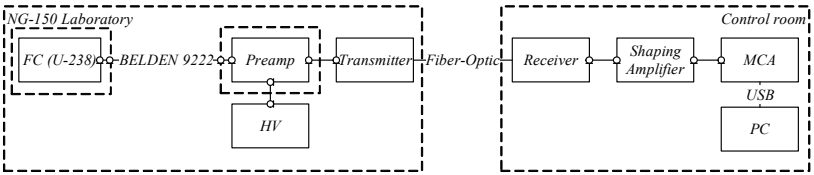
In this work we present a description of the fast neutron flux monitor (NFM) which is used in Russian State Primary Special Standard (SPSS) GET 51-80 with 14 MeV neutron source. This etalon is used for fast neutron flux density and fluence metrology at nuclear facilities. The SPSS GET 51-80 facility is hosted in FSUE "VNIIFTRI" (Mendeleevo, Moscow region).

SPSS GET 51-80 consists of a set of measuring tools, including sets of neutron activation and fission detectors, measuring system of induced activity and modeling neutron reference fields based on 14 MeV neutron generator NG-150.

The NG-150 facility carried an "associated alpha-particles method", in which the intensity of the neutron source is determined by count rate of α-particle produced in the reaction $T(d,n)^4He$.

However, this method is complicated for implementation in case of the rotating target used in a high yield NG-150. To ensure the stability of metrological characteristics of NG-150 reference neutron fields the SPSS GET 51-80 has been supplemented by additional high performance NFM with threshold FC (U-238).

The structure of NFM for the SPSS GET 51-80 is shown in figure below.



FC (U-238) signal is amplified by charge-sensitive preamplifier (Preamp) and transferred to the Shaping Amplifier. The shaped signal sends to the multi-channel analyzer (MCA).

NFM acquisition system can operate in pulse height analysis mode or as a multichannel pulse counter with a fixed low level threshold.

To provide high metrological characteristics of GET 51-80 standard reference neutron fields and to avoid NFM signal corruption due to

electromagnetic interference caused by the powerful neutron generator with RF ion source, we implemented several technical solutions:

- NFM structurally is split into two parts: FC and Preamp indoors NG-150 Laboratory while acquisition system indoors Control room;
- FC housing is galvanic isolated from the detector assembly housing;
- FC signals are transmitted to the Preamp input via triax RF cable BELDEN 9222;
- Preamp output signals are transferred via fiber-optic link to the acquisition system in the Control room.

Finally NFM with threshold FC (U-238) provides measurement of NG-150 intensity at Russian State Special Standard GET 51-80 with an average standard deviation less than 0.3% and non-exceptional systematic error of measurement less than 0.7%.

CsI: A LOW COST SCINTILLATOR FOR TOF-PET?

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Recent progress in various fields of scintillator applications has created a high demand for fast scintillators. In particular, for medical applications the Time-Of-Flight Positron Emission Tomography (TOF-PET) technique requires coincidence time resolutions (CTRs) better than 100 ps FWHM in order to improve the image signal to noise ratio and thus to offer the benefit of shorter scanning times and better image quality. Also developments in high energy physics demand improving the timing capabilities of calorimeters down to 10 ps. Conventional L(Y)SO scintillators were demonstrated to provide a CTR of about 100 ps FWHM when used with Silicon Photomultiplier (SiPM) detectors. The time resolution in this case is limited by the photon time-density at the onset of the scintillation process and can be further improved by using a different scintillation mechanism featuring a prompt response.

Hot intraband luminescence (IBL) is a low yield ultrafast emission connected with the radiative transitions of hot electrons or hot holes between the sub-levels of the conduction or valence band of a crystal, respectively [1]. The continuous and structureless spectrum of IBL covers the whole transparency region of a material, with increase of the intensity in NIR [2]. The IBL decay time and yield are to a large extent defined by the competitive process of nonradiative transitions which are far more probable than the radiative ones. The decay time is expected to be below 1 ps, while the quantum yield has been reported as 10^{-4} photons per electron-hole pair for potassium iodide [1]. Despite its low yield, IBL can potentially improve the scintillation time resolution by providing an almost instant time marker for the event.

In this regard, the search for materials with high IBL yield is of particular importance. It has been shown [3], that to reach an ultimate goal of 10 ps CTR at least 500 prompt photons are required per absorbred 511 keV γ-quantum. However, if combined with conventional fast scintillation, already 40 prompt photons can significantly improve the CTR of a scintillator. We report our latest investigation of the yield of IBL in different materials, including the leading compound among those tested so far – CsI, which provides about 30 detectable IBL photons per MeV. Combined with

Cherenkov radiation of secondary electrons created by an absorbed gamma quantum, a substantial CTR improvement can be achieved.

Measurements of the time resolution on pure CsI have revealed that it performs very well indeed, showing up to 120 ps CTR. It is the second best result shown so far, losing only to L(Y)SO family of compounds. The best material – LSO:Ce,Ca – has been specifically designed to achieve up to 73 ps CTR [4]. We believe that the availability of prompt photons in CsI plays a crucial role in such excellent time resolution. The further optimization of this classical scintillator could possibly yield a low cost material for TOF-PET applications.

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GROWTH AND SCINTILLATION PROPERTIES OF $Na_6Mo_{11}O_{36}$ SINGLE CRYSTAL

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The AMoRE (Advanced Mo Based Rare Process Experiment) collaboration is using molybdenum based crystal $^{40}Ca^{100}MoO_4$ for searching the extremely rear event process of neutrino less double beta decay of ^{100}Mo isotopes and also looking for new scintillators which contain molybdenum. In the present work, we discuss the Czochralski technique for growing $Na_6Mo_{11}O_{36}$ single crystal for the first time. The polycrystalline material was synthesized on the basic of Thermogravimetry Analysis and Differential Scanning Calorimetry (TGA/DSC) result. The crystal structure was studied by X-Ray diffraction (XRD) analysis. The luminescence properties and lifetime of the crystal at low temperature was studied by using 266 nm pulse laser source. By using the transmittance spectra measurement we estimate the optical quality and band gap information of the crystal. Total energy intensity and total intensity of the crystal at low temperature (10 K) was calculated and it was normalized with $CaMoO_4$ crystal result. In future, this crystal might be one of the candidates of Mo-containing crystal for the $0\nu\beta\beta$ decay search.

CRYSTAL FIBERS FOR FUTURE CALORIMETERS

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Future high energy physics experiments, such as HL-LHC, CLIC, ILC and FCC, need major improvements in the performances of hadron and jet calorimetry. Because of the challenging conditions in which they will be operated, unprecedented levels of energy and timing resolutions, as well as efficient particle identification are required. We proposed earlier an approach based on heavy inorganic crystal fibers to form a fully homogeneous calorimeter. Designs based on assemblies of small elements of undoped and doped materials can simultaneously obtain excellent energy resolution and perform particle identification with its dual readout and vertexing/tracking capabilities.

This contribution explains the motivation of the work being performed within the Marie Curie Action INTELUM. More specifically we will explain how crystal fibers can be used to achieve the required high performances in future calorimeters and give a review of the R&D performed during the last years. In these studies, garnet materials (LuAG and YAG) grown in various fiber geometries were considered. Two lines of work will receive emphasis. First, the improvement of the growth of fiber-shaped single crystals enhanced the optical quality and the propagation of the light through the crystal fibers, which in turn reduces significantly the constant term of the energy resolution. Second, multiple test beam campaigns with the grown crystal fibers were performed to evaluate the crystal fibers performances in various configurations.

The flexibility of this innovative type of calorimetry was demonstrated and Physics results were obtained in both transverse and projective designs, with modules either with very fine granularity or rather loose sampling fraction. Based on Geant4 simulations, we also studied the best way to find a good compromise between cost and performances by smartly sacrificing the homogeneity of the calorimeters in specific regions.

The research conducted in the frame of the Crystal Clear Collaboration was partly funded by the French National Agency for Research under grand agreement ANR-10-BLAN-0947 (INFINHI), by a Marie Curie Early Initial Training Network Fellowship of the European Community's FP7/2007-2013 under contract number PITNGA-2011-289355-PicoSEC-MCNet, by a Marie Curie Action under grant agreement number 644260-INTELUM-H2020-MSCA-RISE-2014, by the Competence Centers of the Technology Agency of the Czech Republic under grand agreement RANUS-TDTE01020445, by the PHC DNIPRO program under grant agreement number 28317ZC and an Eiffel grant.

APPLICATION OF SEMI-TRANSPARENT INTERPIXEL GAPS FOR IMPROVEMENT OF SPATIAL RESOLUTION IN PIXILATED SCINTILLATION DETECTORS

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The size of individual pixels determines spatial resolution in position-sensitive scintillation detectors based on pixilated crystals. In detectors, based on monolithic crystals, spatial resolution depends on a number of things including crystal shape, absolute light-yield, type and size of photodetector, and signal processing in DAQ system. For the typical PET detector the mathematical task of restoration of the interaction point is poor conditioned because of strong light spread in the crystal and, consequently, light sharing between photodetectors.

In this work, pixilated detectors with semi-transparent gaps are studied using Monte-Carlo simulation of scintillation light transport. Two types of pixilated detectors are considered. In the first one interpixel gaps are filled with silicon grease mixed with $BaSo_4$ powder as an effective reflector. The content of powder in the mixture allowed adjustment of light scattering distance in the gaps. Optical properties of mixtures with different powder content were determined experimentally. The second model described the detector where pixels are formed inside continuous crystal with excimer laser.

It is shown that light spread function on the detector output window can be controlled by adjusting optical properties of gap material. Two detector configurations belonging to different models are considered in details. In comparison to continuous crystal, reduced light sharing between photo sensors makes spatial resolution less sensitive to Poisson noise on the one hand. On the other hand the coordinate of the point of interaction inside particular pixel can be restored due to light leakage between neighbor pixels.

THE PLASTIC SCINTILLATOR TEMPORAL PROPERTIES IMPROVEMENT

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New compositions of fast PS, which have, unlike known, both the short scintillation flash rise time and the high light yield. In known fast PS, the scintillation process quenching mechanism is used, that leads to significant light yield decrease. The principal difference of new PS is that the scintillation flash rise rate increase mechanism in the new PS is realized by use substances with the strong electron-donating properties, such as triphenylamine and tolylcarbazole. That leads to accelerated recombination of electrons with holes in the ionizing particle track and, consequently, to accelerated generation of singlet excited states.

Kinetic curves for the new fast PS are obtained and their light yield is measured. The front rise time of PS, with base of polystyrene with 40% triphenylamine or 40% tolylcarbazole amounts 0.7 ns and 0.4 ns, and the light yield relatively to the “standard” PS is of 122% and 143%, respectively.

Light yield increase of the new fast PS is associated with the lower ionization potential of triphenylamine and tolylcarbazole relatively to polystyrene.

GROWTH OF GARNET AND PEROVSKITE SCINTILLATORS WITH NON-ISOVALENT MINOR COMPONENTS AND RELATED EFFECTS

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Co-doping of Ce-doped oxide scintillators with divalent impurities is among the most promising concepts developed in recent years to improve the time-response properties and the light yield [1, 2]. The observed positive effects have been related to formation of Ce^{4+} centers which trap excited electrons directly from the conduction band leading to excited Ce^{3+} and their radiative de-excitation. The studies on aluminum garnets (LuAG:Ce,Mg) were performed on single crystals grown by the micro-pulling method [2]. Competition in electron capture between Ce^{4+} and other traps was found to improve the radiation hardness as well (LuAG:Ce,Ca grown by Bridgman) [3].

In this presentation various types of non-isovalent co-doping in aluminum garnets and perovskites will be considered. Selected examples on LuAG, YAG, LuAP and YAP doped with Ce or Pr and containing divalent (Ca,Mg) or monovalent (Li) impurities will be described. Compositions based on YAG, LuAG and LuAP were grown by the vertical Bridgman; YAP crystals were grown by Czochralski. The quality of crystals and defects originating at high co-dopant concentrations have been studied by means of optical and electron microscopy. Absorption and radioluminescence measurements were performed on as-grown and oxidized samples.

No appreciable degradation of quality was found in YAP:Ce,Ca in the range of tested concentrations of Ca (up to 500 ppm) assuming higher amounts can be tolerated by this matrix. However, as reported [4, 5], improvement in the overall scintillation decay time is being achieved at quite low Ca contents, while at higher amounts this positive effect is counterbalanced with increasingly stronger reduction in the luminescence efficiency. As for the garnets, introduction of Ca or Mg above 150–200 ppm leads to degradation of crystalline quality due to interface instability and liquid capture by advancing interface, even at growth rates below 1.0 mm/h (inclusions enriched with second phases and Ce). The overall strain coming from growth striations and facets is also noticeably increased. The solubility limit of Ca

preserving structural quality is 100–150 ppm which nonetheless is sufficient to improve the timing performance [3].

Introduction of Li to YAG:Ce up to tested amounts of 2000 ppm does not worsen the structural quality and optical transmittance (the latter is even improved in the 250-300 nm range). The lattice constant measurements do not give any evidence for substitution for either of Y or octahedral Al sites. Presence of Li in the lattice is however evidenced by lower radioluminescence intensity and longer decay, as compared to Li-free crystals with similar Ce contents. Preferential incorporation in interstitial positions is realistic, as suggested for YAG:Nd,Li basing on spectroscopic studies [6].

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CRYSTAL GROWTH AND SCINTILLATION PROPERTIES OF Eu^{2+} DOPED $RbCaCl_3$

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Single crystals of complex compounds $CsMX_3:Eu^{2+}$ (M=Ca, Sr; X=Cl, Br, или I) are now considered among the most promising materials for detection of ionizing irradiation. However, the Rb-containing analogs of the mentioned compounds practically are not studied although their physicochemical and functional properties may be rather different from those of $CsMX_3:Eu^{2+}$. Thus, the presented work is devoted to crystal growth and scintillation properties of $RbCa_{1-x}Eu_xCl_3$.

Single crystals of $RbCaCl_3$ containing 3, 5 and 8 mol.%Eu^{2+} were grown by the vertical Bridgman–Stockbarger technique. CsX (99.9%), CaX_2, and EuX_2 (X=Cl, Br) were used as starting chemicals. Before the crystal growth RbX (99.9%) was dried at 200 °C; CaX_2, and EuX_2 were obtained preliminary from $CaCO_3$ (99.999%) and Eu_2O_3 (99.99%), respectively.

The grown boules of $RbCaCl_3:Eu^{2+}$ were 70 mm long and 12 mm in diameter. The single crystals had slightly green coloration confined to the region in contact with the quartz ampoules and slightly violet coloration inside the crystal. All the crystals had good transparency.

Radioluminescence spectrum of $RbCaCl_3$:5%Eu^{2+} had a sharp emission band with a peak maximum at 441 nm (the emission band width is 19 nm). The emission spectrum of photoluminescence is characterized by a sharp band with a maximum placed at 433 nm (the emission band width is 22 nm). The shape of photoluminescence excitation spectrum for $RbCaCl_3$:5%Eu^{2+} are typical for Eu^{2+}-doped scintillators and include a broad band between 250 nm and 420 nm. The decay curves were measured for $RbCaCl_3$ containing 5 and 8 mol.% of Eu^{2+}. The scintillation pulse decay curves are simple and they may be described using one exponent with the decay constants equal to 2.48±0.008 μs for $RbCaCl_3$:5%Eu^{2+} and 2.73±0.08 μs for $RbCaCl_3$:8%Eu^{2+}.

The maximal value of relative LY (in respect to NaI:Tl) has been observed for $RbCaCl_3$:8%Eu^{2+}. It is approximately equal to 50% with energy resolution of 12%.

LUMINESCENT AND SCINTILLATION PROPERTIES OF $K_2BaX_4:Eu^{2+}$(X=Cl, Br)

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Dihalides can react with alkali-metal halides to form ternary halides with the formula types AM_2X_5, AMX_3, A_2MX_4 and A_4MX_6, where A = alkali metal, M = alkali earth metal, and X = chlorine, bromine or iodine. Some AM_2X_5, AMX_3 materials have been recently reported to be very efficient scintillator. KX-BaX_2 (X=Cl, Br) systems have only one compound K_2BaCl_4 and K_2BaBr_4. In this work we present the crystal growth, luminescence and scintillation properties of Eu^{2+}- doped $K_2BaCl_4:Eu^{2+}$ and $K_2BaBr_4:Eu^{2+}$.

Single crystal of $K_2BaX_4:Eu^{2+}$ (X=Cl, Br) was grown by the vertical Bridgman–Stockbarger technique. KX (99.9%), BaX_2, and EuX_2 (X=Cl, Br) were used as starting chemicals. Before the crystal growth KX (99.9%) was dried at 200°C; BaX_2, and EuX_2 were obtained preliminary from $BaCO_3$ and Eu_2O_3, respectively. Single crystal of $K_2BaX_4:Eu^{2+}$ showed significantly lower moisture than NaI:Tl. The emission spectra of crystals consist of a broad band from 370 nm to 520 nm with maximum intensities at 421 nm for $K_2BaCl_4:Eu^{2+}$, 425 nm for $K_2BaBr_4:Eu^{2+}$. The emission bands are attributed to the $4f^65d^1$-$4f^7$ transition of Eu^{2+} The excitation spectra of these two crystals are very similar to each other, which could be ascribed to close structures of $K_2BaCl_4:Eu^{2+}$ and $K_2BaBr_4:Eu^{2+}$.

The maximal values of relative LY (in respect to NaI:Tl, 43,000 ph/MeV) are observed for the samples doped with 5 mol% of Eu^{2+} and it is approximately equal to 20% for the chloride material and 34.3% for the bromide one. In order to achieve better scintillation characteristics, future investigations will focus on improving the quality of the single crystal, which includes purification of the raw material, optimization of growth parameters and different polishing method of the crystal surface.

THE VOLUMETRIC ACTIVITY OF I-131 VAPOR DETECTION DEVICE

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Activity of Iodine-131controle in NPP rooms and ventilation systems is important for the radiation safety assurance of in-plant personnel and civilians because of Iodine-131's high cumulative yield when nuclear fission into nuclear debris is taking place, Iodine-131's bioactivity and mobility. Current reducing trend of maximum permissible discharge and radioactive waste disposal to the environment requires improvements of methods of control of radionuclides including radioiodine.

In connection with above new volumetric activity of I-131 vapor detection device is developed by JSC SNIIP. The detection device provides permanent monitoring of I-131 vapor concentration in working room and ventilation systems in autonomous mode and as a part of radiation control systems. The device consists of the control unit, the detector unit based on scintillation detector (Fig.), the tungsten body and the flow-measuring unit.

Fig. Control unit and detection unit

The device has two modifications – with detector unit based on sodium iodide or lanthanum bromide according to required energy resolution. Application of tungsten body as an external gamma background shieling material and development of new algorithm of volumetric activity permanent measurement using one detector unit, allowed to improve weight-size parameters of the device.

SPECTRAL DISTORTION CAUSED STRAY LIGHT AND ITS CORRECTION

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Spectral distortions caused by scattered light are studied. To register the luminescence and excitation spectra, the usual technique is used: "white" light of excitation source, a monochromator to select a narrow band from its spectrum and another monochromator to select a narrow band from the luminescence spectra of the crystal. However, a small amount of light of unwanted wavelengths (named stray light) always emerges from a monochromator owing to optical scattering [1]. Profiles of stray light were studied by an optical spectrometer, where emission of a xenon arc lamp XBO-150 is focused onto the entrance slit of a high-aperture single-grating monochromator MDR-2, which resolved the emission into its discrete wavelengths and directed that dispersed radiation on a sample fixed in the holder placed in the focus of a parabolic mirror at an angle of 45 degrees to the incident beam of the excitation radiation.

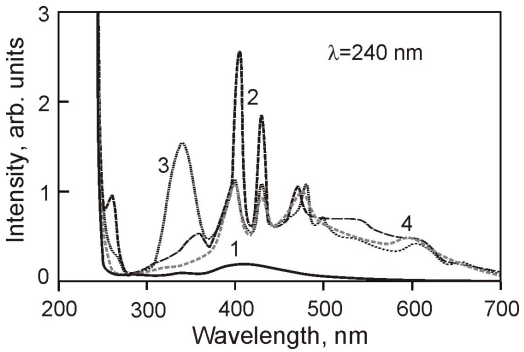

Fig. Stray light profiles: 1 – empty sample holder, 2 – specular reflector, 3 – polished CsI crystal

The mirror projected the sample image to the entrance slip of a prism monochromator SF-4 which analyses the luminescence. A photomultiplier tube FEU-100 was used as a photo receiver. The stray light profiles were reg-

istered when (i) the sample holder was empty, (ii) a specular reflector was used as a sample, (iii) a polished CsI crystal was selected as a sample, which responding to excitation with a pulsed electron beam only with one band luminescence at 310 nm.

It was found that the grating monochromator selecting a UV-light line from 240 to 340 nm gives raise stray light, whose profile is the wide structured band with maximum, which is found from 410 to 430 nm, respectively (Fig.). Both samples the specular reflector and polished CsI stimulate the specular reflection of stray light and as a result the band intensity increases and a series of prominent narrow lines named ghost images appear. UV-pass filter on the exit slit of the grating monochromator block all these ghost images.

The stray light profile caused by the prism monochromator is band with maximum 330 nm. Installation of three additional absorbing screens inside the monochromator eliminates the stray light. Although stray light distorts only spectra of weak luminescent specimens, but the ignorance of the fact might lead to a misconception about origin of luminescence caused by dopants, such as Eu^{2+} ions in lightly-doped alkali halides, oxygen ions in alkali iodides, Tl^{+}-like ions in alkali halides at temperature lower 30 K.

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SCINTILLATION DETECTORS IN EXPERIMENTS ON HIGH ENERGY PHYSICS

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Since early times of nuclear physics scintillation counters have been served as one of the main detectors of nuclear radiations. In the first experiments charged particles had been detected by the light flashes emitted when the particles hit a zinc-sulphate screen. This light was registered with a naked eye. By now a number of scintillation detectors types and detector systems were developed and used widely in high energy physics experiments to detect charged and neutral particles in a large energy range from 1 keV to hundreds of GeV.

Main classes of the scintillation materials are inorganic and organic scintillators. Inorganic scintillators (mosly, inorganic crystals) are used first of all for gamma detection providing high energy resolution up to 1% in a wide energy range. A disadvantage of this material is a high price of the crystals and its limited availability. Organic scintillators are used both for the calorimetry and for precise time measurements. These are much cheaper than crystal scintillators and provide a possibility to construct counters of various shapes and very large sizes. The time resolution achieved with large size counters based on the plastic scintillators is better than 100 ps.

It should be noted that a liquid and gaseous scintillators are exploited as well in some experiments.

This review includes the present status of the scintillation technique use in high energy physics experiments, main characteristics of the existing scintillators, examples of experiments and a consideration of the further development of this type of detectors.

ENGINEERING OF YAG-BASED SCINTILLATORS FOR NEW HEP CALORIMETERS

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The present work deals with an optimization of composition and growth parameters of YAG-based fibers and bulk single crystals to meet the requirements to new HEP calorimeters. The key requirements to scintillation fibers are light attenuation length of not less than 20–40 cm and fast scintillation decay time ≤ 40 ns. Meanwhile, a reasonable fiber production cost may be achieved by using cheap raw materials and fast fiber growth rates. As the fast component decay time in "standard" YAG:Ce and LuAG:Ce garnets is around 100 ns, two approaches to its reduction were proposed:

- codoping with divalent cations (Mg^{2+}, Ca^{2+}) [1];
- transfer to $Y_3Al_{5-x}Ga_xO_{12}$:Ce mixed compositions [2].

Light output, scintillation decay time and light attenuation length of YAG:Ce and YAG:Ce,Mg fibers grown using raw materials from different suppliers were tested in the present work. Fibers of 20–25 cm length and various shapes and diameters were fabricated with the growth rate of 0.3 mm/min. No significant effect of raw material origin, fiber shape and crystallographic orientation on the parameters of YAG:Ce fibers was noticed. While the light output of YAG:Ce,Mg fibers is rather good (>10000 phot/MeV), the decay times and attenuation lengths are out of the target values. Mg codoping reduces the decay times of the fast component down to 41–55 ns, but its contribution is below 50 %. The Ce and Mg radial segregation in fibers is evidently the main factors decreasing the attenuation length. We are attempting to minimize the segregation by decreasing the fiber growth rate and tuning the Ce/Mg ratio.

At the same time, the scintillation decay constant decrease down to 21 ns was achieved in bulk YAGG:Ce mixed crystals by optimization of Al/Ga composition in the host.

$Y_3Al_{5-x}Ga_xO_{12}$:Ce crystals at $0.6 \le x \le 0.8$ demonstrate a reasonable combination of light output, decay constant, and show a good radiation hardness.

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RADIATION HARD ELECTRONICS FOR HADRON COLLIDER EXPERIMENTS. LHC EXPERIENCE AND PROJECTS FOR HL LHC

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The design of the LHC experiments presented an unprecedented challenge for both detection technique and readout electronics . For the first time the hadron collider experiments were equipped with the high resolution high granularity detectors working with the extremely intense colliding beams in radiation hard conditions and strong magnetic field.

The choice of the on-detector electronics technologies made at the time of construction of the main LHC experiments with be reviewed. The expected performance will be compared with the real achievements.

New challenges related to the HL-LHC upgrade and the currently considered solutions will de discussed.

SYNTHESIS AND PROPERTIES OF POPOP STRUCTURAL ISOMERS AND THEIR TRIMETHYLSILYL DERIVATIVES

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Organic molecules which emit light in various spectral regions are widely used in many fields of science and technology. For instance, aryl-substituted violet-emitting oxazoles are among highly efficient luminophores. A burst of interest towards this class of materials was triggered by their discovered applicability as activators in liquid and plastic scintillators. Moreover, they are widely used as dyes for organic lasers and spectral shifters.

In previous works, we reported preparation of nanostructured organosilicon luminophores (NOLs) which combine the best properties of quantum dots with those of organic luminophores [1, 2]. One of the prospective compounds to be applied for NOLs architecting is a blue-emitting luminophore 1,4-bis(5-phenyloxazolyl-2)benzene (POPOP). It has a high PLQY along with a large Stokes shift. The main technique for its preparation is Robinson-Gabriel synthesis. This method is yet not suitable for the preparation of POPOP organosilicon derivatives as the latter are not stable in acidic conditions.

In this work novel trimethylsilyl derivetives of 1,4-bis(5-phenyloxazolyl-2)benzene (**POPOP**) and 1,4-bis(2-phenyloxazolyl-5)benzene (**iso-POPOP**) structural isomers – **TMS-POPOP-TMS** and **TMS-isoPOPOP-TMS** were synthesized. The investigation of spectral luminescent properties of the synthesized linear oligo phenyloxazoles and their organosilicon derivatives revealed that all of them possess high PLQYs (85–96%) and molar extinction coefficients up to 70200 $L \cdot mol^{-1} \cdot cm^{-1}$. Absorption and emission maxima vary within 357–366 nm and 406–422 nm respectively. Single-crystal X-ray diffraction experiments reveal important structural differences between the lattices. The angle between the molecular planes and positions of the nitrogen atoms is different for **POPOP** and **iso-POPOP** structure. Quantum mechanical characteristics of the linear oligo phenyloxazoles synthesized also were calculated via TD DFT. The obtained values were compared to experimental data of optical spectroscopy and cyclic voltammetry.

In addition, we examined the photooxidation stability of synthesized luminophors in THF solution under UV irradiation. It has been found that compounds containing **POPOP**-like fragment more resistant to degradation

than the **isoPOPOP** derivatives. Moreover, the calculated half-life of **TMS-isoPOPOP-TMS** and **isoPOPOP** luminophores was 19+/-4 and 21+/-4 min respectively. Whereas half-life for **POPOP** and **TMS-POPOP-TMS** was twice more and reached 37+/-4 and 39+/-4 minutes, respectively.

The novel trimethylsilyl derivatives of phenyloxazole synthesized in this work may find application in organic photonics due to high photoluminescence quantum yields, large molar extinction coefficients as well as sufficiently high photo- and thermostability.

This work was supported by Russian Foundation for Basic Research (№ 16-33-01100).

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SYNTHESIS AND SPECTRAL-LUMINESCENT PROPERTIES OF $BaI_2:Eu^{2+,3+}$, M^+ POWDERS (M = Li^+, Na^+, K^+)

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Nowadays there is a large variaty of scintillator materials which find apply as detectors of photons and high-energy particles in areas such as high energy physics, nuclear physics, medicine, national security, exploration and so on. Among the scintillation materials halide compounds in comparison with oxide holds the record in energy resolution ($LaBr_3$:Ce) [1] and light output (SrI_2:Eu) [2]. Due to the relatively low cost and availability halides of alkaline earth elements are sufficiently attractive for mass use. However, their high hygroscopicity and structural anisotropy does not allow to obtain these compounds as a high quality single crystals. Thus, the actual problem is the synthesis of these compounds as powders with different morphology for further creation of various fluorescent materials on their basis, such as ceramics or glassceramics. In accordance with the foregoing, the aim of this work was to develop a reliable method of the synthesis of barium iodide powders doped with europium, and investigate the influence of synthesis conditions on the spectral-luminescent properties.

BaI_2:Eu powders were obtained by heat treatment of an equimolar mixture of $BaCO_3$: Eu and ammonium iodide in an inert atmosphere at 380°C [3]. It was found that the spectral-luminescent properties of BaI_2:Eu powders, in particular the ratio Eu^{2+}/Eu^{3+}, in a large extent depends on the synthesis parameters, such as the synthesis temperature, concentration of the ion-activator, the ratio of the components, the morphology of the precursor particles, etc. In order to influence the ratio of ions Eu^{2+}/Eu^{3+} in the samples the effect of the addition of single-charged cations, such as: Li^+ Na^+, K^+ was investigated. It was found that with monovalent cation radius decreasing occurs shift of the luminescence band maximum characteristic for Eu^{2+} ions in the structure of BaI_2 to longer wavelengths. The mechanism of single-charged cation additions effect will be discussed in details in the report.

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SELF-TRAPPING OF CHARGE CARRIERS IN Li_2MoO_4 AND $ZnMoO_4$ CRYOGENIC SCINTILLATORS

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Molybdates are perspective materials for the cryogenic scintillating bolometers that operate in an ultra-low temperature environment (tens of mK). Crystals with light cations of Zn and Li are of particular interest for this application. The absence of heavy elements and relatively high mass concentration of molybdenum in the crystal make them very promising for registration of extremely rare processes. Nowadays, $ZnMoO_4$ crystals are used for the construction of a next-generation Neutrinoless Double Beta Decay experiment within the LUMINEU project [1]. Extensive studies of luminescent and scintillation properties for Li_2MoO_4 are performed as well [2, 3]. The advantage of Li_2MoO_4 is that the growing of bulk crystals is easier in comparison to $ZnMoO_4$. However, the disadvantage of both crystals is low light yield – 0.7 keV/MeV for Li_2MoO_4 and 1.2 keV/MeV for $ZnMoO_4$. Here we discuss the origin of the trap centers in the $ZnMoO_4$ and Li_2MoO_4 scintillators and their influence on the scintillation light yield.

The $ZnMoO_4$ and Li_2MoO_4 single crystals were grown by low temperature gradient Czochralski technique. Luminescence under UV- and X-ray excitation, TSL glow curves and spectra were measured using a laboratory setup. The EPR measurements on the $ZnMoO_4$ and Li_2MoO_4 samples were performed at X-band (microwave frequency $f \sim 9.2$–9.5 GHz) on a standard EPR spectrometer in the temperature range 10–290 K using an Oxford Instruments cryostat.

The origin of the hole and electron traps is studied for Li_2MoO_4 using the EPR and TSL techniques. It was shown that charge carriers are trapped by the regular complexes at low temperatures. A similar effect was observed in $ZnMoO_4$. The co-existence of self-trapped electrons and holes prevents their

migration to emission centers and results in a considerable decrease of luminescence intensity at low temperatures in $ZnMoO_4$. However, a different temperature dependence is observed for Li_2MoO_4. In spite of the different influence of the self-trapping effect on the temperature dependence of luminescence intensity its value is comparable in both studied crystals at low temperatures ($T < 10$ K). The influence of charge carriers self-trapping on the scintillation process at low temperature is discussed.

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CMS-EXPERIMENT RESULTS AND FUTURE PLANS FOR UPGRADE

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A detailed review of latest results of the experiment CMS (Compact Muon Solenoid) at LHC (Large Hadron Collider) is given. Special attention is put to results presented by CMS during the summer conference ICHEP 2016 (38^{th} International Conference On High Energy Physics) in Chicago, USA. The bulk of CMS results in ICHEP 2016 was presented for analysis, carried out with 3 fb^{-1} of data, collected at LHC during the first half of 2016. The second half of the review is devoted to considering the plans for CMS Upgrade during Phase II and the completion of works during phase I.

ENERGY RESOLUTION OF $LaBr_3$:Ce, $CeBr_3$ AND Ce:GAGG CRYSTAL SCINTILLATORS IN COMBINATION WITH DIFFERENT TYPE PHOTOMULTIPLIERS, AS WELL AS WITH SI-PHOTODIODES, TO BE USED FOR DETECTION OF COSMIC GAMMA-RAYS

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We have studied and report here the performance of different detectors of cosmic gamma-rays, that are using modern type scintillating crystals like LYSO, YSO, $LaBr_3$:Ce, $CeBr_3$ and Ce:GAGG.

The detector itself is based on the use of scintillating crystal and of different type photosensor which were exposed to the conventional set of radiuoactive isotopes.

Energy resolution of gamma-ray detectors as derived for different combinations of scintillating crystals and photosensors, and of detector potential use will be discussed in this talk.

A WAY TO OBSERVE CHANNELING AND QUASICHANNELING OSCILLATIONS IN BENT CRYSTALS

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The report is addressed to the peculiarities of charged particle trajectories under the conditions of channeling effect and beyond but close to these conditions, so-called quasichanneling. Charged particles oscillate in a bent crystal in a transverse direction under both channeling and quasichanneling conditions.

We demonstrate both by theory and simulations [1, 2], that these oscillations are transformed into series of peaks in the deflection angle distribution and, therefore, can be directly observed experimentally.

For channeling oscillations it is possible only for positive particles while for quasichanneling for particles of both signs. Also, in the first case the peaks in the deflection angular distribution are equidistant, while in the second one the interpeak angular distance is changing proportionally to the length of oscillations.

We provide the theoretical constraints for experimental observation of both effects. In addition, we discuss their possible applications. In particular, it is possible to use the measured interpeak distance to specify the bent crystal parameters as well as to considerably increase the accuracy of crystal alignment. The latter has a crucial significance in the application of the bent crystal in beam collimation, extraction and e.m. generation.

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BASIC AND APPLIED SCIENCE AT THE PORTAL OF NUCLEAR KNOWLEDGE BelNET

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Creating specialized educational and research portal of nuclear knowledge BelNET (***Bel***arusian ***N***uclear ***E***ducation and ***T***raining) is an important step at the stage of the Belarusian nuclear power plant construction, since by the IAEA recommendations, each country forming nuclear industry must have an original national portal of nuclear knowledge, integrated into the global nuclear knowledge management system.

BelNET was developed on the basis of the Belarusian content management system (CMS) for educational and scientific portal eLab-Science based on free software. Here we realized all necessary functions of the portal, including the ability to remotely edit the portal structure and recording documents, various sorting and filtering tools, as well as some levels of access to documents depending on the user rights. CMS eLab-Science provides, inter alia, the ability to enter text, formulas in LaTeX-like form, input of different types of files, photos, images, video etc. Principles of organization of users access in the portal BelNET are in multiplayer mode with on-line data entry by filling in web forms, separation of access rights of different categories of users to data and user interface. Work is occurred through the Web-based interface of the widespread browserss.

At present a pilot version of BelNET is located here: https://bsu.inpnet.net/belnet. Now the portal content includes more than 400 different documents on the following themes: management of nuclear knowledge, nuclear energy as a factor of sustainable energy development, basic science, applied science, glossary, analytical review of the terms, laboratory works for students, radiochemistry, water-chemical regimes of nuclear power plants, biographies of Belarusian scientists, news, useful links, forums, resources and others.

Sections "Basic Science" and "Applied Science" (see Fig.) include the most interesting and important materials of several international conferences, which took place in Belarusian State University in 2014–2015. There are the 4th International Conference ISMART 2014 (“Engineering Scintillation Materials and Radiation Technologies”, October 12–16, 2014), the 64-th International Conference "Nucleus-2014" (“Fundamental Problems of Nuclear Physics, Atomic Power Engineering and Nuclear Technologies”, July 1–4 2014),

the International Workshop "Modern Nuclear-Physical Methods of Research in Condensed Matter Physics" (September 15–16, 2015). This section includes also materials of monographs and scientific works of Belarusian scientists. The materials of ISMART 2016 will be placed on BelNET immediately after its finish.

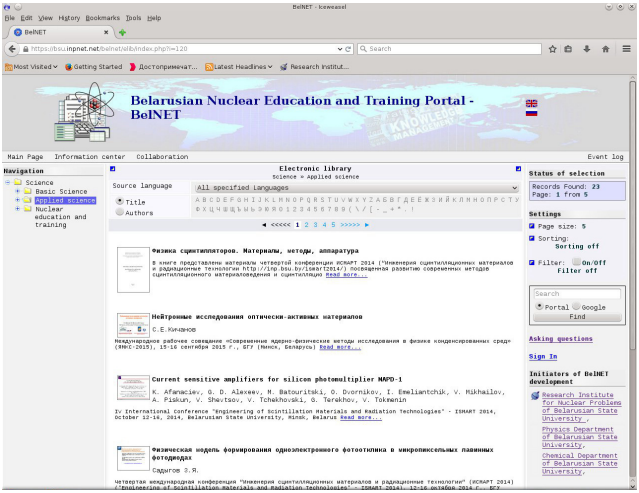

Fig. Section “Applied Science” at BelNET

Why is it important to include materials from the field of basic and applied science, conference proceedings in the portal content? Portal users, especially the younger generation, interested in nuclear knowledge (students and pupils) need to have always serious materials on hand. The user can use the Google search of course. But such a search often yields a great number of references to journal articles, offered be bought for the money, that is unacceptable for our users. Also, in such a search links to dubious or erroneous in the scientific sense materials can mislead the user. The portal developers are very responsible in selection of materials and ensure that all the materials on BelNET are useful and interesting to users.

Work is executed in frame of State Scientific Program "Energy systems, processes and technology", the Subprogram 3 "Nuclear energy and nuclear physics technology".

FAST OPTICAL PHENOMENA IN SELF-ACTIVATED AND CE-DOPED MATERIALS PROSPECTIVE FOR FAST TIMING IN RADIATION DETECTORS

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The time resolution of the next generation radiation detectors for high-energy physics experiments and medical applications is targeted at 10 pico-seconds. Consequently, novel pproaches in scintillation detectors and their application techniques are necessary to meet his ambitious target. In this report, a review of the recent results on fast optical phenomena in scintillation materials, which have been obtained in collaboration between the researchers of CERN, Vilnius University, Institute for Nuclear Problems and the Stepanov Institute of Physics in Minsk is presented.

Our study was aimed at verifying the potential of scintillation materials for fast timing in high-energy physics experiments, positron emission tomography, and positron annihilation lifetime spectroscopy. Two-photon absorption, free carrier absorption and the fast rise in photoluminescence (PL) response to short-pulse excitation have been investigated. Two types of scintillation materials, self-activated lead tungstate (PWO, $PbWO_4$) and Ce-doped garnets (gadolinium aluminum gallium garnet $Gd_3Al_2Ga_3O_{12}$, GAGG, and yttrium aluminium gallium garnet $Y_3Al_1Ga_4O_{12}$, YAGG) were under study.

The optical pump and probe technique was exploited for the study of the two-photon absorption and free carrier absorption. The time resolution in these experiments was limited by the duration of the laser pulses used and was in femtosecond domain. The effect of irradiation on the two-photon absorption was demonstrated by using a ^{57}Co source of gamma radiation (122 keV, 2 mCi). A streak camera was used to accomplish the time-resolved photoluminescence (TRPL) spectroscopy, which was exploited to study the luminescence response to a short-pulse excitation. The best time resolution in the TRPL experiments was 3 ps.

We show that the pump-induced absorption in PWO is caused by two-photon absorption involving one probe and one pump photons, has the rise

time shorter than the pump pulse width of 200 fs and is influenced by gamma irradiation. We demonstrated that the free carrier absorption in PWO and YAGG:Ce crystals is caused by free electrons appearing in the conduction band in the sub-picosecond time domain, whereas the free carrier absorption in GAGG:Ce is dominated by free hole absorption appearing in the valence band via $^{8}S \rightarrow {}^{6}D_{7/2,9/2}$ intra-center transition of Gd^{3+} ions with characteristic time of few nanoseconds. A sub-picosecond PL rise time is observed in PWO, while longer processes in the PL response in GAGG:Ce are detected. The mechanisms limiting the rise time of PL response are discussed.

SCINTILLATION CRYSTALS GROWTH METHODS FOR LABORATORY RESEARCH AND INDUSTRIAL PRODUCTION

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From R&D to industrial production the success in obtaining scintillation crystals with a high scintillation performance depend on the choice of crystal growth method. In laboratory, when researcher chooses the crystal growth method his purpose is to obtain series of small experimental samples of crystals. In the case of mass production it is necessary to use high productivity methods with cost minimization. The choice can be done as between traditional crystal growth methods like method Bridgman [1], method Czochralski [2] and their modifications [3] so between alternative approaches [4, 5].

The aim of this work is to make a review of the state of the art of scintillation crystals growth methods which are used in laboratory research and industrial production. It will be considered traditional methods of crystal growth and alternative solutions aimed at simplification of technological process, increase of growth equipment productivity and decrease of crystal cost.

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MICROTHEORY OF SCINTILLATION IN CRYSTALLINE MATERIALS

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The review of the processes in solid state scintillators is presented. All steps of the transformation of energy in scintillators (production of secondary electronic excitations, thermalization, migration and recombination, photon emission) are observed. The processes at these steps are characterized by quite different spatial and time scales. These scales differs for various classes of scintillators, depending on electron structure of conduction and valence bands, energy position of core levels, phonon spectrum, presence of activators and dopants. Therefore the microscopic structure of electronically and vibrationally excited regions is material dependent. In general this structure is characterized by high non-homogeneity. For instance, in crystals consisted from heavy ions with several low-energy core bands the effect of the clusterization of secondary electronic excitations plays important role in formation of new emission centers. We discuss the estimation of the scintillation yield, non-proportionality, energy resolution and decay characteristics based on the analysis of elementary processes in scintillators.

OPTICAL AND SCINTILLATION PROPERTIES OF Ce-DOPED $(Pb,Gd)_3(Al,Ga)_5O_{12}$ EPITAXIAL GARNET FILMS

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The garnet single crystalline films of Ce-doped $(Pb,Gd)_3(Al,Ga)_5O_{12}$ (Ce:GAGG) which are grown by liquid-phase epitaxy (LPE) from a supercooled $PbO–B_2O_3$ based melt solutions possess scintillation properties [1] and have been already applied as a phosphor in the construction of an electron-optical converter [2]. During the epitaxial process the film captures solvent impurities from the melt solution: Pb^{2+}, Pb^{4+}ions and also Pt^{4+} ions due to the dissolution of a platinum crucible. The concentration of these ions can be controlled. For example, the Pb^{2+} and Pb^{4+} ions can be avoided by changing of the oxide concentration in the melt solution and the growth temperature. However this method does not allow to get rid from Pb^{2+} ions. In this regard, one can assume the formation of Ce^{4+} centers in the epitaxial films Ce:GAGG in the case of the presence of Pb^{2+} impurity ions.

Here we report the results on the growth, optical and scintillation properties of Ce-doped $(Pb,Gd)_3(Al,Ga)_5O_{12}$ epitaxial garnet films.

The garnet films were grown on (111)-oriented single crystal $Gd_3Ga_5O_{12}$ substrates by LPE from a supercooled $PbO–B_2O_3$ based melt solutions with gadolinium oxide ($C(Gd_2O_3)$) concentrations between 0.2 and 0.5 mol% in the mixture, $C(CeO_2)$ concentrations 0.2 and 0.3 mol% and $C(Al_2O_3)$ concentrations between 2.1 and 4.5 mol%. Studies of the optical absorption of the

grown films have shown that the increase of aluminum concentration shifts the absorption band of the $5d_1$ level to longer wavelengths and the absorption band of $5d_2$ level – to shorter wavelengths. The films grown from the melt solution with $C(Gd_2O_3)$ = 0.5 mol% in the mixture have shown broadening of the absorption band of the $5d_2$ level. The effect is attributed to the formation of Ce^{4+} centers near the bottom of the conduction band. The emission spectra of the Ce-doped $(Pb,Gd)_3(Al,Ga)_5O_{12}$ films at interband excitation contained a broad luminescence band in the 475–700 nm range with maximum at 532 nm (2.33 eV). The most intensive luminescence was observed in the $Pb_{0.01}Ce_{0.03}Gd_{2.96}Al_{3.14}Ga_{1.86}O_{12}$ film which was grown from melt solution with $C(CeO_2)$ = 0.2 mol% and $C(Gd_2O_3)$=0.4 mol%. The luminescence decay curve for this film was modeled by triple-exponential decay law with parameters τ_1 = 2.1 ns (2%), τ_2 = 24.9 ns (30%) and τ_3= 61.0 (68%). The mean scintillation decay time in this film was 43 ns. The light output was ~25000 photon/MeV by electron excitation at 50 keV and ~20000 photon/MeV by the Radio Isotope source at 32 keV.

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DEMAND FOR A NEW DETECTING MATERIALS FOR OIL AND GAS EXPLORATION

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Oil well logging has been known for many years. It provides an oil and gas well driller with information about the particular earth formation being drilled. In conventional oil well logging, during drilling and/or after the well has been drilled, radiation detectors and a radiation source, combined into a tool, may be conveyed into the borehole and used to determine one or more parameters of interest for the formation. Well logging progress has also followed the progress in the development of scintillation materials. The first generation of the tools was able to measure formation natural gamma radioactivity (NGR). The modern NGR tools can provide a log of total gamma ray intensity as well as spectral gamma ray measurement. The spectral measurement is important to discriminate the presence and contribution of Potassium (K), Thorium (Th) and Uranium (U). Reading from NGR logging tools can be correlated with NGR spectrometric systems used on the surface to measure geological cores. Another category of wireline tools use radiation sources to expose the formation. A typical tool includes one of gamma ray source, chemical neutron source or pulse neutron generator (PNG) (14 MeV neutrons source) and one or more detectors placed some distance from the source of radiation. Moreover, modern detectors have to survive temperatures above 175^{o}C. The requirements for scintillation materials are even stricter when the tool is used while drilling. Such Logging While Drilling (LWD) tools are powerful instruments for in-earth navigation. However, these tools are subject to vibration while drilling. Therefore, the mechanical stability of the scintillation material and its resistance to cracking are crucially important requirements for LWD applications. In this paper, we discuss the requirements for new detectors and new detecting techniques used in the nuclear well logging in both wireline and LWD logging modes. The selection of the scintillator crystals is usually application dependent. Among many new crystals, there are some with very desirable attributes but with internal radioactivity. Some might perform quite well at higher temperature. A detailed discussion of crystal scintillators with and without internal radioactivity, nanostructured glass ceramics and related temperature requirements and their suitability to various applications will be provided.

RARE-EARTH DOPED SILICA-BASED OPTICAL FIBERS FOR HIGH ENERGY PHYSICS DETECTORS

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Previous studies demonstrated that rare-earth doped silica glasses prepared by sol-gel route are suitable materials for the realization of scintillating optical fibers, opening their application perspectives in medical imaging systems [1, 2]. The present work is aimed at the investigation of the optical properties of Ce and Pr doped silica fibers under strong irradiation fields, in order to verify the possibility to employ them also in High Energy Physics experiments.

Photo- and radio-luminescence measurements have been coupled to optical absorption and attenuation length investigations, obtained before and after irradiation with X rays and with ^{60}Co gamma rays. Comparisons between bulk preforms and fibers have been performed in order to disclose the role of the fiber drawing process in the radiation hardness. Fibers with fluorinated glass or polymeric cladding have also been compared.

The evolution of the optical absorption spectra as a function of recovery time has been investigated in order to understand the room temperature stability of point defects acting as color centers. Moreover the samples have been treated with thermal annealing cycles up to 800 °C, to check the temperature activated carrier release from radiation-induced defects and the possibility of a complete recovery of the damage.

Eventually, photoluminescence time decays and light yield measurements have been carried out on bulk samples to better investigate the application perspectives of such kind of material as scintillator in High Energy Physics detectors.

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TRAPPING CENTRES FORMATION IN $LI_2B_4O_7$-BASED THERMOLUMINESCENT MATERIALS

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Lithium tetraborate is a well-known base material for tissue-equivalent radiation detectors. Doping with transition metals is essential to introduce trapping and luminescence centres. The most studied materials are $Li_2B_4O_7$:Cu, $Li_2B_4O_7$:Ag, and $Li_2B_4O_7$:Mn. Despite of multiple publications, no general approach has been developed yet to the problem of trapping centres formation. Nevertheless, there is enough information to formulate some basic ideas. According to the studies of the behaviour of transition metals in glasses, there are two principal different positions to adopt the impurity into the framework. First one is characterized with more covalent bonds with oxygen and coordination number 4. This position causes one bond with oxygen to be weakened, and a hole if preferably captured at the oxygen near such an impurity. Another position is characterized with less covalent bonds and with a higher coordination number (usually 6). This position promotes electron capturing, with the latter being shared between an impurity and the closest boron. The situation seems to be very similar in doped with d-elements $Li_2B_4O_7$ [1, 2]. This behaviour is connected with coordination and bonding properties of d-orbitals. When $Li_2B_4O_7$ is doped with two impurities, the concurrent incorporation occurs. Some impurities win the tight 4-coordinated position in the framework, the other are moved to loose 6-coordinated position where they can occur both as isolated ions and as the impurity clusters. The concurrent incorporation of Be and Mn into $Li_2B_4O_7$ is a good example [3], where Mn is removed from 4-coordinated positions by Be. We have tried different impurity pairs, Mn-Sn, Eu-Be, Mn-Zn, and some others. Here we compare two impurity systems, Be-Mn and Zn-Mn. The basic idea is to adjust the temperature of hole release to be suitable for most industrial TLD readers. The main dosimetric peak occurs in $Li_2B_4O_7$:Be,Mn system at too high temperature (535 K), while $Li_2B_4O_7$:Zn,Mn

gives the TL curve at lower temperatures (470 K). However, the efficiency of Zn incorporation under the same conditions is somewhat lower than in case of Be, so the additional technological studies are required to improve the sensitivity of $Li_2B_4O_7$:Zn,Mn system which is presently lower than that of $Li_2B_4O_7$:Be,Mn.

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PRE-IRRADIATION ANNEALING INFLUENCE ON EFFICIENCY OF THE NEAR-SURFACE COLOR CENTERS FORMATION IN LITHIUM FLUORIDE NANOCRYSTALS

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Lithium fluoride nanocrystals are irradiated by gamma quanta at 77 K. The radiation color centers formed in a near-surface layer of nanocrystals are studied. Absorption, luminescence and luminescence excitation spectra of the surface defects have been measured. It has been found that the luminescence excitation spectra for aggregated surface centers consist of two or three bands with not very much different intensities. Reactions of the surface centers separately with electrons and with anion vacancies have been investigated.

It is shown that after γ-irradiation in a near-surface layer and in areas with the broken by laser light crystal structure inside a lithium fluoride crystal the same near-surface color centers are formed.

Results of pre-irradiation annealing influence on efficiency of formation of the near-surface color centers in lithium fluoride nanocrystals are presented. The measured at registration wavelength λ_{reg} = 670 nm photoluminescence excitation spectra normalized to a maximum intensity for different pre-annealing temperatures are shown in Fig. The bands with maximum wavelengths λ_m = 393, 493 and 564 nm belong to F_{S3}^+ near-surface color centers, and bulk F_2 color centers are responsible for the band with λ_m = 444 nm. The increase of the pre-irradiation annealing temperature from the room one to 250 ^oC leads to considerable reduction of near-surface centers formation efficiency. At pre-irradiation annealing temperatures about 300 ^oC and above the near-surface color centers after gamma irradiation are not found. The mechanical fragmentation of the crystal or destruction of the bulk crystal structure by laser radiation creates definite defects which are base to create investigated near-surface centers. Pre-irradiation annealing eliminates these defects and conditions necessary for the formation of near-surface color centers.

It is established that adsorption of atmospheric gases on a surface of a crystal can't be considered as a necessary condition of radiation near-surface centers formation.

Measurements of photoluminescence and thermoluminescence glow peaks for dosimeter TLD-100 as well as for nanocrystals prepared from these dosimeters were carried out. The differences were established.

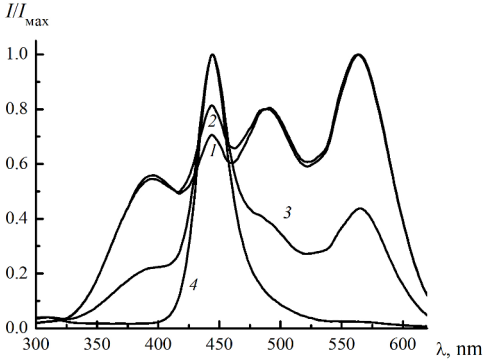

Fig. Normalized to the maximum photoluminescence excitation spectra for LiF nanocrystals measured at registration wavelength λ_{reg} = 670 nm for different pre-annealing temperatures T_{ann} = 100 (1), 150 (2), 200 (3) and 300 (4) ^{o}C before gamma irradiation

FIBER-OPTIC LINKS IN THE DISTRIBUTED RADIATION MEASURING SYSTEMS

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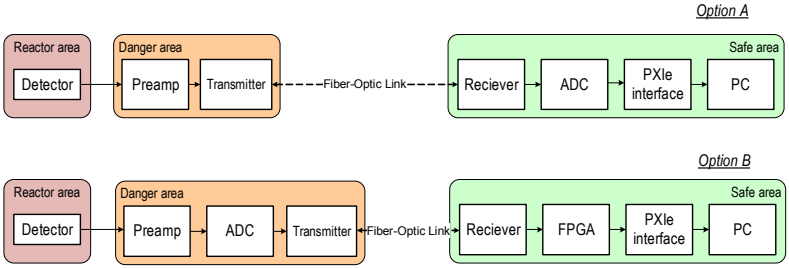
This report presents the results of design of distributed ionizing radiation measuring systems with fiber-optic links. The works are carried out as a part of neutron flux monitor development for the International Thermonuclear Experimental Reactor ITER being built at the moment in France.

Diagnostic equipment in ITER will operate at the harsh environment (intensive neutron and gamma radiation, strong magnetic field, microwave and RF radiation, electromagnetic interference, electrical safety and electrical isolation requirements, and others). One of possibility to avoid signal corruption is an implementation of fiber-optic link.

Currently, we are considering two options for neutron flux measurement system with signal transmission via fiber-optic link (see figure below).



Option A has been realized with «AVAGO» components HFBR-1414Z (transmitter) and HFBR-2414Z (receiver). To transmit analogue signals we use a multimode fiber-optic 62.5/125 with ST connectors. Fiber-optic link has the following specifications:

- bandwidth (level -3dB) 10Hz ÷ 50MHz;
- dynamic range 60dB;
- non-linearity gain less 0.6%;
- input 1V;
- transmission ratio of 1.

For the option B is designed 3-channel acquisition system based on a fast digitizer (ADC). A feature of this system is the performance of fiber optic

adapter as FlexRIO module for direct digital data transfer to commercial available FPGA module. The system has following parameters:

- ADC – 14 bit;
- sampling rate – 100 MHz;
- channels for measurement data signals transmission – 3;
- channels for transmitting test signals – 1;
- channels for two-way digital data transmission – 1 (8 bits).

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ACTIVATED CRYSTALS OF KDP GROUP FOR SELECTIVE REGISTRATION OF NEUTRONS

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The obtaining of selective scintillators for monitoring of mixed neutron-gamma radiation fluxes is a topical problem. For its solution, KDP group crystals (KH_2PO_4, NH_4PO_4 LiH_2PO_4) seem to be promising, due to their density of 2.34 g/cm^3, effective atomic number Z = 14, oxygen content of ~10^{22}cm^{-3}. Moreover, such crystals weakly absorb gamma-quanta. In the present research we studied the possibility to obtain a scintillation matrix for selective registration of fast neutrons by introducing activating additives (thallium, cerium, etc.) into the lattices of KDP group crystals.

KDP and ADP crystals activated with thallium ($\mathbf{C_{Tl}}$ =$10^{-5}\div10^{-1}$mass %) or cerium ($\mathbf{C_{Ce}}$ =$10^{-2}\div10^{-1}$mass %, by using the organic ligand alizarin-complexon AC+Ce) were grown from aqueous solutions. The character of the entering and distribution of thallium was shown to be defined by the charge state of the prismatic and pyramidal growth faces {100} {101} of the crystals, and be dependent on the difference between the ionic radii of the lattice and the additive cations. LDP single crystals were grown from phosphate solutions by the method of evaporation and activated with derivatives of salicylic acid.

The absorption and luminescence spectra of the grown crystals were studied. As is known, thallium ions have the ground level $^1S_0$ and a number of excited levels such as $^1P_1$, $^3P_0$, $^3P_1$,$^3P_2$. In the crystal lattice field of the tetragonal symmetry of KDP crystal, the allowed transitions are: $^1S_0 \rightarrow {}^3P_1$ (absorption band A), $^1S_0 \rightarrow {}^3P_2$ (absorption band B), $^1S_0 \rightarrow {}^1P_1$(absorption band C). The absorption spectra of KDP:Tl^+ and ADP:Tl^+ contain A-, B- and C-bands absent in the spectra of the non-activated crystals. The maximum of the A- band corresponds to 220 nm (at room temperature). UV-excitation in this band gives the maximum of the photoluminescence band of 275 nm. The Stokes shift is 55 nm. The absorption and luminescence spectra of LDP correspond to 300 and 450 nm, respectively.

The absorption spectra of KDP:(AC+Ce) crystals contain two absorption bands with λ_{max} = 470 and 290 nm bound up with the ligand and Ce^{3+} absorption, respectively. The crystals possess dichroism. Excitation with 290 nm

light gives rise to luminescence with λ_{max} = 350 nm due to the interconfigurational transitions 5d→4f of the shell of Ce^{3+} ions, whereas excitation at 470 nm causes long-wavelength luminescence with λ_{max} = 650 nm which is the luminescence band of the said ligand.

Irradiation of the activated crystals with neutrons from Pu-Be source leads to scintillations caused by the formation of recoil protons in elastic collisions of fast neutrons with the hydrogen sublattice. In their turn, the recoil protons form hydrogen vacancies in the phosphate anionic complex followed by the appearance of the A-radical : $(H_2PO_4)^- + n \rightarrow p + (HPO_4)^-$. The latter is a hole located on an oxygen ion in the vicinity of a hydrogen vacancy. Recombination of an electron-hole pair on the activator gives rise to a radioluminescence pulse which maximum corresponds to photoluminescence emittive transitions. The efficiency of fast neutron registration makes 12–15%, that is on the level with that of anthracene. The registration efficiency for γ-quanta from ^{60}Co is by an order lower in comparison with the one of anthracene. At $E_\gamma = 0.83 \div 1.33$ MeV $\varepsilon^{\gamma}_{ant} / \varepsilon^{\gamma}_{KDP} \approx 10$.

AFTERGLOW OF SCINTILLATOR CsI(Tl) IRRADIATED GAMMA RAY OF DURATION 1÷10 μs

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In some references [1–3] it is indicated high value of the effect of the afterglow of scintillators CsI (Tl) – up to 5% in 3–5 ms after irradiation. This factor makes the developers of imaging systems to refuse the use of the scintillator, as the impact of the effect of the afterglow of the scintillator crystal used in the imaging system, limits the contrast of the resulting image. However, studies of the afterglow are usually conducted under conditions of prolonged exposure – from 100 milliseconds to tens of seconds. In [4, 5] it is indicated that the afterglow of CsI (Tl) is dependent on pulse duration and intensity of radiation. It should be noted that in some systems of digital imaging the duration of gamma radiation pulse is less than 10 microseconds. For example, the pulse duration of betatron, which are used in imaging systems of large objects, is about 5 microseconds.

For measuring of the afterglow when irradiated with pulsed radiation of the betatron frequency pulses 400 Hz and duration 1–6 microseconds it was performed an experiment using the developed system of detectors. The experiment shows that the magnitude of the afterglow effect is not more than 0.15% on the value of the detector signal over 2400 ms (see Fig.).

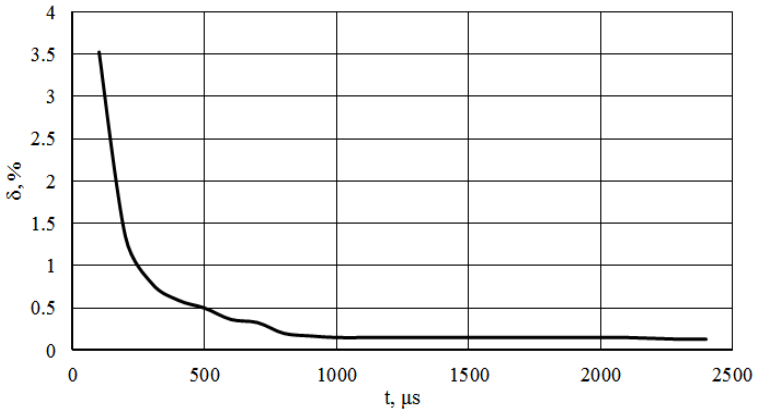

Fig. Afterglow of *CsI(Tl)* when duration of pulse less than 10 μsec

Thus, in this case, the effect of the afterglow of the scintillator CsI (Tl) has no significant effect on the result of the radiation intensity measuring and contrast of the shadow image as a whole.

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DETECTORS OF CARGO SCANNING SYSTEM

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Perspective direction of development of systems of imaging large objects is the introduction of systems with induction accelerators – betatron with radiation intensity is 10–50 times lower than one of the linear accelerator. Thus, to ensure safety of personnel and the driver, it requires less physical protection. However, small intensity of radiation reduces signal/noise ratio of system, which leads to deterioration of the imaging system properties. The relevance of the work was due to the need to improve the efficiency of imaging systems in which the radiation source was a betatron. Increased efficiency has been achieved through the development of more sensitive radiation detectors.

As a result of the research it was obtained theoretical dependence of the sensitivity of the detector of ionizing radiation on the density, conversion efficiency, attenuation own radiation, the size of the scintillator and the coefficient of matching the emission spectra of a scintillator and a photodiode, and defined requirements for the material and design of the crystal scintillator for providing high sensitivity radiation detector in the 0.1–5 MeV range. Furthermore, based on this relationship we give recommendations for developing the photodiode with low dark current, low capacity and increased spectral sensitivity in the emission region of the proposed scintillator (CsI(Tl)). A detector designed with sensitivity 1700 nC/R, exceeding sensitivity of known analogues in 1.5 times.

A method to optimize the configuration structure of the detector of gamma radiation was developed. The method consists in the analysis of the experimental dependence of the detector signal from the distance between the light field and the photo diode, allowing to obtain a signal/noise ratio is 9% higher than in a mirrored configuration of detector of imaging system with betatron on energy 5 MeV.

In order to optimize the choice of the material of the crystal of detector, it was developed a method of comparison the magnitude of scattered gamma radiation between crystals scintillators, as well as there were given practical recommendations on creation of detector construction, improving its efficiency by choosing the surface material of the scintillator and using light-blocking material between the crystals.

As a result, it is designed the system with betatron on energy 7.5 MeV which penetrating ability is 260 mm in a steel equivalent, that is 1.5 times higher than the value of this parameter of similar systems developed earlier, at a speed of movement of vehicles up to 8 km/h and a spatial resolution of 5 mm.

COLLECTION DATA SYSTEM FOR CARGO SCANNING

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In connection with the need to ensure the safety of personnel of cargo scanning system when working with high-energy radiation source the system must be spatially distributed. Thus, the development of detection systems, control systems, data collection and transmission system in the operator's computer requires solving a large number of problems, e.g. the distance of the radiation source and the detector from locations of the information processing in conditions of continuous stream of data from the sensors, the number of which is more than 1000 units. Overall system block diagram of scanning of heavy vehicles is shown in Fig.

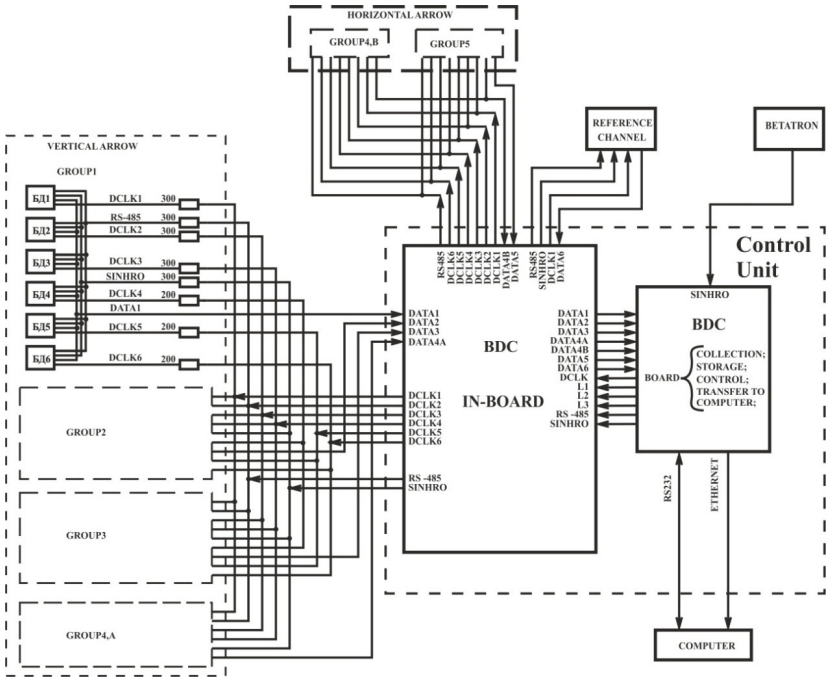

Fig. Structure of cargo scanning system

The main nodes of the system are:

1) horizontal and vertical arrows of detector units;

2) the unit of the reference channel;

3) Control Unit block of complex control, which is represented by two functional circuit boards: a) entrance board – board of synchronization work of detector units and betatron, and of collecting data from the detector unit; b) board of transmitting control signals from computer to the detection units and transmitting of data of detection units to a computer for processing;

4) the computer through which the operator controls the complex and performs conversion of the detector array data in a shadow image of the scanned object.

GAMMA SPECTROMETER FOR RADIATION MONITORING WATER AREAS AND BOTTOM SEDIMENTS

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In order to solve the problem of continuous or periodic monitoring of water areas affected by radioactive contamination in the result of scheduled emissions in nuclear power plants or in the result of emergency situations in nuclear fuel cycle plants we need to develop measurement instruments with advanced mathematic and program support to assess the level of radioactive contamination with required accuracy. We have developed and built multifunction gamma spectrometer for "in situ" radiation monitoring of water areas and bottom sediments.

This instrument and consists of spectrometric scintillation detection unit packed into sealed container with NaI(T1) crystal of Ø63×63mm size, cable reel with deep-sea cable and a tablet PC for data processing and display. The container withstands static hydraulic pressure up to 1.5 MPa and can be used for measurements at depths of 500 m maximum. Detection unit measures energy distribution of gamma radiation with energy from 70 keV to 3000 keV.

Developed mathematical models of spectrometer and controlled objects make it possible to identify detector response function to predefined radionuclides in specified measurement geometries without physical volumetric measures of activity.

The implemented three-dimensional system to determine detection unit position and orientation allows automatic operation of the device (without operator) for water areas or bottom sediment scanning. The spectrometer can output measurement results with three-dimensional geographical coordinates as index maps of distribution with necessary resolution and accuracy.

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

НЕКОТОРЫЕ ОСОБЕННОСТИ ПОВЕДЕНИЯ ВЕЛИЧИНЫ НЕОДНОРОДНОСТИ РАСПРЕДЕЛЕНИЯ СВЕТОВЫХОДА ВДОЛЬ ДЛИННОМЕРНОГО СЦИНТИЛЛЯТОРА НА ПРИМЕРЕ КРИСТАЛЛОВ CsI(Tl)

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Энергетическое разрешение электромагнитного калориметра ($\sigma_E/E=R$) – одна из наиболее важных характеристик ядерно-физических установок. Достигнутые в экспериментах значения R превосходят те, которые ожидались от вклада шумов и статистики фотонов и сопоставимы с вариациями световыхода (L_Y) в объеме кристаллов [1]. Поэтому величина неоднородности распределения светоотдачи сцинтиллятора (Δ) – фактор, доминирующий в величине R [2]. В связи с этим исследования поведения Δ в различных экспериментальных ситуациях приобретают первостепенное значение.

Закон изменения L_Y с координатой сцинтилляций как вдоль длинного сцинтиллятора (BaBar, GLAST), так и по поверхности счетчика большой площади (HXMT) может быть задан путем частичного матирования поверхностей кристаллов. Этот способ использовался и для получения минимальных значений Δ у кристаллов CsI(Tl) в форме неправильной усеченной пирамиды длиной 22 см и основаниями 1.6×2.24 см^2 и 3.05×4.07 см^2, концентрация активатора (C_{Tl}) в которых принадлежала интервалу $0.04 \le C_{Tl} \le 0.16$ моль%. Выбранный метод уже после первой обработки кристаллов обеспечивает близкое к гауссовому распределение Δ между образцами шириной 1.9% и центром – 2.14%. Распределение близко к гауссовому из-за того, что оно несколько «затянуто» в сторону больших Δ. Одной из причин асимметрии распределения служит тот факт, что L_Y счетчиков с матированными кристаллами зависит от C_{Tl} и L_Y=const существует в значительно более узком интервале изменения значений этого параметра. Другим фактором, влияющим на оптические характеристики сцинтилляторов, служит зависимость ширины спектра радиолюминесценции (σ_λ) CsI(Tl) от C_{Tl}. Изменение спектрального состава света сцинтилляций происходит и при постоянных значениях C_{Tl} в случае, если кристалл подвергался пластической деформации. Более значимый по сравнению с матированием вклад в деформацию CsI(Tl) возникает на этапе роста монокристаллов. Этот эффект отвечает

за несовпадение распределений кристаллов по L_Y, вырезанных из разных частей монокристаллов из-за роста геометрических флуктуаций коэффициентов светособирания и конверсионной эффективности (η), а также статистических флуктуаций η. Зависимость Δ от E_γ можно получить из определения Δ. Для $L_{Y,max}$ и $L_{Y,min}$ справедливы соотношения

$$L_{Y,max} = \theta_a \cdot E_\gamma + \beta_a, \quad L_{Y,min} = \theta_b \cdot E_\gamma + \beta_b,$$

и тогда

$$\Delta = [(\theta_a - \theta_b) \cdot E_\gamma + (\beta_a - \beta_b)] / [(\theta_a + \theta_b) \cdot E_\gamma + (\beta_a + \beta_b)],$$

где $\theta_a \neq \theta_b$ и $\beta_a \neq \beta_b$.

Представив L_Y в виде:

$$L_{Y,max} = \tau_a \cdot \eta_a \text{ и } L_{Y,min} = \tau_b \cdot \eta_b,$$

можно убедиться, что $\eta_{a,b}$ при разных E_γ будут совпадать только если

$$\Delta(E_{1\gamma}) = \Delta(E_{2\gamma}),$$

так как

$$\eta_{a,E1} / \eta_{a,E2} = (\eta_{b,E1} / \eta_{b,E2}) \cdot (k_{E2} / k_{E1}),$$

где $k_m = (1-\Delta_m)/(1+\Delta_m)$, $m = E_1 = E_{1\gamma}$ и $E_2 = E_{2\gamma}$.

Величины η_a и η_b могут не совпадать между собой в силу того, что они подвержены и геометрическим флуктуациям, которые не зависят от E_γ. Результаты экспериментов показывают, что при одних условиях роста монокристаллов можно получить $\Delta(E_{1\gamma}) = \Delta(E_{2\gamma})$, а при других – $\Delta(E_{1\gamma}) \neq \Delta(E_{2\gamma})$ безотносительно значений C_{Tl} и ∇C_{Tl}, но изменяющихся в пределах, где $L_Y(C_{Tl}) = \text{const}$.

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АВТОРСКИЙ УКАЗАТЕЛЬ

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Научное издание

Пятая международная конференция

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