National Science Center
Kharkov Institute of Physics and Technology

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

RADIATION DETECTORS
at the Institute of Solid State Physics, Materials Science and Technologies of NSC KIPT, Kharkov, Ukraine

V.E.Kutny, A.V.Rybka, V.Voyevodin, L.Davydov

National Science Center
Kharkov Institute of Physics and Technology

Director General – Prof. N. Shulga

Kharkov Institute of Physics and Technology (the KIPT, earlier Ukrainian Institute of Physics and Technology), being one of oldest and largest centers of physical science in Ukraine, was created in 1928 for the purpose of developing urgent lines of research (at that time - nuclear physics and solid-state physics).

Main entrance to the NSC KIPT

As soon as four years later, on October 10, 1932, an outstanding result was received by A.K.Val'ter, K.D.Sinel'nikov, A.I.Leipunsky, G.D.Latyshev, namely, the nucleus of lithium atom was caused to undergo disintegration.

Monument to the scientists who in 1932 first split up Lithium nucleus in the Institute

NSC KIPT structure

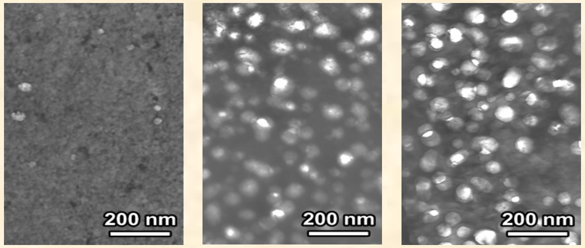
- Institute of solid-state physics, materials science and technologies
- Institute of high-energy physics and nuclear physics
- Institute of plasma electronics and new methods of acceleration
- Institute of plasma physics
- Akhiezer Institute for theoretical physics
- Separate departments
  - The Science and Technical Establishment "Nuclear Fuel Cycle" (NFC STE)
  - The Science and Production Establishment "Renewable Energy Sources and Sustainable Technologies" (SPE RESST)
  - “Accelerator” Science and Research Establishment
  - Accelerator Driven System and Neutron Source

Institute of solid-state physics, materials science and technologies

Director – Prof. V.N. Voyevodin

Research in:

- Fundamental and applied aspects of low-temperature and high-temperature **superconductivity**.
- Physics of **strength** and **plasticity** of solids.
- Physics of **radiation effects** and **radiation materials** science. Radiation, ion-beam technologies. Transmutation of nuclei and other nuclear technologies.
- Physics and chemistry of ion-plasma, plasma-chemical and diffusive methods of depositing **coatings** to increase wear resistance, high temperature strength, corrosion stability and to improve other properties of materials.



Voidage at radiation damage in EP-450 reactor steel after 150, 200 and 250 dpi

Accelerator for reactor radiation damage imitation

- Physical materials science of pure and **superpure metals** and semiconductors. Development of technology for their production and analysis.
- R&D of structural materials. **Composite materials**. Carbon and graphite materials. High-temperature and gasostatic technologies.
- Development and research of **nuclear fuel and neutron absorbing materials**. Design and technology of manufacturing fuel and control rods, and fuel assemblies. Handling of spent nuclear fuel. Technological support of a nuclear fuel cycle of Ukraine.

RADIATION DETECTORS

in the Institute of Solid State Physics, Materials Science and Technologies of NSC KIPT (Laboratory of New Technologic Designs)

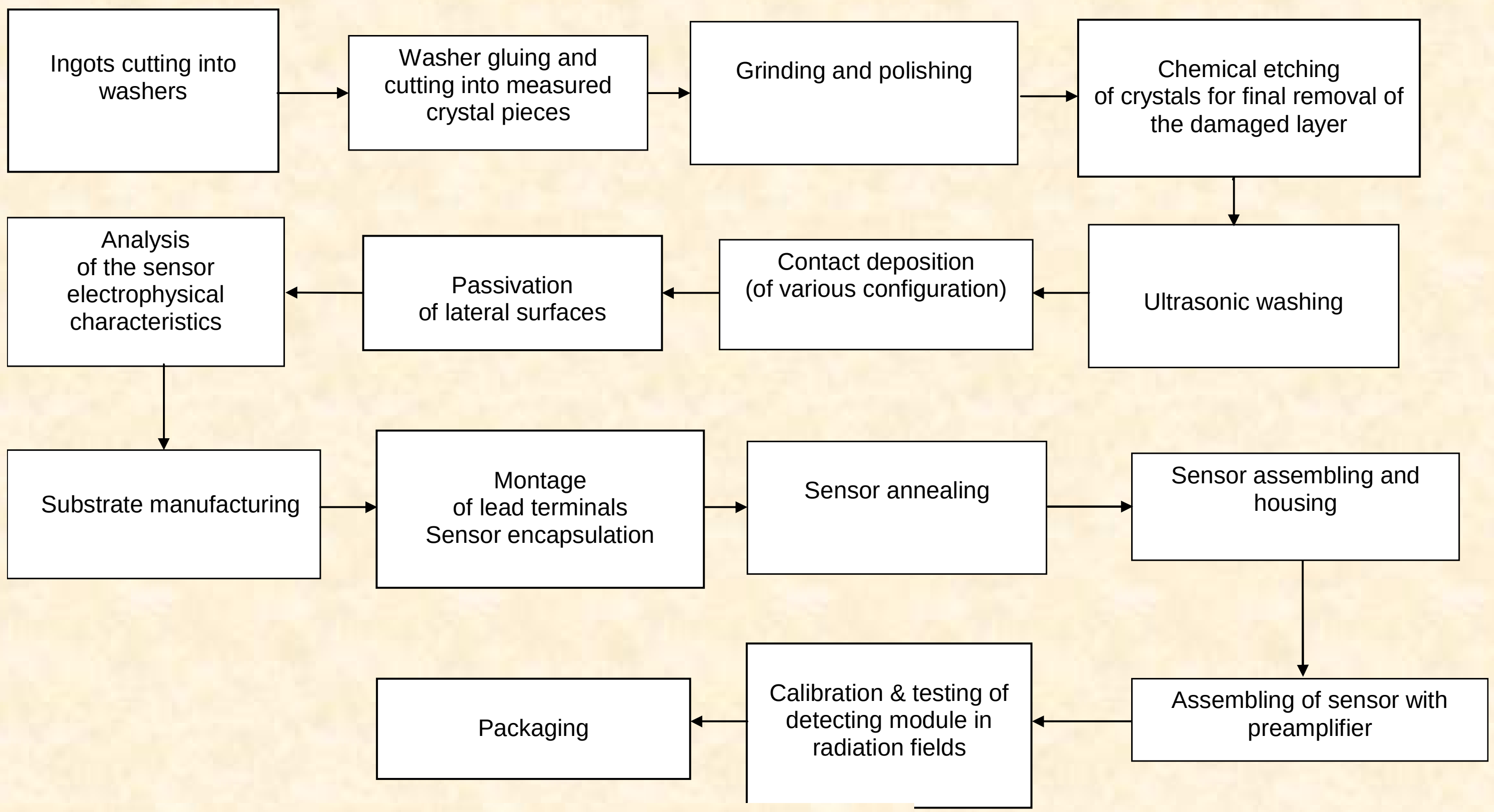
Outline

1. Investigation and manufacture of CZT and CdTe sensors, detector modules and instrumentation
2. Dosimetry and spectrometry
3. Monte-Carlo simulation of CdZnTe detectors
4. Practical realization of measuring equipment with CdTe and CdZnTe detectors in NSC KIPT
5. Radiation detectors made of CVD diamond films
6. Self-powered neutron detector
7. Gamma-ray proportional gas detector
8. High pressure Xe gamma-ray spectrometry detectors

Vladimir Kutny, PhD,
Head of Laboratory

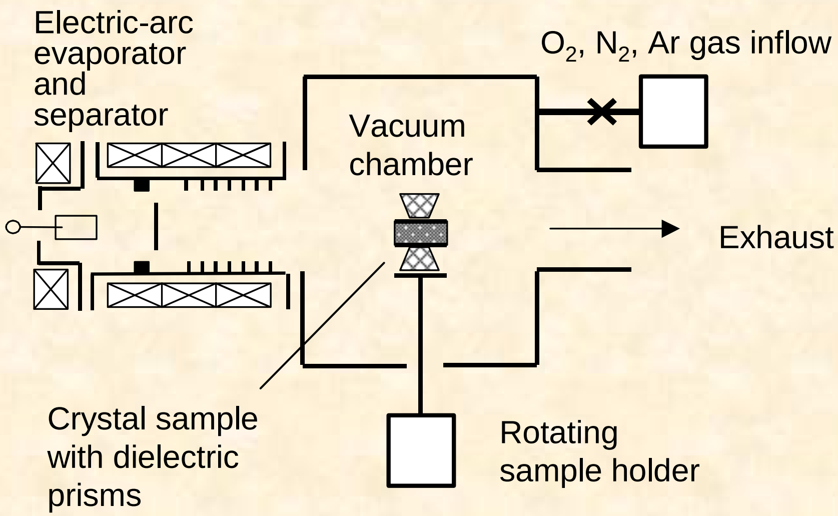
1. Investigation and manufacture of CZT and CdTe sensors, detector modules and instrumentation

Production process of CZT and CdTe detecting modules



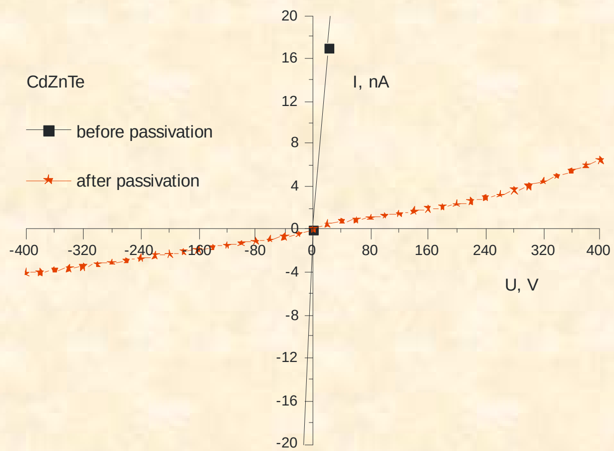
Passivation of CZT detector lateral surface

Plasma-chemical passivation

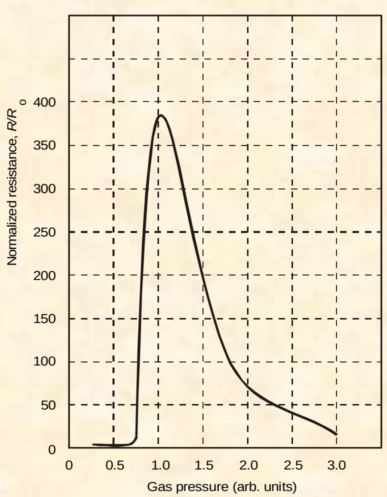


Scheme of an installation for ion plasma passivation of CdZnTe lateral surface.

Parylene passivation



I/V characteristics of CdZnTe detector before and after cleaning and covering with parylene.



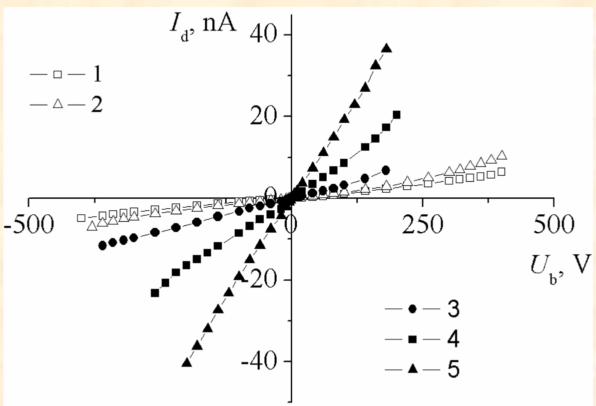
Ratio of the detector resistance before and after passivation as function of the gas pressure in the passivation installation.

Among several passivation methods investigated the best performances of CdZnTe detectors are obtained with plasma-chemical coating of HfO_2.

However, for technological process requirement a parylene (poly-para-xylylene) coating, ensuring temporal stability, is preferred. The cover is applied from the gas phase, after preliminary sample cleaning in the magnetron discharge

I-V Characteristics of Au/CdZnTe/Au detectors

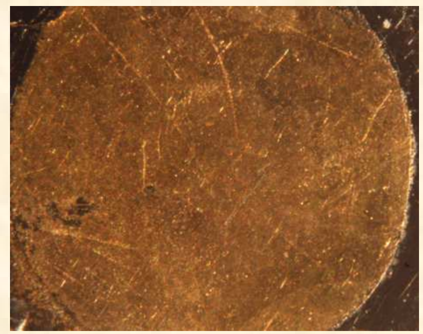
Traditional manufacturing of detector contacts: etching in at 5 % bromine-methanol and chemical sedimentation Au from a solution of chloroauric acid linear ohmic I/V characteristic in a broad range of bias voltages.



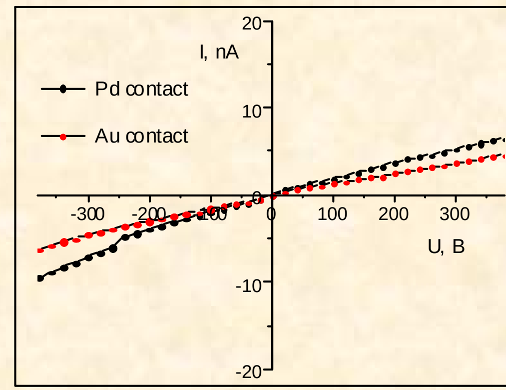
I/V characteristics of CdZnTe sensor at different temperatures: 1– –20°C; 2– 0 ºC; 3– +20 °C; 4 – +40 °C; 5 – +60 °C.

Palladium ohmic contact on semiinsulating CdZnTe

Palladium ohmic contact on the semiinsulating CdZnTe Pd coating is harder than golden coating (3-5 times), able to soldering even after being in corrosive environment, have greater wear resistance compared with Au-covers.



CdZnTe crystal (5x5x2 мм^3) with Pd contact deposited by restoring 0.4 %-solution of [Pd $(NH_3)_4$] Cl_2.



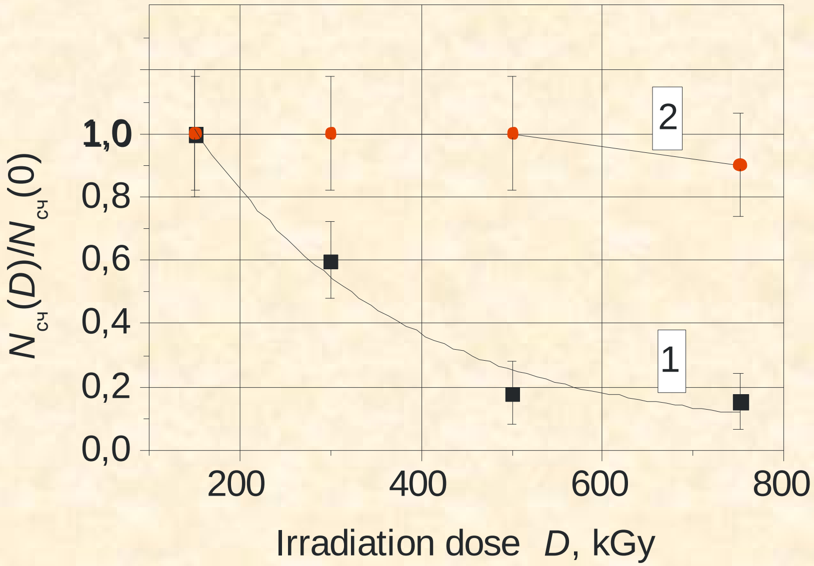
I/V characteristics of detectors with Pd and Au chemically deposited contacts.

The contacts have high adhesive ability, increased mechanical strength and possibility of adjusting the coating thickness.

Au-Pd-contacts ensure operating performances not worse than standard Au-contacts.

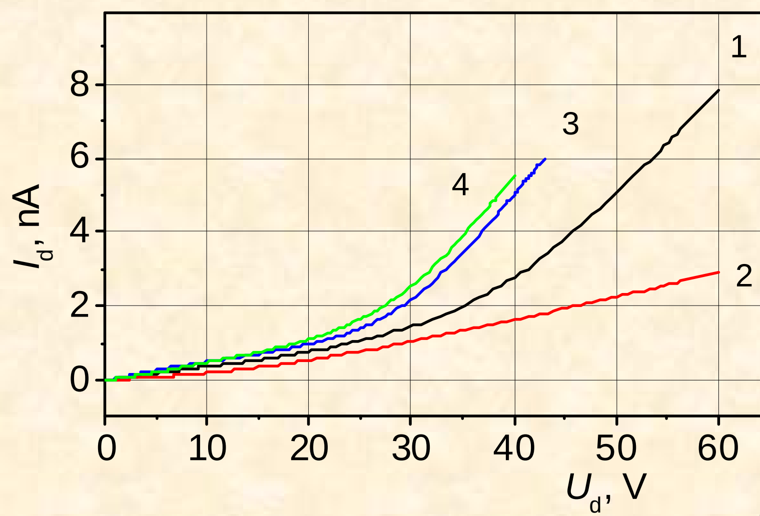
Investigation of the radiation hardness of CdTe and CdZnTe detectors

Stable radiation defects are accumulated during lasting gamma irradiation and despite of small cross-section of their formation at large doses deteriorate the material. The limiting absorbed dozes for CdTe and CdZnTe make ~200 kGy and ~800 kGy correspondingly. The doze limit for dosimetry detectors is substantially larger than for spectrometric devices.



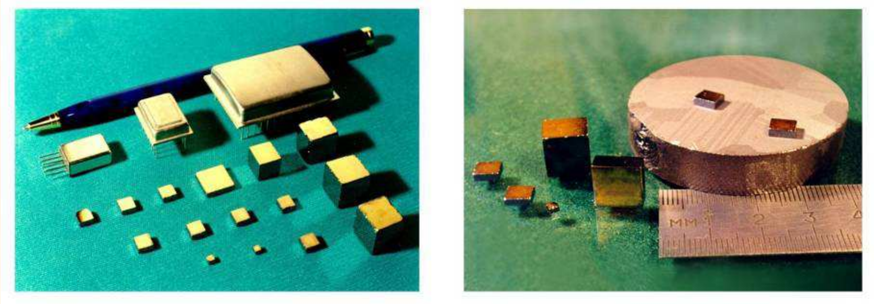
Samples were irradiated by Bremsstrahlung at an electron linac (11 MeV) and average beam current 430 uA. The Bremsstrahlung absorbed dose rate was 7.5 Mrad/h (75 kGy/h).

Dose dependence of detectors count performance. 1 – CdTe, 2 – CdZnTe. The ordinate axis presents a ratio of the count rate after the irradiation *N(D)* to the count rate N_0 of the unirradiated detector.

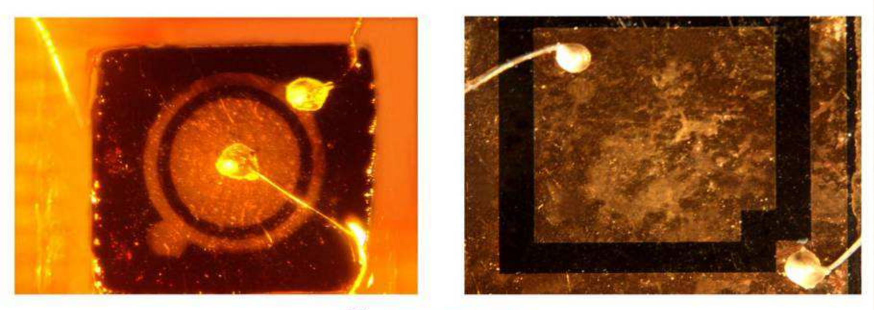


I/V characteristic (leakage current) of a CdZnTe detector for different gamma-irradiation doses:
1 - unirradiated; 2 – 0.5 Mrad; 3 – 1.1 Mrad; 4 – 2.1 Mrad.

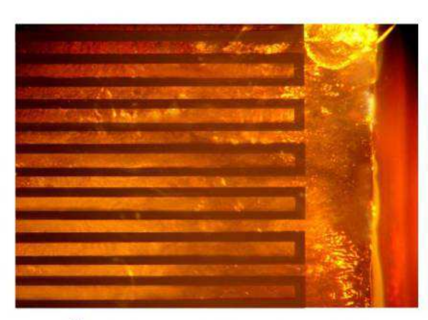
Investigation and manufacture of CZT and CdTe detector instrumentation



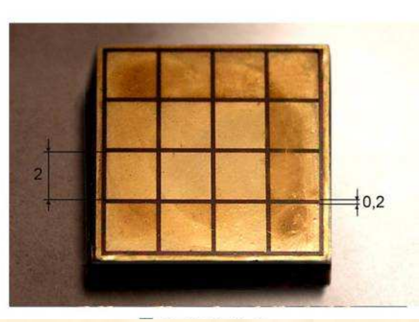
Detectors and crystals



Contacts and guarding ring



Detector with planar mesh contact



Pixel contacts

Gamma-ray detectors using semiconductor compounds CdTe and CdZnTe

With the use of semiconductor compounds CdTe and CdZnTe at NSC KIPT a new generation of ionizing radiation detectors was developed. They have high count efficiency, high energy resolution, high sensitivity at small size, and do not require cryogenic cooling.

Breadboard detector devices using CdTe and CdZnTe for dosimetry and spectrometry of gamma-rays

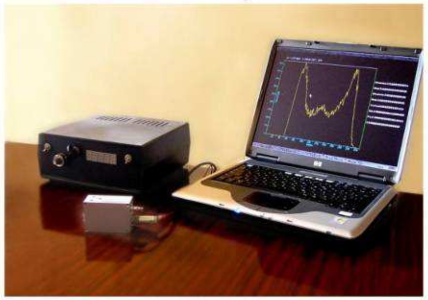
Experimental detector modules (DM) are developed to be integrated in the systems of radiation monitoring of NPP of Ukraine. Such DM, base on CdTe and CdZnTe sensors, operating in a **count mode**, satisfy the requirements for radiation monitoring instrumentation.

DM, operating in a **current mode,** are intended for measurements of high-intensity gamma-radiation at the monitoring system of the fuel containing masses at «Shelter» in Chernobyl and for estimation of radiation loads for patients at radiation therapy and screening.

Emergency γ-ray detector module

CdZnTe large-size spectrometry detectors (~1 cm^3)

Detector module for X-ray dose rate control



CdTe и CdZnTe γ-ray spectrometers

Wide-range γ-ray dose rate detector module

Circular matrix of 120 detectors with preamplifiers

National Science Center
Kharkov Institute of Physics and Technology

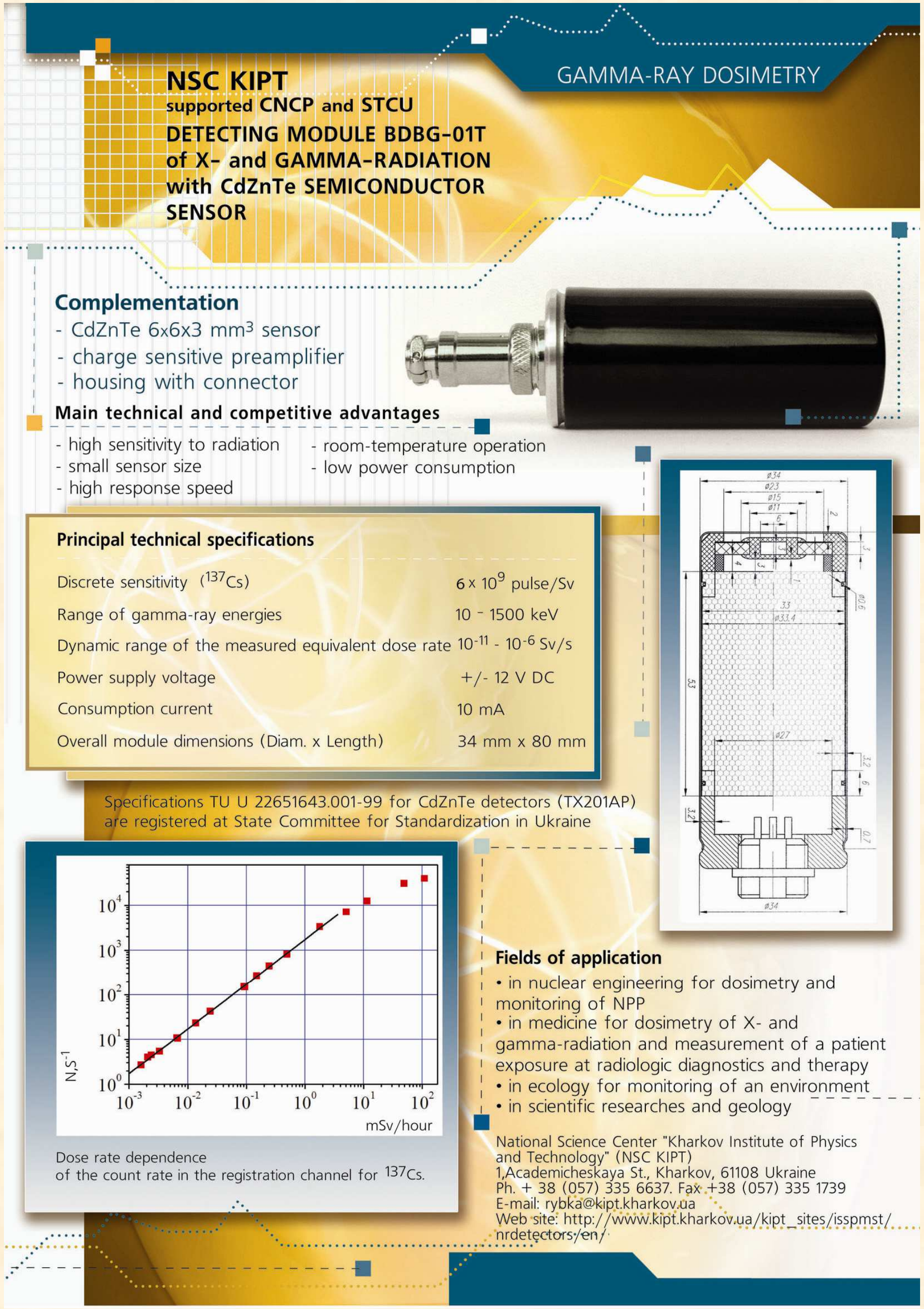
Detector modules for system of gamma-ray control

Detector module BDBG-01T with semiconductor CdZnTe sensor was developed for dosimetry of X- and gamma-radiation.

It consists of CdZnTe detector 6×6×3 mm^3 and charge sensitive preamplifier.

Its principal technical and competitive advantages are high sensitivity to radiation at small size, high processing speed, and low energy consumption.

The State Bureau of Standards of Ukraine has registered the specifications TU U 22651643.001-99 for our CdZnTe detectors.



GAMMA-RAY DOSIMETRY

NSC KIPT
supported CNCP and STCU
DETECTING MODULE BDBG-01T of X- and GAMMA-RADIATION with CdZnTe SEMICONDUCTOR SENSOR

Complementation
- CdZnTe 6x6x3 mm^3 sensor
- charge sensitive preamplifier
- housing with connector

Main technical and competitive advantages
- high sensitivity to radiation
- small sensor size
- high response speed
- room-temperature operation
- low power consumption

Principal technical specifications

Discrete sensitivity (^{137}Cs)	6 x 10^9 pulse/Sv
Range of gamma-ray energies	10 - 1500 keV
Dynamic range of the measured equivalent dose rate	10^{-11} - 10^{-6} Sv/s
Power supply voltage	+/- 12 V DC
Consumption current	10 mA
Overall module dimensions (Diam. x Length)	34 mm x 80 mm

Specifications TU U 22651643.001-99 for CdZnTe detectors (TX201AP) are registered at State Committee for Standardization in Ukraine

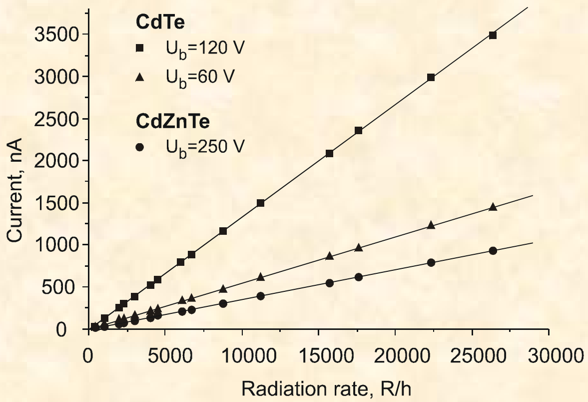
Dose rate dependence of the count rate in the registration channel for ^{137}Cs.

Fields of application
- in nuclear engineering for dosimetry and monitoring of NPP
- in medicine for dosimetry of X- and gamma-radiation and measurement of a patient exposure at radiologic diagnostics and therapy
- in ecology for monitoring of an environment
- in scientific researches and geology

National Science Center "Kharkov Institute of Physics and Technology" (NSC KIPT)
1,Academicheskaya St., Kharkov, 61108 Ukraine
Ph. + 38 (057) 335 6637. Fax +38 (057) 335 1739
E-mail: rybka@kipt.kharkov.ua
Web site: http://www.kipt.kharkov.ua/kipt_sites/isspmst/nrdetectors/en/

2. Dosimetry & Spectrometry

Emergency dosimeter for NPP

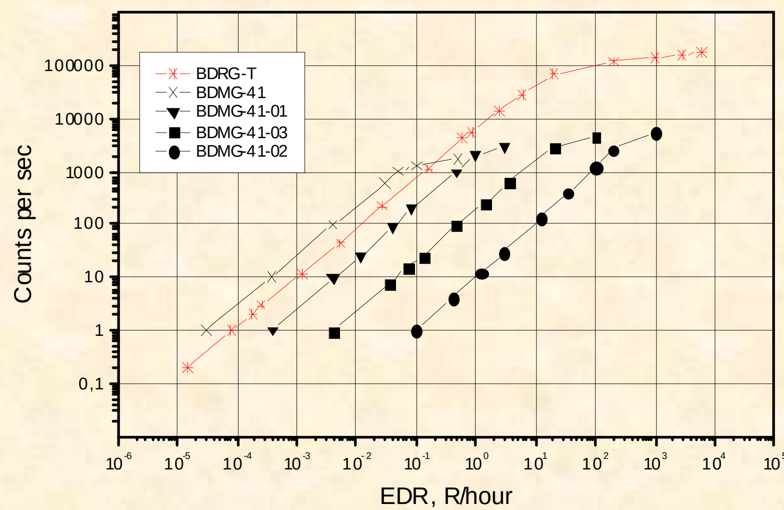


Current characteristic of CdTe and CdZnTe dosimeters for intensive X-rays.

Wide-range γ-ray dose rate detector module

Commercial BDMG-41

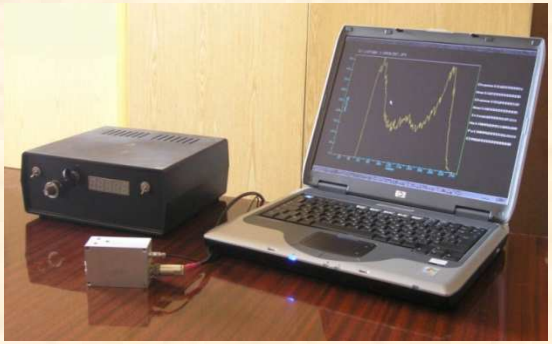
BDRG-T with CdZnTe detector



Calibration characteristics of the commercial detector module BDMG-41 compared to detector module BDRG-T with CdZnTe detector.

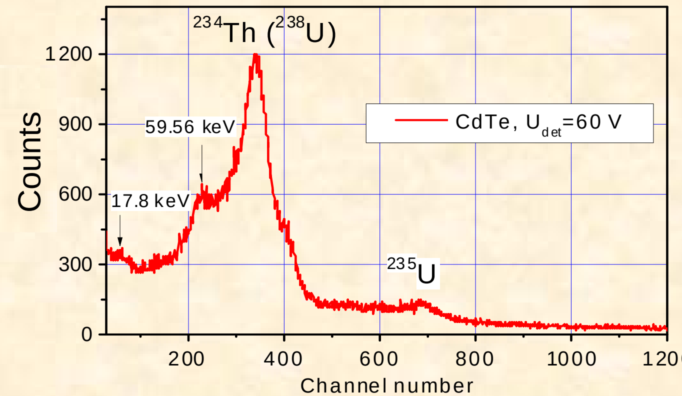
The effect of filters on the γ-ray registration was simulated for CdTe (CdZnTe) detectors both with simple metal filters (Al, Cu, Cd, Sn, Pb, W), and with composite filters either with perforation or without it.

2. Dosimetry & Spectrometry



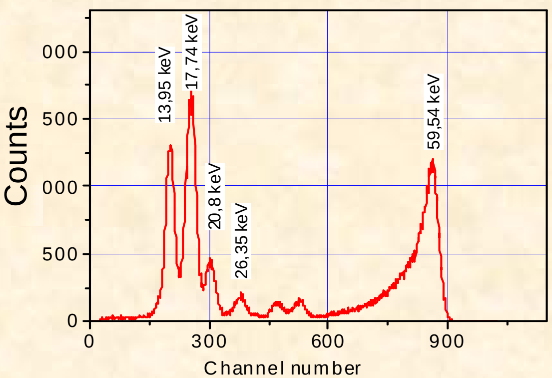
Hand-held gamma-ray spectrometer

Detectors are equipped with Be windows (10-50 um) of in-institute fabrication

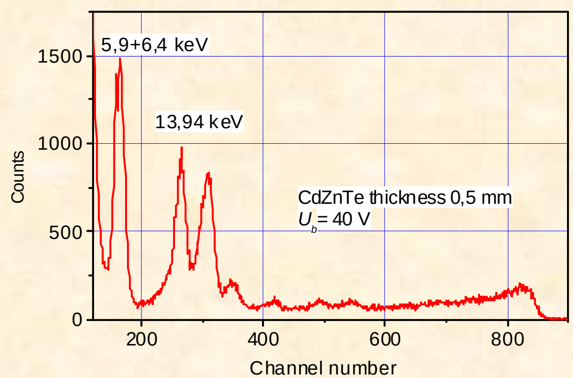


Energy spectrum of fuel containing masses from Chernobyl "Shelter"

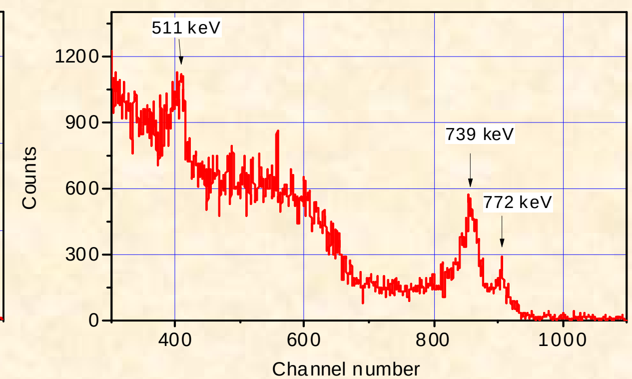
Functions: radionuclide analysis of the fuel containing masses, monitoring of the coolant of the NPP primary circuit, monitoring of fission products in nuclear waste, ^{99m}Tc production



Spectrum of ^{241}Am, measured with CdZnTe detector module.



Spectra of ^{55}Fe and ^{241}Am taken with CdZnTe detector cooled at – 30ºC.



Gamma-ray pulse height spectrum of ^{99}Mo nuclide activated with 15 MeV γ-quanta

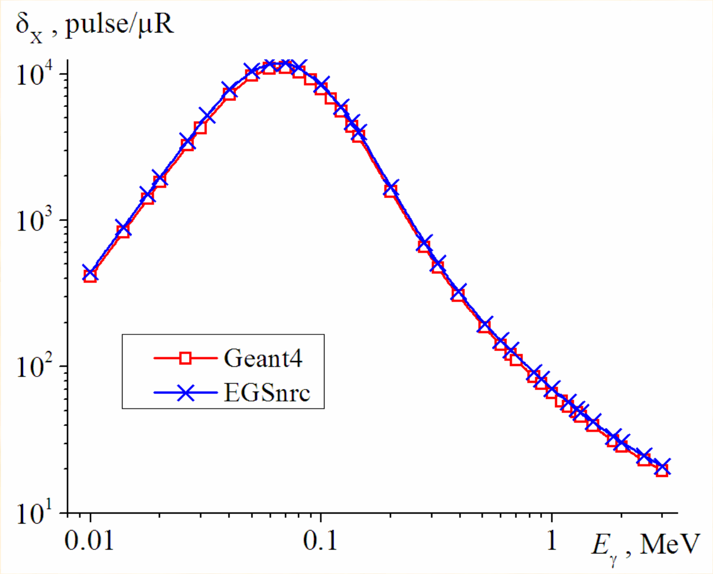
3. Monte-Carlo simulation of CdZnTe detectors

The energy dependence of the sensitivity of planar CdZnTe gamma-ray detectors

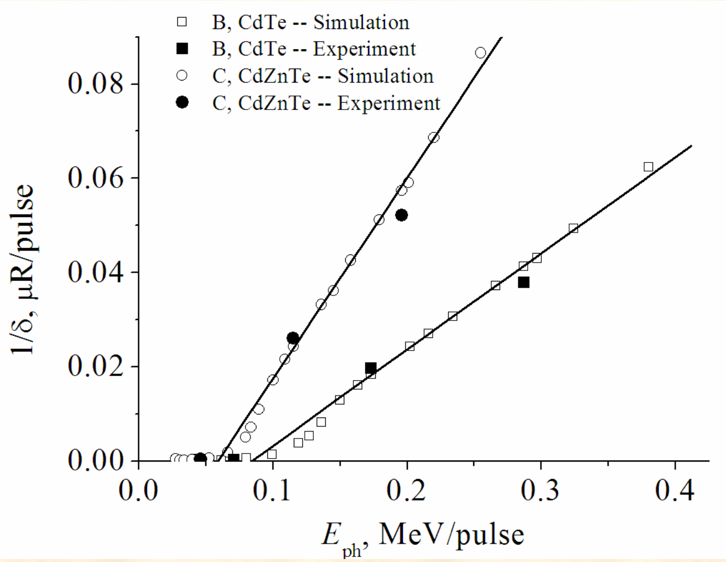
The sensitivity is the ratio of the number of pulses, *N*, produced by the detector to the value of exposure (*X*) or absorbed (*D*) radiation dose:

$\delta_X = N/X$ or $\delta_D = N/D$.

It is sharply depends on gamma-radiation energy, $\delta_{X,D}(E_g)$.



Monte-Carlo simulation of the sensitivity of 6×6×3 mm³ CdZnTe detector, $\delta_X(E_\gamma)$, at a zero-noise discrimination threshold.



Exposure radiation dose is $X = N_T \frac{1}{\delta} = N_T \left(M \times E_{ph} + C \right)$

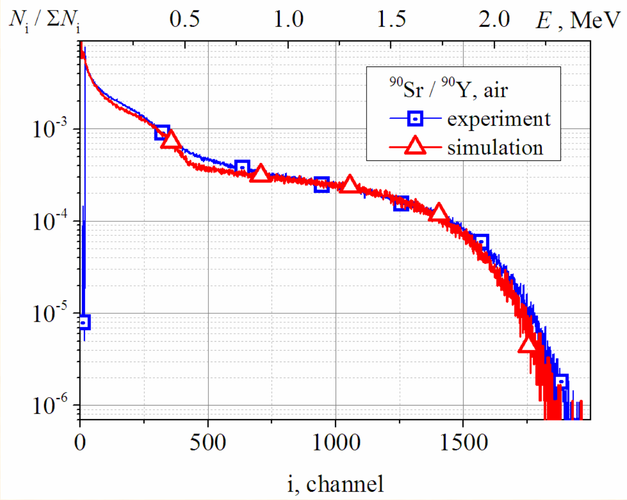
where *M* и *C* – constants to be determined at detector calibration;

N_T the total number of pulses;

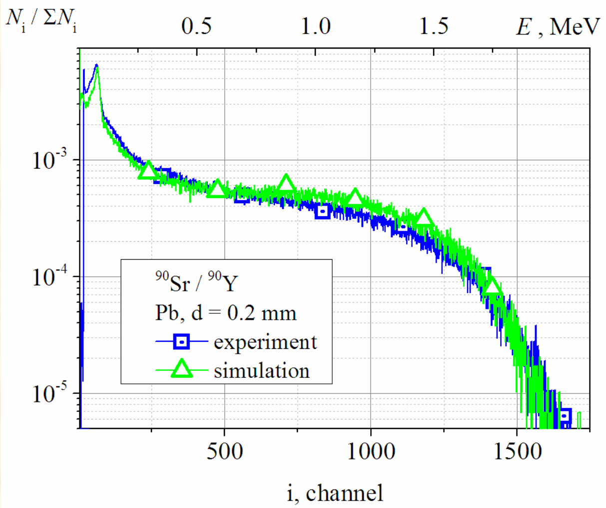
E_{ph} the averaged pulse height.

Monte-Carlo simulation of CdZnTe detector response to beta-radiation

- The electron energy spectra of $^{90}Sr/^{90}Y$ radiation source were measured with a planar CdZnTe detector.
- The model of the wide gap semiconductor gamma-ray detector, developed earlier, was used for the simulation of CdZnTe detector response functions by Monte-Carlo method.
- Only two fitting parameters: products of mobility and lifetime for electrons and holes:
- $(\mu\tau)_e$ and $(\mu\tau)_h$
- Applied for the extraction of beta radiation spectrum from the mixed beta and gamma fields (i.e., at in situ determination of ^{137}Cs and ^{90}Sr sources activity).



$^{90}Sr/^{90}Y$ source spectrum measured with CdZnTe detector without any slowing-down filter.



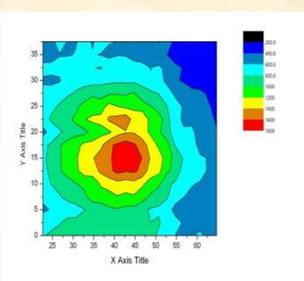
$^{90}Sr/^{90}Y$ source spectrum measured with CdZnTe detector with lead filter.

4. Practical realization of measuring equipment with CdTe and CdZnTe detectors in NSC KIPT

- Imitation research of **radiation protective properties** of materials using linac **electrons** and standard sources electrons
- Imitation research of **radiation protective properties** of materials using **proton** beams
- Research of **absorbing ability of materials** for attenuation of radiation from standard **gamma-ray sources**
- Research of **spatial and energy distributions** of high energy **Bremsstrahlung** with CdZnTe detectors





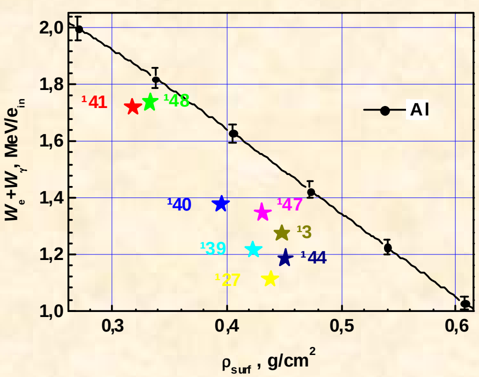


National Science Center
Kharkov Institute of Physics and Technology

Imitation research of radiation protective properties of materials using CdZnTe detectors and e^-, p^+, and γ radiation

The properties of different materials intended for radiation protection of space vehicles were investigated under **electron** accelerator beam.

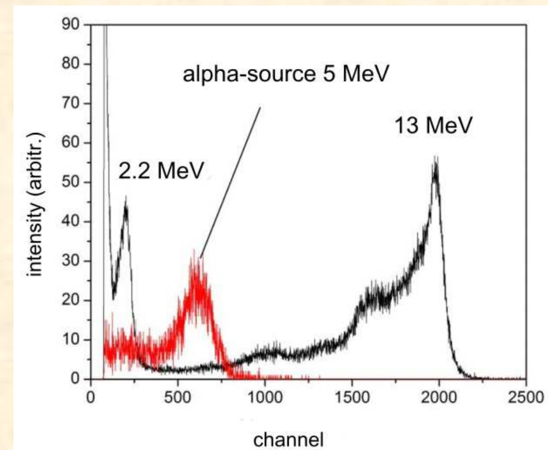
Test facility with CdZnTe detector (10×10×5 mm^3) under electron beam (2.5 MeV).



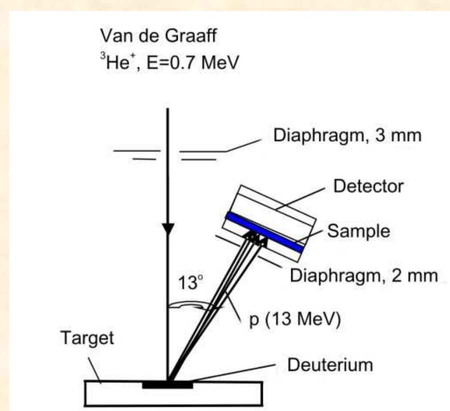
Electron beam total energy after attenuation against Al and polymeric composite materials surface density.

A beam of **protons** was produced at accelerator "ESU-2" in the nuclear reaction D(^{3}He, p)^{4}He.

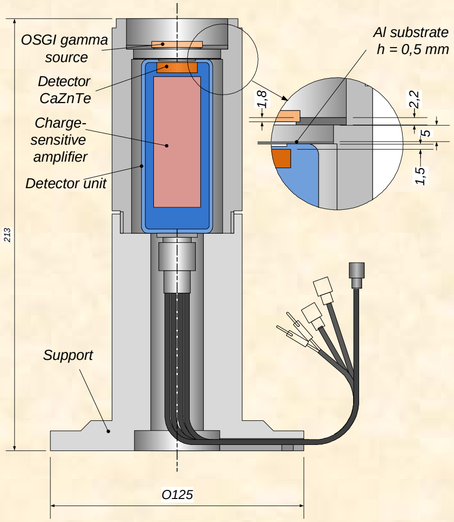
For He ions energy of ^{3}He=0.7 MeV the energy of protons was 13 MeV.



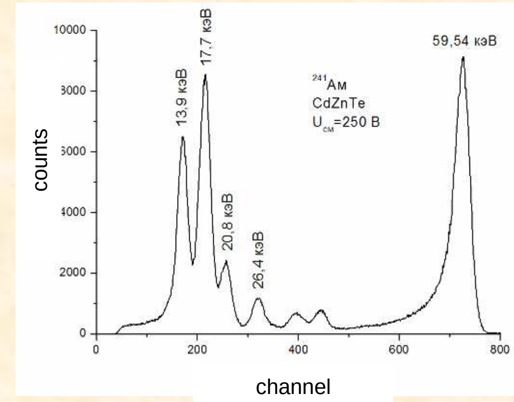
Spectra of 13 MeV protons (black), obtained in reaction at deuterium, and of 5 MeV alpha-particle source (red).



Research of absorbing ability of materials for attenuation of gamma-rays

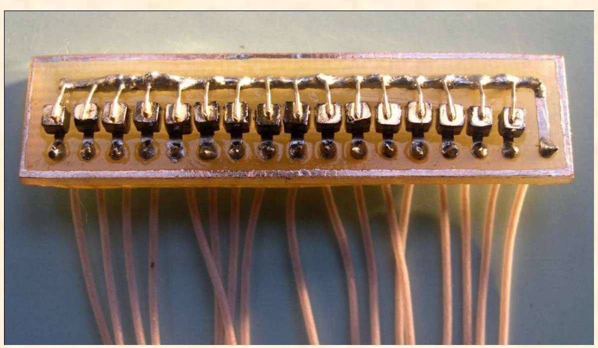


The facility for measuring the absorbing ability of samples with different thickness using reference gamma-ray sources (^{241}Am, ^{137}Cs, ^{60}Co, ^{133}Ba, ^{152}Eu).

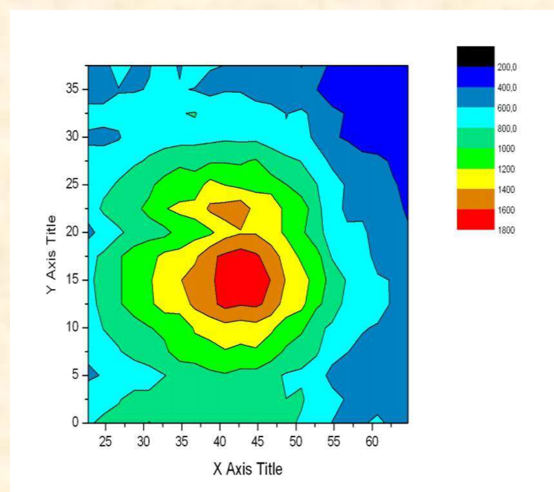


CdZnTe detector pulse-height spectrum

Spatial and energy distributions of high energy Bremsstrahlung



Bar of miniature CdZnTe detectors (1×1×1 mm^3) used for the coordinate analysis of surface activity of irradiated metal foils



The axes display the coordinates of the photonuclear converter in mm. The color scales the gamma-ray activity of the foil in pulse/s.

National Science Center
Kharkov Institute of Physics and Technology

Certificates and Patents of Ukraine

Patents of Ukraine

УКРАЇНА

ПАТЕНТ

НА ВИНАХІД

№ 101270

СПОСІБ ВИМІРЮВАННЯ ПОГЛИНУТОЇ Д
ВИПРОМІНЮВАННЯ

Видано відповідно до Закону України "Про охорону пра
і корисні моделі".

Зареєстровано в Державному реєстрі патентів Україн
11.03.2013.

Голова Державної служби
інтелектуальної власності України

УКРАЇНА

ПАТЕНТ

НА КОРИСНУ МОДЕЛЬ

№ 72121

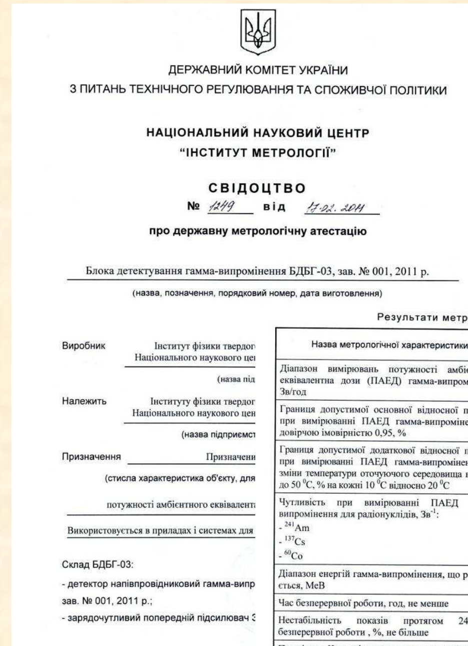
ДЕТЕКТОР ІОНІЗУЮЧОГО ВИПРОМІНЮВАННЯ

Видано відповідно до Закону України "Про охорону прав на винаходи і корисні моделі".

Зареєстровано в Державному реєстрі патентів України на корисні моделі 10.08.2012.

Перший заступник Голови
Державної служби
інтелектуальної власності України О.В. Янов

Certificates of the gamma-ray detectors issued by Ukrainian State Metrological Service



ДЕРЖАВНИЙ КОМІТЕТ УКРАЇНИ
З ПИТАНЬ ТЕХНІЧНОГО РЕГУЛЮВАННЯ ТА СПОЖИВЧОЇ ПОЛІТИКИ

НАЦІОНАЛЬНИЙ НАУКОВИЙ ЦЕНТР
"ІНСТИТУТ МЕТРОЛОГІЇ"

СВІДОЦТВО
№ 1249 від 17.02.2011

про державну метрологічну атестацію

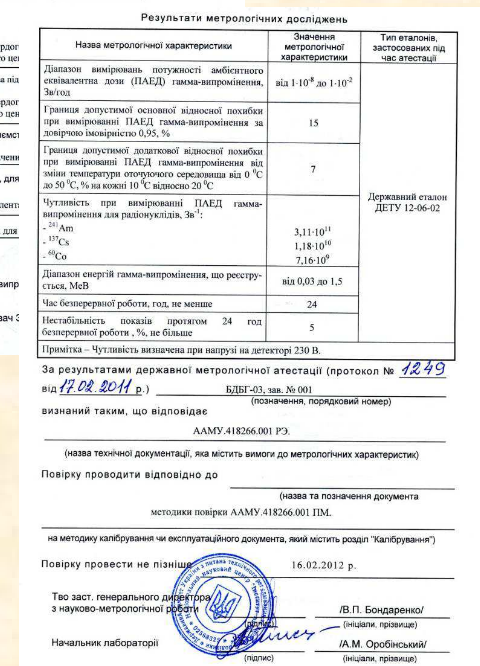
Блока детектування гамма-випромінення БДБГ-03, зав. № 001, 2011 р.
(назва, позначення, порядковий номер, дата виготовлення)

Виробник Інститут фізики твердог
Національного наукового цен
(назва під

Належить Інституту фізики твердог
Національного наукового цен
(назва підприємст

Призначення Призначени
(стисла характеристика об'єкту, для
потужності амбієнтного еквівалент
Використовується в приладах і системах для

Склад БДБГ-03:
- детектор напівпровідниковий гамма-випр
зав. № 001, 2011 р.;
- зарядочутливий попередній підсилювач З



Результати метрологічних досліджень

Назва метрологічної характеристики	Значення метрологічної характеристики	Тип еталонів, застосованих під час атестації
Діапазон вимірювань потужності амбієнтного еквівалентна дози (ПАЕД) гамма-випромінення, Зв/год	від $1 \cdot 10^{-8}$ до $1 \cdot 10^{-2}$	Державний еталон ДЕТУ 12-06-02
Границя допустимої основної відносної похибки при вимірюванні ПАЕД гамма-випромінення за довірчою імовірністю 0,95, %	15	
Границя допустимої додаткової відносної похибки при вимірюванні ПАЕД гамма-випромінення від зміни температури оточуючого середовища від 0 °C до 50 °C, % на кожні 10 °C відносно 20 °C	7	
Чутливість при вимірюванні ПАЕД гамма-випромінення для радіонуклідів, $Зв^{-1}$: - ^{241}Am - ^{137}Cs - ^{60}Co	 $3{,}11 \cdot 10^{11}$ $1{,}18 \cdot 10^{10}$ $7{,}16 \cdot 10^{9}$	
Діапазон енергій гамма-випромінення, що реєструється, МеВ	від 0,03 до 1,5	
Час безперервної роботи, год, не менше	24	
Нестабільність показів протягом 24 год безперервної роботи , %, не більше	5	
Примітка – Чутливість визначена при напрузі на детекторі 230 В.		

За результатами державної метрологічної атестації (протокол № 1249 від 17.02.2011 р.) БДБГ-03, зав. № 001
(позначення, порядковий номер)

визнаний таким, що відповідає

ААМУ.418266.001 РЭ.
(назва технічної документації, яка містить вимоги до метрологічних характеристик)

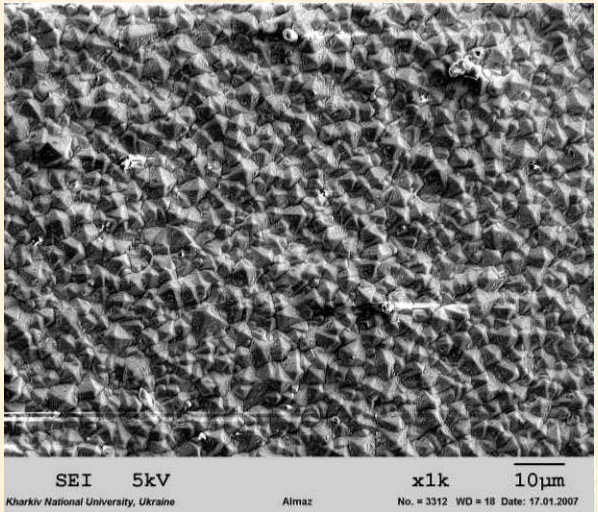
Повірку проводити відповідно до
(назва та позначення документа
методики повірки ААМУ.418266.001 ПМ.
на методику калібрування чи експлуатаційного документа, який містить розділ "Калібрування")

Повірку провести не пізніше 16.02.2012 р.

Тво заст. генерального директора
з науково-метрологічної роботи (підпис) /В.П. Бондаренко/ (ініціали, прізвище)

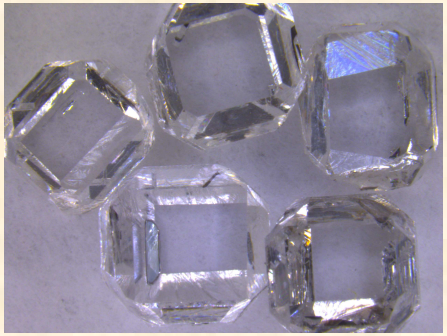
Начальник лабораторії (підпис) /А.М. Оробінський/ (ініціали, прізвище)

5. Radiation detectors made of CVD diamond films

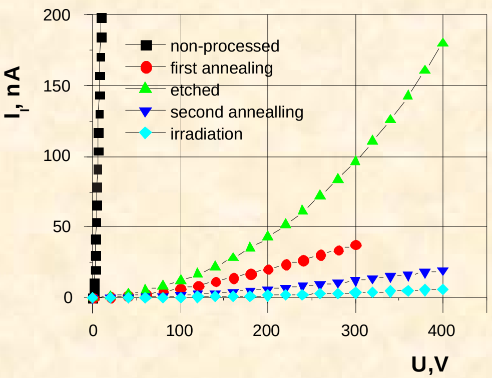


A diamond film of detection quality up to 350 µm thick was synthesized by chemical sedimentation from the gas phase (with activation of a carbon-hydrogen mixture by glow discharge stabilized by magnetic field)

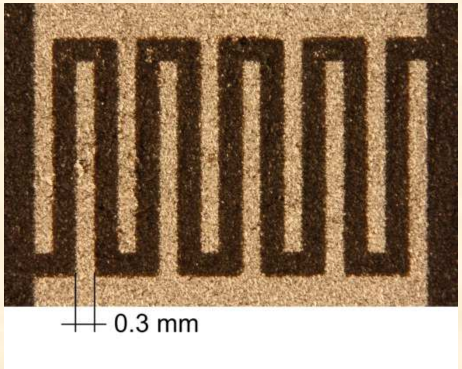
We investigated the material physical properties in dependence on thermal treatment, chemical etching, irradiation and ways of contact application.



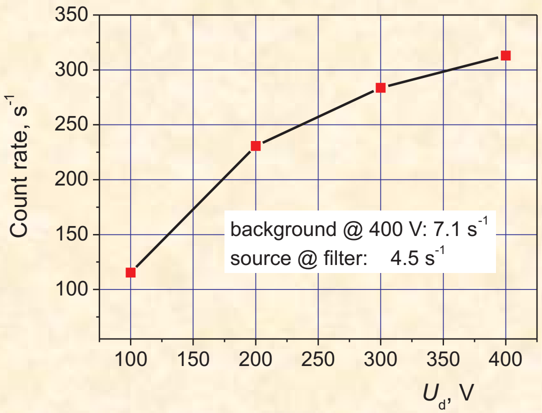
HPHT diamond crystals of detector quality (2-3 mm)



I-V characteristics of CVD diamond after different stages of treatment.



Interdigitated Al contacts on the growth surface of the diamond film.

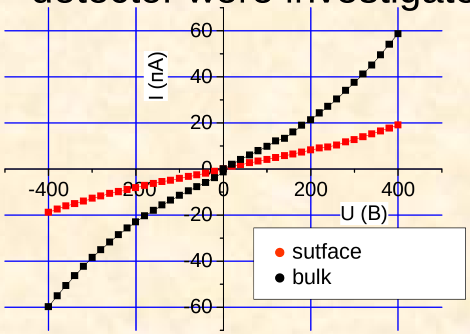


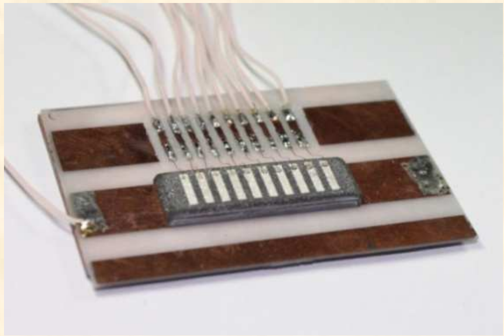
Bias-voltage dependence of the pulse count-rate of the diamond detector exposed to α-particles.

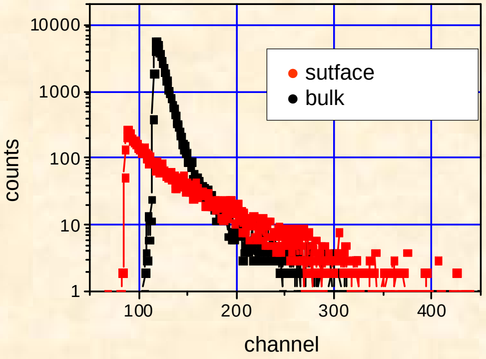
National Science Center
Kharkov Institute of Physics and Technology

Coordinate-sensitive diamond detector

A multichannel strip diamond detector of electron- and gamma-radiation was developed for a precision measurement of the electron beam profile at the escape of accelerator. The intrastrip resistance and uniformity of electrophysical and radiation performances of the detector were investigated.







Bulk and surface leakage currents and pulse-height spectra are measured for different ways of connection to a recording equipment (single strip, a group of strips).

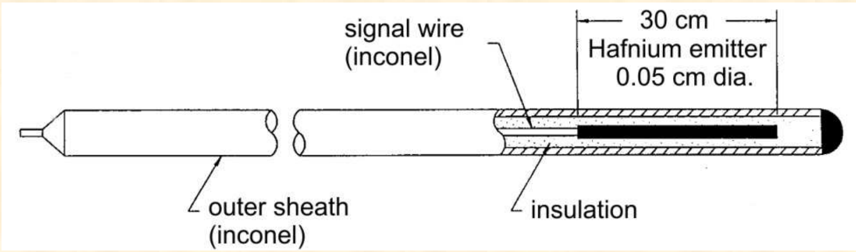
Dosimetry of electron radiation with CVD diamond detectors

The detectors analog sensitivity was measured at LU-10 accelerator under combined irradiation of Bremsstrahlung and 10 MeV electrons.

$\delta_\gamma = 10^{-10}$ C/Gy $\delta_e = 1.2^{-10}$ C/Gy

Bremsstrahlung crosscut profile at LU-10 linac, measured by diamond detector

6. Self powered Compton-emission neutron detector (SPND) with Hf emitter



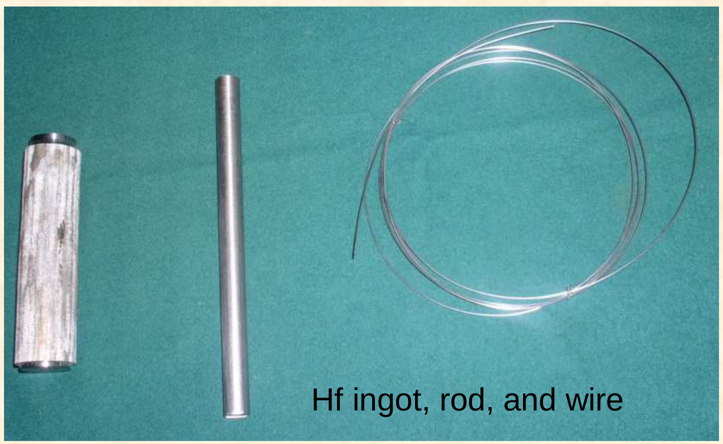
The schematic of the detector with the metallic Hf emitter

Application: for measurement of thermal neutron fluxes in all nuclear power reactors, namely for in-core monitoring systems (ICMS).

$^{177}Hf_{105} + n \rightarrow {}^{178}Hf^*_{106} \rightarrow {}^{178}Hf_{106}$ + gammas

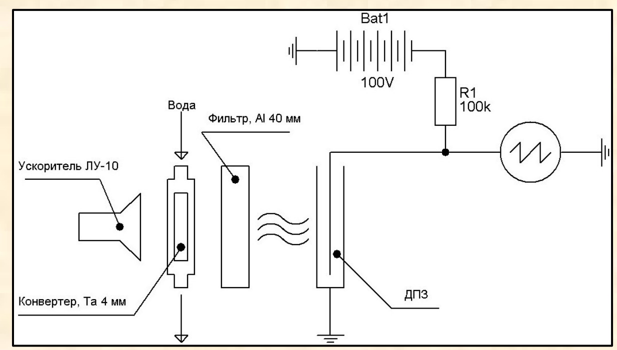
Advantages
(compared to commercial Rh *β*-emission SPND)

1. **The delay time is practically absent**
2. **Longer time of burn-out**
3. **HfO_2 insulation**
4. **Inexpensiveness**



Hf ingot, rod, and wire

NSC KIPT possesses the unique technology of mechanical-thermal processing of hafnium with the possibility of obtaining bars, sheets, and wires of wide nomenclature

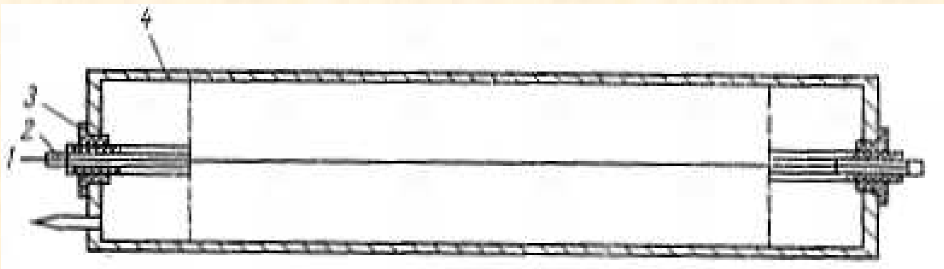


A breadboard of SPND with Hf emitter developed and manufactured. The detector was experimentally tested in Bremsstrahlung field of a 10 MeV linac.

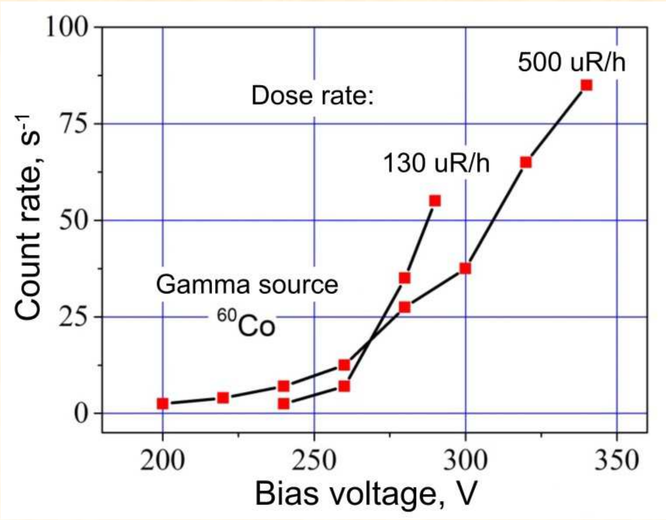
7. Gamma-ray proportional gas detector

The idea was to use the proportional mode with high pressure Xe (up to 10 atm) having Fano factor 0.13. Proportional counter operates at low voltage (compared with Geiger counter) and thus has a longer lifetime.

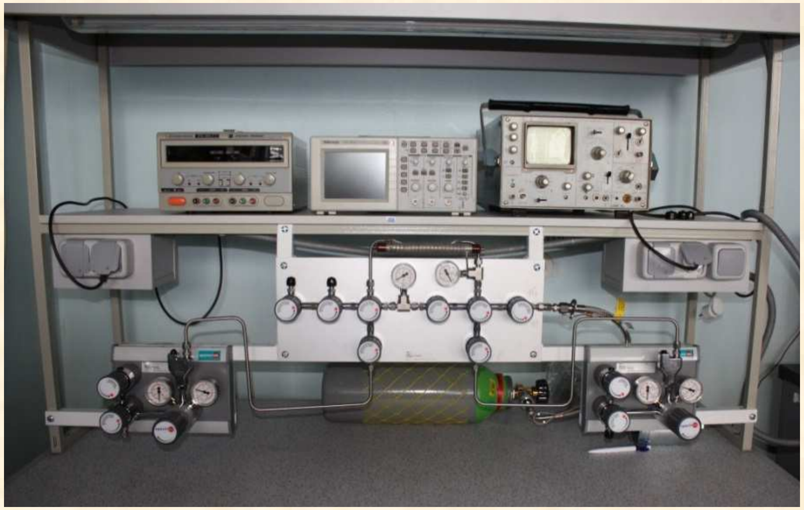
The output pulse is proportional to the energy of registered particle. Thus the proportional counter can serve as a spectrometer.



1 – anode; 2 – guarding ring; 3 - insulator; 4 - housing



Count rate against bias voltage



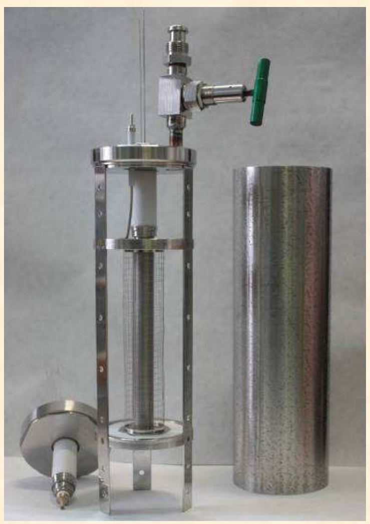
Stand for filling detectors with gas mixtures

A bread board detector filled with Xe of 99, 9999 purity was prepared and pro-visionally tested

8. Gamma-spectrometer using high pressure and high purity Xenon gas

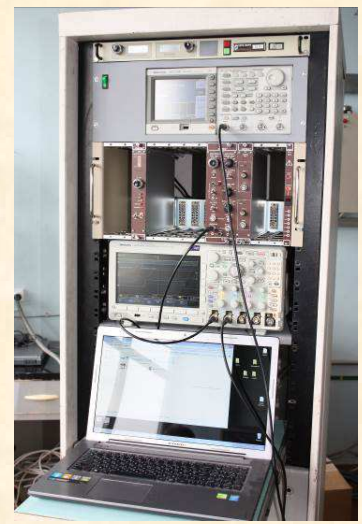
The aim: development of a gamma-spectrometer, with high energy resolution and wide temperature operational range as alternative to HPGe and scintillator spectrometers.

Advantages of HPXe spectrometers for NPP operational radiation monitoring



The breadboard model of HPXe detector

The complex pilot vacuum system for filling of the detector chamber with Xe



Spectrometric “Ortec” channel, Tektronix oscilloscope and pulse generator, and Spellman high-voltage supply

Thank you for your attention

Publications: http://www.kipt.kharkov.ua/kipt_sites/isspmst/DEPARTMENT_11/1180/en/publications/
Site: http://www.kipt.kharkov.ua/kipt_sites/isspmst/nrdetectors/en/
E-mail: Vladimir E. Kutny (kutny@kipt.kharkov.ua), Ph.D., head of laboratory
Leonid N. Davydov (ldavydov@kipt.kharkov.ua) — Ph.D., senior researcher

Authors are greatly appreciative for the support of
DOE P406, NATO SfP G4655, CNCP P374, and STCU projects