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Scintillation panels based on zinc selenide and oxide scintillators

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The possibility of obtaining large area dispersed scintillators based on zinc selenide has been demonstrated. Potentiality of creation of two-component scintillation panels based on ZnSe(Te) and other scintillator (such as $CdWO_4$, $ZnWO_4$, GSO and LGSO) which has a luminescence maximum in the photo-absorption zone of zinc selenide was investigated too. Obtained experimental data testified to the effect of the adding oxide scintillators on radioluminescence spectra of the samples and the level of X-ray absorption of the scintillation panels on the basis of chalcogenide scintillator zinc selenide. The optimum size of the inorganic scintillator ZnSe(Te) particles for obtaining the high scintillation parameters in scintillation panels has been determined. Methodology of production of the scintillation panels based on fine-dispersed powder of ZnSe(Te) with stable and steady scintillation characteristics in the area of the panels was developed.

Показана возможность получения дисперсных сцинтилляторов большой площади на основе селенида цинка, а также исследована возможность получения двухкомпонентных сцинтилляционных панелей на основе ZnSe(Te) и других сцинтилляторов (CdWO4, ZnWO4, GSO, LGSO), обладающих максимумом люминесценции в области фотопоглощения селенида цинка. Приведены экспериментальные данные о влиянии добавок оксидных сцинтилляторов на спектры радиолюминесценции образцов и на поглощение рентгеновского излучения сцинтилляционными панелями на основе халькогенидного сцинтиллятора селенида цинка. Определен оптимальный размер частиц неорганического сцинтиллятора ZnSe(Te) для получения максимально высоких сцинтилляционных параметров в сцинтилляционных панелях. Разработана методика получения сцинтилляционных панелей на основе мелкодисперсных порошков ZnSe(Te), обладающих стабильными и равномерными сцинтилляционными характеристиками по площади образцов.

1. Introduction

ZnSe(Te) scintillator belongs to the semiconductor materials class of A_2B_6 group. It is widely in use in scintillator-silicon photodiode systems for X-ray detectors of modern multichannel low energy tools of visualization of hidden image (systems of non-destructive control, medical tomography, radiography) [1]. Crystals of zinc selenide possess a high luminescent efficiency (60 thousands photons/MeV) and short afterglow duration, which allows registration of the shadow image of biological objects in real time. Also the emission colour of this phosphor is orange-red, which makes it perfectly suited to detection by silicon semiconductor devices [2].

In some fields of X-ray device production photodetectors have not only a flat configuration, but also they can posses a complex shape. For example, in medical radiography there are spherical CCD-matrix for tomography which have cylindrical shape or in the field of radiation flaw detection photodetectors designed for the examining the objects

Table 1. Scintillation and physical characteristics of the scintillators $Gd_2O_2S(Tb)$ and ZnSe(Te)

Parameter	Scintillator	
	$Gd_2O_2S(Tb)$	ZnSe(Te)
Density ρ, g/cm^3	7.3	5.42
Effective atomic number, Z	60	33
Light yield, photons/MeV	60 000	60 000
The emission maximum λ_{max}, nm	545	640
Conversion efficiency, %	19	up to 22
Afterglow (after 6 ms), %	1	<0,05
Hygroscopicity	no	no
Chemical stability	unlimited	unlimited
The mechanical and thermal resistance	good	good
Radiation resistance	good	good

with complex configuration (flaw detection of welds or pipes, flaw detection of products with complex shape obtained by molding). Such optimization of the photodetector's final configuration allows obtaining the most complete information about investigated object. For the efficient registration of X-rays and in order to avoid distortion of information about the object scintillator should completely repeat the shape of a photodetector. The most successful solution of this problem is the flexible scintillation panel which fits maximally tightly to the surface of a photodetector of any type.

At the present time as a scintillation material for the manufacture of scintillation panels, X-ray intensifying screens and other disperse scintillators are widely in use the scintillation materials such as $Gd_2O_2S(Tb)$, CsI:Na, CsI:Tl, NaI:Tl, ZnS:Cu, (Zn,Cd)S:Cu, (Zn,Cd)S:Ag, $CdWO_4$, $Bi_4Ge_3O_{12}$(BGO), $(Y,Gd)_2O_3:Eu^{3+}$(Pr), Gd_2O_2S:Pr(Ce,F) and others [3]. The most commonly used material for manufacturing disperse scintillators for different purposes is $Gd_2O_2S(Tb)$ [4]. For example, Table 1 shows comparative data of scintillation characteristics of ZnSe(Te) and $Gd_2O_2S(Tb)$. The data confirm that zinc selenide is not inferior to $Gd_2O_2S(Tb)$ in its characteristics and in some parameters superior to it (the conversion efficiency, the afterglow). Scintillator on the basis of ZnSe(Te) in a dispersed form is not limited in area and has an order of magnitude greater homogeneity of luminescence than the crystalline sample [5–12]. Ability to obtain a large area crystalline samples of ZnSe(Te) is technologically limited, because with increasing of crystal's size homogeneity of luminescence is decreasing due to the segregation of dopants in the crystal in the process of it growth.

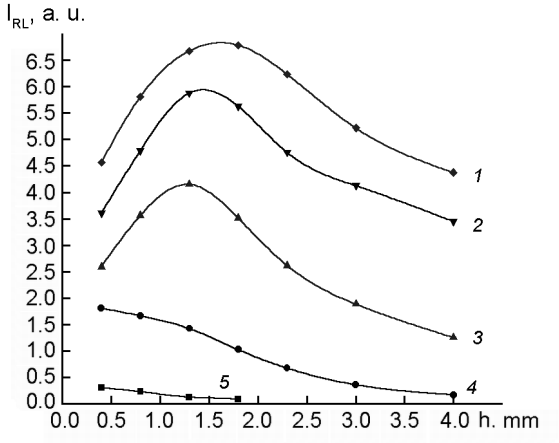

Fig. 1. The dependences of the light yield on the particle size and thickness of the polycrystalline dispersed samples of the scintillation panels based on ZnSe(Te). *1*— corresponds to the sample of panel with a particles size in 200–600 μm, *2* — particles size is 120–200 μm, *3* — particles size is 40–120 μm, *4* — particles size is 25–40 μm, *5* — particles size is 1–25 μm.

This article presents the characteristics of experimental samples of flexible scintillator panels made of fine powders on the basis of ZnSe(Te), as well as a number of oxide scintillators, such as $CdWO_4$, $ZnWO_4$, GSO, LGSO. The purpose of the work was to obtain large area dispersed scintillation panels with a high quantum yield and homogeneity of the luminescence. Also in the current work we investigated the possibility of increasing the light output of the main scintillator (zinc selenide) in two-component systems by introducing an additional scin-

tillation material with a maximum luminescence in the photoabsorption zone of zinc selenide.

2. Experimental

As the objects of study we used single- and two-component scintillation panels made in the form of a layer of polycrystalline particles of irregular shape of inorganic scintillators in the optical immersion medium — silicone rubber. Samples of the panels were made by pouring a mixture of powder scintillator and immersion medium in the container which covered with anti-adhesion material.

Single- and two-component samples of scintillation panels on the basis of different scintillators such as ZnSe(Te), $CdWO_4$, $ZnWO_4$, GSO, LGSO, with different ratio of the components in the samples were made in the framework of this work. The spectra of radioluminescence of the samples were obtained using monochromator MDR-23 with ADC signal converter and a photodetector PMT-80. As a source of ionizing radiation ^{241}Am with a photon energy of 60 keV was used. Measurements of the intensity of the light output of the samples was carried out by a known method by using the unit for measurement of light yield and afterglow — "Smiths Heimann AMS-1".

3. Results and discussion

For optimization of the scintillation parameters of scintillation panels the dependence of the light output of panels on the particle size of the scintillator ZnSe(Te) and the thickness of the screen was determined (Fig. 1). The dependence of the light output of ZnSe(Te) on the dispersion of the particles is determined by the degree of absorption of X-rays by particles of scintillator. The large particle absorbs the larger portion of X-rays, hence, the luminescence intensity increases with increasing particle size. According to Fig. 1 particles with dispersion of 200–600 μm have the highest intensity of the luminescence. Thus, particles size reducing leads to the decreasing of the luminescence intensity of the particles and when you reach a certain size (about 30 μm), the luminescence becomes very low. This is related to the electron capture length in this material, and if it becomes longer than the size of the particles, then only a small fraction of the X-ray radiation is absorbed in the material and induces the luminescence. The dissipative properties of the dispersed

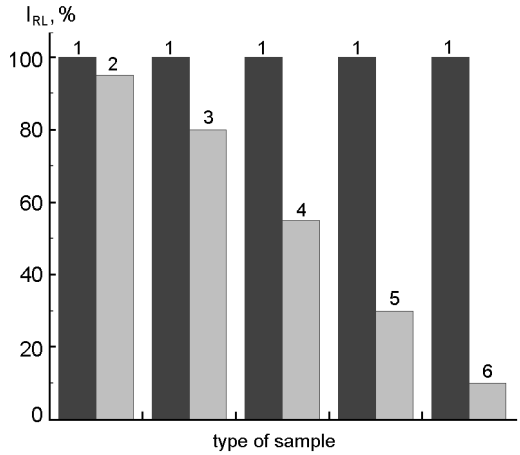

Fig. 2. Comparison of the light yield of a dispersed and crystalline scintillators based on ZnSe(Te) of identical dimension-type. *1* — crystalline scintillator, *2* — dispersed scintillator (particles size is 200–600 μm), *3* — dispersed scintillator (particles size is 120–200 μm), *4* — dispersed scintillator (particles size is 40–120 μm), *5* — dispersed scintillator (particles size is 25–40 .μm), *6* — dispersed scintillator (particles size is 1—25 μm).

scintillator medium such as scattering and reabsorption of emitted luminescence photons also leads to reducing the luminescence with decreasing particle size. The optimum thickness of the scintillation panels for maximum quantum yield for samples with dispersion of particles of 40–120 μm is 1–1.5 mm, for dispersion 120–200 μm is 1.3–1.8 mm and for dispersion 200–600 μm is 1.5–2 mm. When the thickness of the panel more then optimal the X-ray radiation is absorbed in the upper layer of the sample and its intensity in the lower layers of the sample isn't sufficient to excite the maximum luminescence. Also scintillation photons from the upper layers do not reach the photodetector and released in the form of thermal energy. When the thickness of the panel is less than the optimal the maximum luminescence of the panel also isn't achieved because of lack of the scintillation material in the sample. For samples of the panels from smaller fractions of the scintillation material the optimal thickness of the screen becomes smaller.

The relative light output of dispersed and crystalline samples of scintillators based on ZnSe(Te) is presented in Fig. 2. The level of light output of scintillation panels made of the coarse powder of zinc selenide with particles size in 200–600 μm

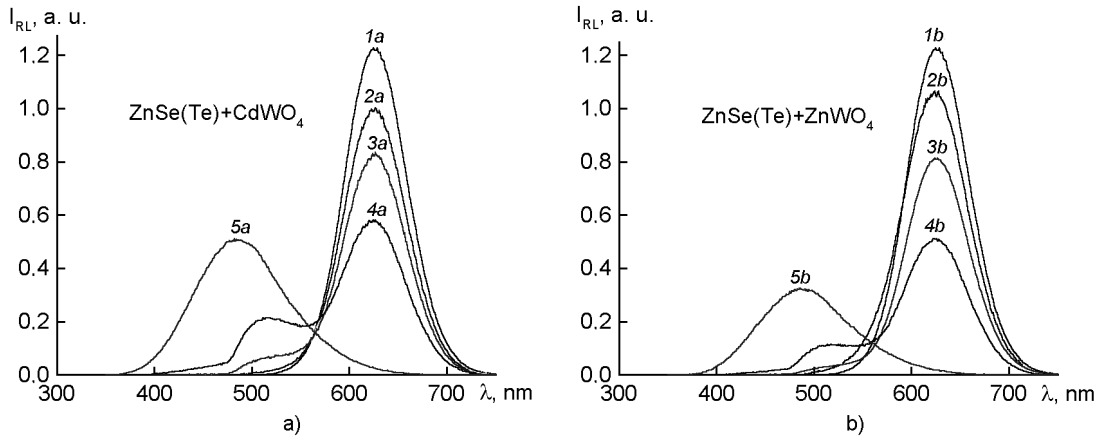

Fig. 3. The radioluminescence spectra of the samples of scintillation panels based on ZnSe(Te), $CdWO_4$, $ZnWO_4$ at different ratio of the components in the panels. Curves *1a* and *1b* correspond to the samples based on ZnSe(Te). Curves *2a*, *3a*, *4a* correspond to a ratio $CdWO_4$/ZnSe(Te) — 1:3, 1:1, 3:1, curve *5a* — $CdWO_4$. Curves *2b*, *3b*, *4b* correspond to a ratio $ZnWO_4$/ZnSe(Te) — 1:3, 1:1, 3:1, curve *5b* — $ZnWO_4$.

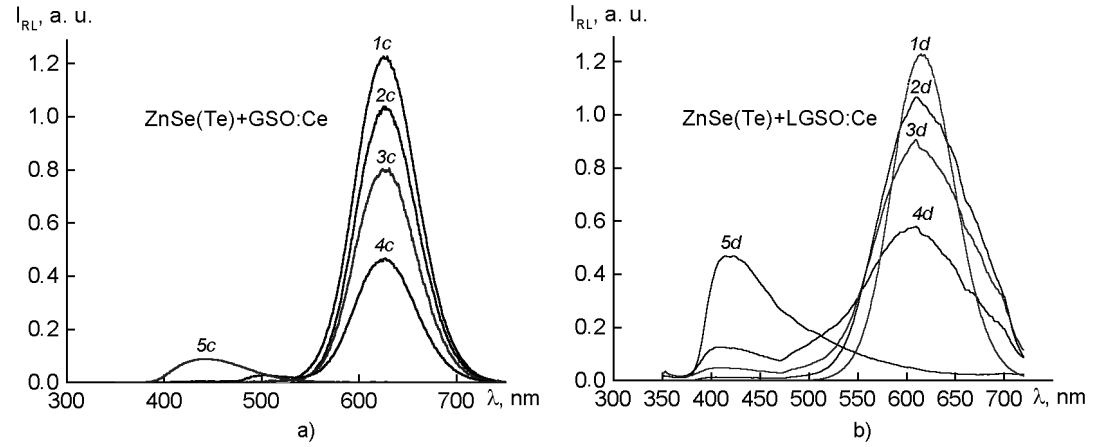

Fig. 4. The radioluminescence spectra of the samples of scintillation panels based on ZnSe(Te), GSO, LGSO at different ratio of the components in the panels. Curves *1c*, *1d* correspond to the samples based on ZnSe(Te). Curves *2c*, *3c*, *4c* correspond to a ratio GSO/ZnSe(Te) — 1:3, 1:1, 3:1, curve *5c* — GSO. Curves *2d*, *3d*, *4d* correspond to a ratio LGSO/ZnSe(Te) — 1:3, 1:1, 3:1, curve *5d* — LGSO.

becomes close to the level for crystalline sample (up to 95 % of the light output of the crystal). With decreasing of particle size the light output is also decreasing according to the explanations given above. And for particles with a fineness of 120–200 μm light output reaches about 80 %, for particles with dispersion in 40–120 goes up to 55 % and for dispersion in 25–40 μm goes up to 30 % relative to the crystalline sample. The particles with dispersion less then 25 μm are of no practical interest, due to extremely low level of light output which goes up to 10 %. Comparison of the light yield of the dispersed samples and crystalline samples were made in the same conditions and with the samples of the same dimension-type.

To determine the possibility of increasing the light output of the main scintillator (zinc selenide) by introducing an additional scintillation material with a maximum luminescence in the photoabsorption zone of main scintillator and for application the basic manufacturing technology of the scintillation panels on the other scintillation materials we fabricated single- and two-component scintillation panels based on ZnSe(Te), $CdWO_4$, $ZnWO_4$, GSO and LGSO. The radioluminescence spectra of such scintillation panels are presented in Fig. 3 and Fig. 4. In the two-component systems ac-

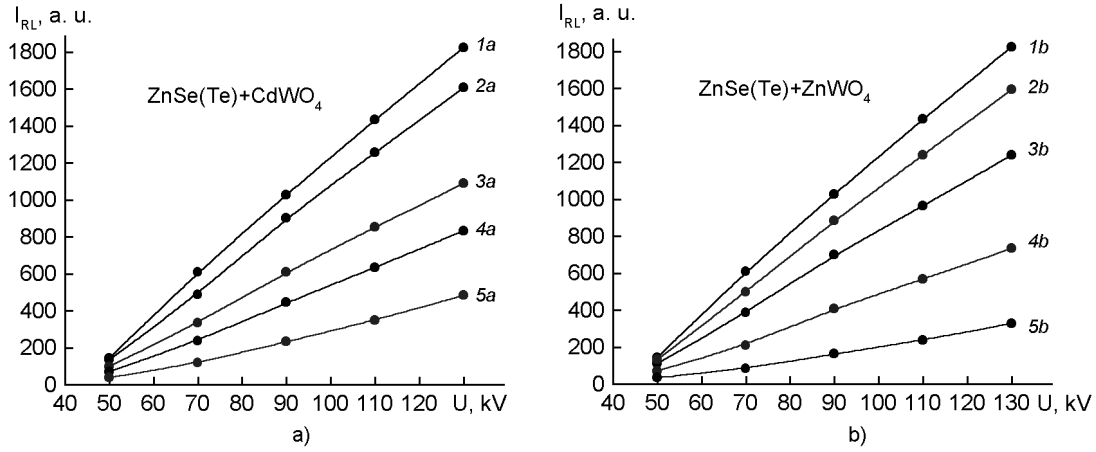

Fig. 5. The dependences of the radioluminescence intensity of the samples of scintillation panels based on ZnSe(Te), $CdWO_4$, $ZnWO_4$ on X-ray tube voltage (voltage variation is 50–130 kV). Curves *1a* and *1b* correspond to the samples based on ZnSe(Te). Curves *2a*, *3a*, *4a* correspond to a ratio $CdWO_4$/ZnSe(Te) — 1:3, 1:1, 3:1, curve *5a* — $CdWO_4$. Curves *2b*, *3b*, *4b* correspond to a ratio $ZnWO_4$/ZnSe(Te) — 1:3, 1:1, 3:1, curve *5b* — $ZnWO_4$.

cording to the ratio of zinc selenide and an additional scintillator the redistribution of the luminescence intensity of samples and a change of the luminescence spectra according to the intensity and spectral range of luminescence of each component of the panel are observed. The one-component panels based on zinc selenide have a maximum intensity of luminescence. Increasing the luminescence intensity due to photoexcitation of ZnSe(Te) isn't observed. The total light output from the two-component samples is lower than that of the single-component one based on zinc selenide which can be associated with a significant difference of the light yield of zinc selenide and other scintillators. Also the specifics of the disperse medium prevents efficient energy transfer from the additional scintillator to the main scintillator. The increase of share of the additional scintillator in the panel leads to the decrease of the total luminescence of scintillation panel. Because the luminescence caused by photoexcitation of zinc selenide does not compensate the loss of light output of the panel due to a decreasing the share of main scintillator in the sample.

The dependence of luminescence intensity of the single-component and mixed panels based on zinc selenide and tungstate zinc or cadmium from the photon energy of X-ray emission is shown in Fig. 5. The absolute light yield of ZnSe(Te) is 60 000 photons/MeV, the absolute light output of $CdWO_4$ and $ZnWO_4$ is 22 000 photons/MeV. Thus, on the base of the experimental data a linear dependence of changes of the luminescence intensity of two-component samples relative to the luminescence intensity of one-component models according to the proportion of zinc selenide and tungstates is observed. The luminescence intensity of the panels rises with increasing the photon energy of X-ray due to increase of the conversion efficiency of X-ray radiation.

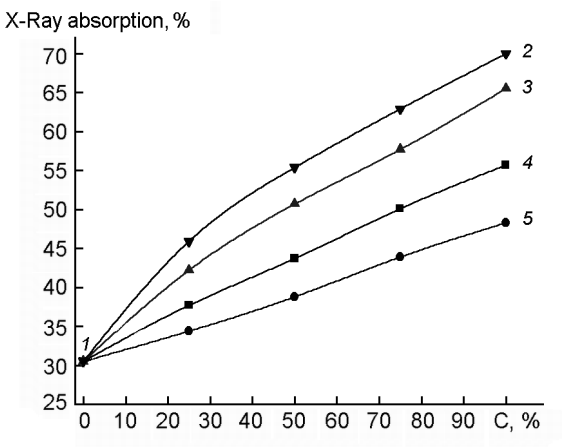

Fig. 6. Data on the X-ray absorption by one- and two-component scintillation panels (X-ray tube voltage is 140 kV). Point *1* corresponds to the panel based on ZnSe(Te), point *2* — $CdWO_4$, point *3* — $ZnWO_4$, point *4* — GSO:Ce and point *5* — LGSO:Ce, the other points correspond to intermediate ratio of the components in the mixed scintillation panels.

Data on the X-ray absorption of one-component and two-component samples of the scintillation panels are shown in Fig. 6. The

Table 2. Scintillation and physical characteristics of the dispersed and crystalline scintillators based on ZnSe(Te)

Parameter	Crystal ZnSe(Te)	Scintillation panel ZnSe(Te)
The inhomogeneity of the luminescence of the sample's area, %	up to 30	up to 5
Surface area of the sample, cm^2 up to 25	400	
Mechanical characteristics	fragile solid	elastic flexible

degree of absorption of X-ray by two-component samples is an additive quantity and it is determined by the percentage of components in the mixed system. Due to the higher effective atomic number oxide scintillators have higher absorption coefficients of X-ray radiation than zinc selenide. Accordingly, the addition of oxide scintillators lead to an increase of the share of absorbed X-ray radiation in samples of two-component scintillation panels.

For practical application of scintillation panels is necessary to ensure the homogeneity of luminescence in the area of the panel. Measurement of luminescence homogeneity in the area of dispersed and crystalline samples based on zinc selenide of the same dimension-type showed that dispersed scintillator has approximately from 6 to 7 times greater homogeneity of luminescence than crystalline analog (see Table 2). This is achieved by homogenizing the powder of ZnSe(Te) during its preparation and its uniform distribution over the area of the panel.

4. Conclusions

As a result of the work the technology of producing large-area dispersed flexible scintillation panels based on fast-phosphor ZnSe(Te) with high quantum yield and luminescence homogeneity has been developed.

The influence of additives of oxide scintillators on the radioluminescence spectra of the samples and the absorption of X-ray by scintillation panels (based on chalcogenide scintillator zinc selenide) was specified. It can give possibilities to vary the optical and luminescent parameters of the obtained panels in a wide range.

Achieved resolving power of the scintillation panels based on zinc selenide allows their application in any field of digital radiography.

Scintillation panels obtained after accomplishing this research work can be applied for the X-ray imaging, spectroscopy and dosimetry of ionizing radiations of small and medium-energy [13–15]. For example, powder scintillators can be used instead of crystalline samples in 16, 32, 62 and 128 scintillation elements for silicon photodiodes because of their dispersed structure they have a smaller cross-talk between channels of the photodiode than the crystalline analogue. Another application for the scintillation panels based on ZnSe(Te) can become the X-ray imaging of internal organs (in particular heart muscle). Zinc selenide have a higher speed of response than the widely used gadolinium oxysulfide and according to the short afterglow provides a more distinct picture of moving objects. Consequently the higher quality of heart disease diagnostics can be achieved. Due to the fact that zinc selenide is a low-energy scintillator and it can be easily combined with a pulsed X-ray emitter which is synchronized with the phases of the heart instead of continuous exposure there is a possibility of significant reducing the radiation exposure to patient.

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Сцинтиляційні панелі на основі селеніду цинку і оксидних сцинтиляторів

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Показано можливість одержання дисперсних сцинтиляторів великої площі на основі селеніду цинку, а також досліджено можливість отримання двокомпонентних сцинтиляційних панелей на основі ZnSe(Te) та інших сцинтиляторів (CdWO4, ZnWO4, GSO, LGSO), що мають максимум люмінесценції в області фотопоглинання селеніду цинку. Наведено експериментальні дані відносно впливу домішок оксидних сцинтиляторів на спектри радіолюмінесценції зразків і на поглинання рентгенівського випромінювання сцинтиляційними панелями на основі халькогенідного сцинтилятора селеніду цинку. Визначено оптимальний розмір часток неорганічного сцинтилятора ZnSe(Te) для одержання максимального сцинтиляційного сигналу у сцинтиляційних панелях. Розроблено методику отримання сцинтиляційних панелей на основі дисперсних порошків ZnSe(Te), що мають стабільні та однорідні сцинтиляційні характеристики за площиною зразків.