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COUNTING EFFICIENCY AND NEUTRON/GAMMA RATIO FOR KDP: TL$^+$ AND UPS-923A SCINTILLATORS IN A SINGLE PHOTON DETECTION MODE

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This research related to registration of the fast neutrons with a detector based on the inorganic KDP: TL$^+$ mono crystal (KH_2PO_4 potassium dihydrogen phosphate) and plastic UPS-923A. The crystal of the KDP: TL$^+$ detector grown from a water solution by the method of lowering the temperature. The high concentration of hydrogen nuclei in the KDP: TL$^+$ crystal grid makes it possible to detect neutron radiation with an efficiency comparable to polystyrene scintillators. KDP: TL$^+$ crystals have a high radiation resistance (up to 10^{10} neutrons/cm^2), which significantly expands the spectrum of their application in high-energy physics applications, intense neutron fields. In this work, we used a technique for recording the detector response in the photon counting mode and pulse filtering mode. Since the detector operates on the principle of detecting gamma quanta from the reactions (n, n 'γ), $(n, n' \gamma)_{res}$, $(n, \gamma)_{cap}$ and others, this makes it possible (in a filtering mode) to isolate the mechanisms of cascade generation processes in the volume of the detector caused by secondary gamma quanta from excited states of compound nuclei. The gamma quanta of the elastic scattering reaction (n, n' γ) for the KDP: TL$^+$ scintillator nuclei are the start of the cascade process of the discharge of excited isomeric states of the input, intermediate, and final nuclei. Measurements of the detection efficiency of fast neutrons were carried out with a KDP: TL$^+$ crystal of size 18x18x42 mm in spherical geometry. The obtained detector reviews in units of impulse / particle for sources and ^{239}Pu-Be and ^{137}Cs were 3.57 and 1.44. In this case, a broadband path with a speed of 7 ns was used. In addition, the counting efficiency of the narrow-band tract measured simultaneously with a processing time of 1 µs and 6.4 µs. The received response from the KDP: TL$^+$ detector (in units of impulse/particle) for both sources ^{239}Pu-Be and ^{137}Cs was 0.09 and 0.00029. The n/γ ratio coefficient was 310. The given measurements of a polystyrene-based scintillator size of 40×40×40 mm. The received response in a single photon-counting mode from the plastic detector (in units of impulse/particle) for both sources ^{239}Pu-Be and ^{137}Cs was 19.4 and 3.9. The n/γ ratio coefficients for detectors are also given: KDP: TL$^+$ - 2.47 and UPS-923A - 4.97 in the 7 ns mode. The statistical error in measurements of the neutron detection efficiency was about ~ 5%.

KEY WORDS: neutron, detector, fast neutron, KDP: TL$^+$ crystals, detection efficiency, registration threshold, PX-5, counting rate, radiation monitor

In the previous works [1, 2] are shown that mechanism of inelastic scattering could be useful for the fast neutron registration. In these detectors, fast neutrons could be detected by counting impulses from the secondary gamma-quanta, inside the detector volume. Since a spectrometric path with an integration time of ~ 1 µs and 6 µs was used in our studies for registration purposes, this ensured almost complete suppression of the registration of cascade processes in the detector. If a neutron detector uses only the one mechanism of inelastic scattering, in which one the secondary gamma-quanta are generated due to the discharge of single-particle excitations of nuclei, this allows the use of a narrow-band detection path (1 µs). In this case, the counted efficiency coincides with the energy of the registration efficiency, which cannot exceed one. The mechanism of inelastic scattering of fast neutrons is a starting process that can be as a trigger for the process of resonant scattering, radiation capture and secondary nuclear reactions. In this case, excited states in the nuclei of the crystals under study generate cascades of gamma rays with energies ranging from E ~ 2-3 MeV to units of keV. Note that the energy of the secondary neutron n' from the reaction $(n, n'\gamma)_{res}$ can exceed the energy of the incident neutron from the reaction (n, n′γ) due to the binding energy, so the channel $(n, n'\gamma)_{res}$ is also an effective source of secondary gamma rays. Secondary neutrons can subsequently be captured by nuclei in the radiation capture reaction $(n, \gamma)_{cap}$. For applications, secondary gamma rays are of interest, the emission times of which are in the range of ~ 1 ns - 100 µs. Also in this interval are the collision times of secondary neutrons from these reactions with scintillator nuclei. Therefore, secondary neutrons can participate in reactions $(n, n'\gamma)_{res}$ and thereby increase the number of cascade gamma rays. Note that the nuclear composition of oxide scintillators significantly affects the intensity of the gamma-ray cascades of the discharge of excited nuclear states, and hence the detector counting efficiency [2]. Earlier [1-2], for the purpose of recording efficiency, a counting path operating in the spectrometric mode (t = 1 µs and 6 µs) was used. As long as the lifetimes of highly excited states of compound nuclei, which could be also excited in the fast neutron reactions, are stay in the range from a few nanoseconds to hundreds of microseconds. To increase the contribution of various mechanisms that are possible when the neutron is slowed down in the detector the single-photon detection mode [1] was used in this work and have a significantly lower registration threshold. In view of the increased radiation resistance (~ 10^{10} neutron/cm^2) of the obtained new crystals, an urgent task is to study the interaction of neutron radiation with the substance of KDP: TL$^+$. As shown in our previous works [1–10], neutron radiation can be detected using scintillation crystals of potassium dihydrogen phosphate KH_2PO_4 (KDP), which are doped with thallium ions Tl$^+$ [5]. This paper presents the experimental results of a study of the efficiency of fast neutron detection in water-soluble crystals in the photon-counting mode and pulse time-filtering mode. The purpose of the work is to study the scintillation properties, efficiencies of detecting fast neutron and gamma fluxes and n/γ coefficients by the new KDP crystal and UPS-923A scintillator.

RESEARCH AND METHODS

Inorganic crystals of KDP: TL$^+$ are grown by the method of the temperature lowering. The crystals have a wide optical transparency band, low dislocation density $<10^2$ cm^{-2}, and high radiation resistance when exposed to fast neutron fluxes of ~ 10^{10} neutrons/cm^2. The presence of hydrogen bonds in the KDP lattice provides the possibility of doping with additives [5]. In Figure 1 shows KDP: TL$^+$ crystals grown on a seed of orientation (101), in the form of 18×18×42 mm plate. The concentration of thallium additives is 0.1%.

Figure 1. The KDP: TL$^+$ crystal sample was grown from water solution.

The physical parameters of measured crystals are shown in the Table 1.

Table 1.

Parameters comparison table of hydrogen based organic UPS-923A and inorganic KDP scintillators.

Scintillator	Z_{eff}	Density, g/cm^3	Hydrogen nuclei density, cm^{-3}	Neutron run-length l_n, cm
Plastic UPS-923A, 4×4×4 cm^3	5.7	1.04	4.82×10^{22}	3.30
KDP: Tl$^+$ (0.1 wt.% Tl), 1.8×1.8×4.2 cm^3	14.3	2.34	2.07×10^{22}	3.93

The neutron energy from radioactive sources during slowing in the detector to a complete stop changes more than 10^8 times - from 10 MeV to 0.025 eV. This energy region can be conditionally divided into three specific regions, which differ in the interaction mechanisms and cross sectional values: the inelastic scattering region (n, n 'γ) from 10 to 0.1 MeV, the resonant scattering region $(n, n' \gamma)_{res}$ from 0.1 to 0.001 MeV and the radiation capture region $(n, \gamma)_{cap}$ from 1 keV to 0.025 eV. Currently, the most common fast neutron detectors using one specific energy conversion mechanism - either a reaction with the formation of recoil protons, or a deceleration method using a radiation capture reaction. Both of these methods have disadvantages - either the low efficiency of neutron flux conversion during deceleration, or the complex electronic for the neutron/gamma separation systems.

In the present work, it is proposed to register cascade signals as from the reaction of inelastic scattering, resonance scattering, and radiation capture. For this purpose, a technique was developed that is a further improvement of the technique used in our works [2, 3]. The detection efficiency of fast neutrons and gamma rays by KDP: TL$^+$ crystals and UPS-923A polystyrene was measured by the following method. The block diagram of the experiment is shown in Fig. 2. The KDP: TL$^+$ crystal with dimensions 18x18x42 mm^3 was wrapped with a PTFE tape reflector. The UPS-923A 40×40×40 mm^3 with polished edges was wrapped with a PTFE tape reflector also. A ^{239}Pu-Be source was used as a neutron source (neutron energies from 0.1 to 10 MeV, average neutron energy $E_n = 4.2$ MeV, 4×10^5 neutrons per second). The source is placed in a lead spherical shield to attenuate the accompanying gamma radiation (photons with E_γ ~ 59 keV from ^{241}Am impurity arising from ^{239}Pu decay products, as well as high-energy gamma rays with E_γ ~ 0.1- 4.43 MeV from the accompanying reactions in the source). The distance between the center of the neutron source and the detector window was in range of 20 - 50 cm.

As the photodetector, the PMT Hamamatsu R1307 was used [12]. The voltage of the PMT was 1250 V. The lower threshold of the pulse counter in the fast channel was obtained using an Amptek DPP PX-5 [13] digital analyzer and monitored with GDS-3504 GW Instek oscilloscope (500MHz bandwidth). The lifetimes of isomeric states excited in reactions with fast neutrons are in the range [3] from a few nanoseconds to hundreds of microseconds. Therefore, the measuring path includes a fast preamplifier [4] with a gain of 70 dB and an intrinsic rise time of ~ 1.5 ns. The preamplifier is used to register signals in the photon-counting mode. The application of this mode is due to the need to register signals of small amplitudes and durations resulting from the discharge of excited states in the compound nuclei, the need for separate registration of signals caused by slowed neutron collisions in a crystal. The amplitude of the single-photon response signal was ~ 1.5 V.

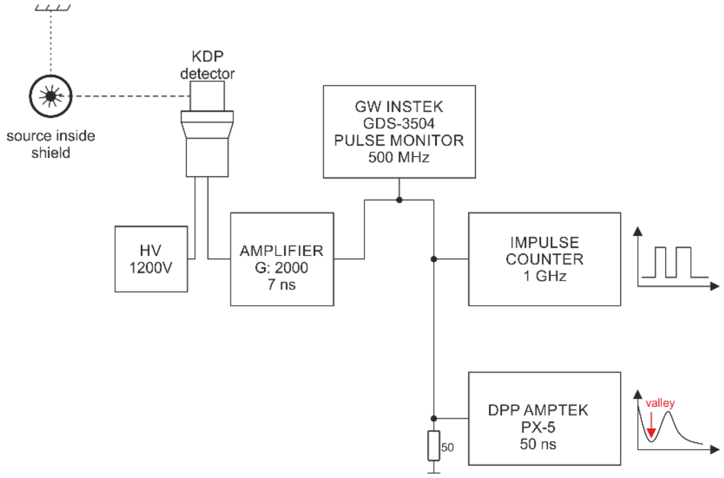


Figure 2. The experimental setup diagram

Figure 3 represents the signal from the preamplifier output during neutron registration with the KDP: TL^+ scintillator. The pulse width at the half maximum is about 20 ns, the pulse amplitude is ~ 1.5 V, and the background pulse load is ~ 200 s^{-1}.

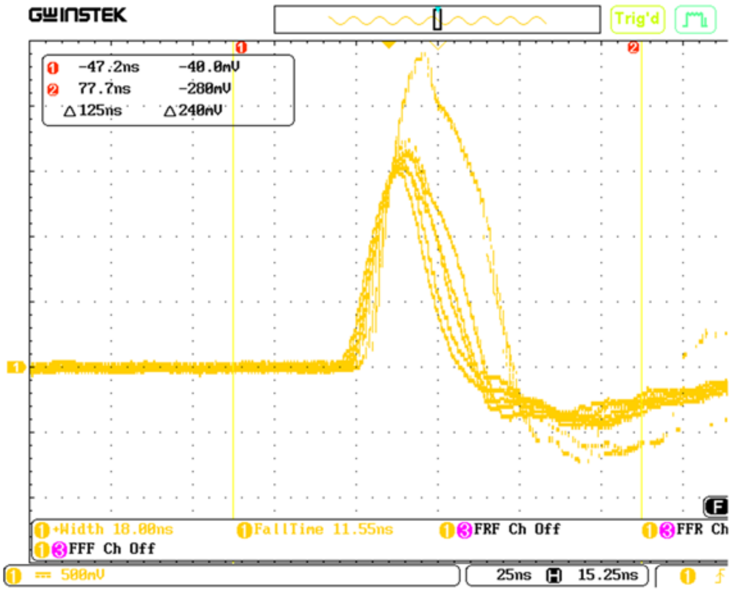


Figure 3. The shape of pulses reached from KDP: TL^+ under fast neutron radiation of ^{239}Pu-Be source
Y – 1 V, X - 25 ns.

Figure 4 shows the hardware spectrum of the investigated scintillator sample upon irradiation with a neutron source; the maximum height of a single-photon peak is in the 1600 channel. The rise time of the signal from the PMT output is ~ 8 ns. The time for collecting statistics in one exposure was 20 minutes, the time for collecting background radiation was 20 minutes, and the number of exposures was 5.

As discussed earlier [2, 3], the response of the detectors is formed by registering cascades of gamma-quanta. The primary gamma-quantum arises from the inelastic scattering reaction. Since the crystal dimensions are comparable with the mean run length of neutrons before moderation, therefore, other than inelastic scattering, other mechanisms leading to the formation of compound nuclei with subsequent removal of excitation by emission of cascades of gamma quanta, such as resonance capture $(n, n' \gamma)_{res}$, radiation capture of the neutrons $(n, \gamma)_{cap}$. Secondary “daughter” gamma-quanta can also arise as a result of a slowdown in the elastic scattering reaction and neutron capture on hydrogen (E = 2223.2 keV).

Thus, the effective registration of signals generated by the scintillator nuclear subsystem is explained when considering the parameters of the nuclei that make up the scintillators. The most significant parameters of scintillator nuclei are cross sections in the region of inelastic scattering, resonance capture, the density of nuclear levels in the resonance region, and the magnitude of the upper boundary of the energies of the resonance region. The cross section of the resonance region has an effect only if it has a region width of ~ 100 keV or more [2]. Figure 5 shows neutron cross sections in the energy range 0.01 MeV - 10 MeV for the nuclei of a natural mixture of potassium, phosphorus, carbon and hydrogen that are part of KDP and polystyrene.

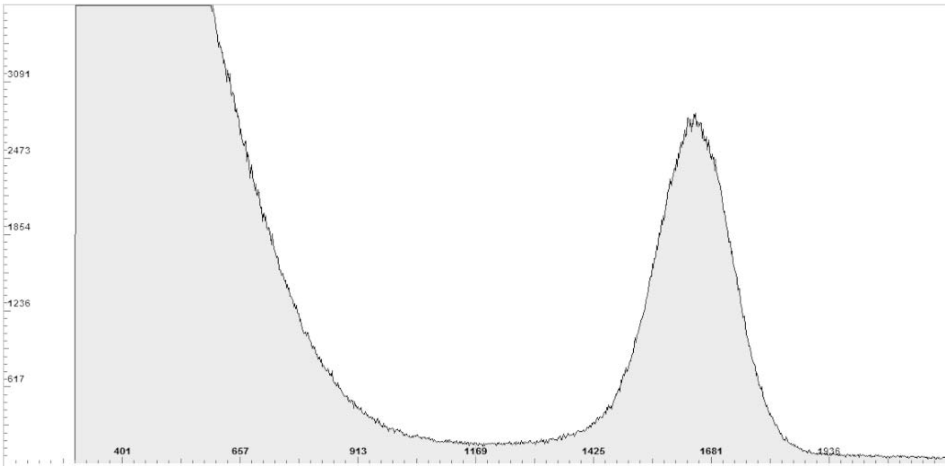
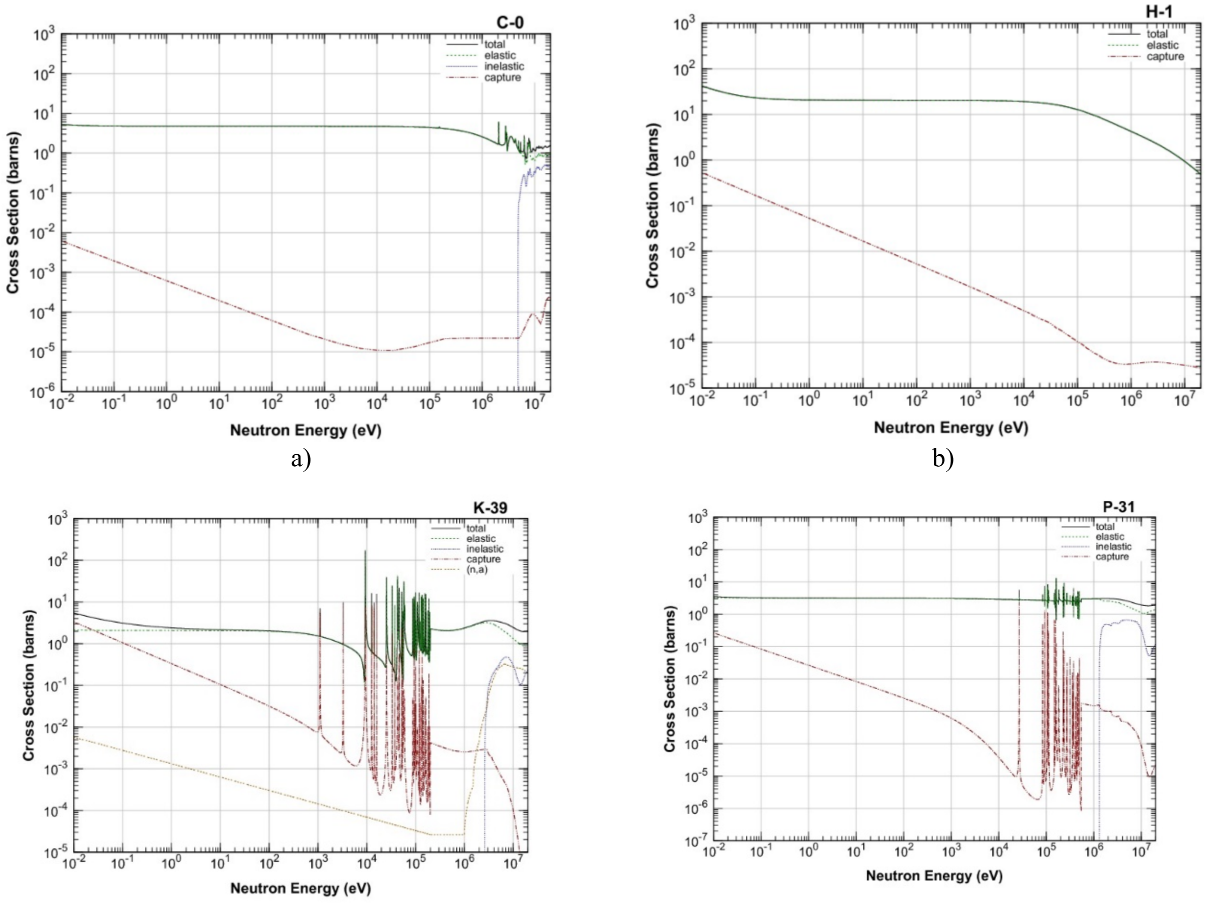


Figure 4. The amplitude spectrum in a photon counting mode from the KDP: TL$^+$ initiated by the ^{239}Pu-Be source, accumulated by Amptek DPP PX-5 with:
Peak Time = 50 ns.
PMT voltage = 1250 V.
Y– counts, X – channels. Single photon peak position – 1600 ch., with amplitude of 1.5 V.



a) b)

c) d)

Figure 5. The neutron cross sections for: ^{1}H (a), ^{12}C (b), ^{39}K (c), ^{31}P (d) in a region of inelastic scattering region, resonant region and radiation capture area [14, 16].

Table 2 [15, 16] shows the parameters of the cross sections for the interaction of neutrons with nuclei for a natural mixture of isotopes of KDP: TL$^+$ scintillator nuclei and polystyrene.

In the range of neutron energies E_n ~ 0.1-10 MeV on hydrogen, reaction (n, p) is observed with the formation of recoil protons (σ ~ 2 b), which can contribute to the detector response if the proton moderation volume is a scintillator. When a neutron is slowed down, a reaction of elastic neutron scattering on hydrogen (σ_{el} ~ 30 b) (n, n) is significant, which one leads to a slowdown of neutrons to an energy of 0.025 eV and radiation capture by protons, with the formation of a deuteron and an emission of gamma rays with an energy of $E_\gamma = 2.223$ MeV (energy deuteron coupling).

Table 2.
The parameters of neutron cross sections σ, barn, quantity of N_γ output and energy E_γ of gamma-quanta from reactions with neutrons from ^{239}Pu-Be (E_n ~ 0.1- 10 MeV)

for the natural abundance of KDP: TL^{+} isotopes mixture and UPS-923A.	σ (n, γ)$_{cap}$ E = 0.0253 eV	σ_{el} E_n ~ 0.0253 eV	σ (n, n' γ)$_{res}$, E_n ~ 0.5 eV – 10 MeV	σ (n, n' γ)$_{inel}$, E_n ~ 0.1 – 10 MeV	σ_{el} E_n ~ 4.5 MeV	N_γ, Emitted gamma from capture	N_γ, Emitted gamma from inelastic
H-1	0.3320 ^{2}H, E_γ = 2.2232 MeV	30.27	0.1492	-	~ 2	1	p recoil
12-C-6	0.00386 13-C, E_γ = 0.595, 1.2618, 1.8567, 3.0891, 3.6839, 4.9453 MeV 6 gamma quants		0.001885 13-C, E_γ = 0.595, 1.2618, 1.8567, 3.0891, 3.6839, 4.9453 MeV 6 gamma quants	0.34 E_n ~ 10 MeV 12C, E_γ = 4.438 MeV	~ 2.4	6 + 6	1
13-C-6	~0.0045 14-C, E_γ = 0.4957, 1.5869, 6.0925 MeV	4.922	0.00162 14-C, E_γ = 0.4957, 1.5869, 6.0925 MeV	-	0.803 E_n ~ 14 MeV	7 + 7	1
31-P-15	0.1662 32-P, E_γ = 0.0781, 0.5126, 0.6367, 1.0713, 2.1145 MeV 158 gamma quants	3.186	0.08079 32-P, E_γ = 0.0781, 0.5126, 0.6367, 1.0713, 2.1145 MeV 158 gamma quants	0.0539 E_n ~ 14 MeV 31-P, E_γ = 1.266, 2.028, 2.148 MeV 14 gamma quants	~2 E_n ~ 4.5 MeV	158+158	14
39-K-19	2,098 39-K, E_γ = 0.0298, 0.7703, 1.1589, 1.2472, 1.3035 MeV 308 gamma quants	2.089	1,081 39-K, E_γ = 0.0298, 0.7703, 1.1589, 1.2472, 1.3035 MeV 308 gamma quants	0,25 E_n ~ 4.5 MeV 39-K, E_γ = 0.3469, 0.7837, 0.9233, MeV 15 gamma quants	~2 E_n ~ 4.5 MeV	308+308	15

In the resonance energy region E_n ~ 0.5 eV - 10 MeV), due to the absence of excited states at the deuteron itself, gamma-ray emission is not observed. Thus, on the nuclei of hydrogen from one incident neutron there is 1 gamma quantum response, in addition, signals from recoil protons will be observed. On carbon nuclei with neutron energies above E_n = 4.812 MeV, an inelastic scattering reaction is observed with excitation of the first ^{12}C level and emission of gamma rays with an energy of E_n = 4.438 MeV. In the resonance region (E_n ~ 0.5 eV - 10 MeV), up to 6 response gamma rays can occur. If the secondary neutron after deceleration is again captured in the scintillator by a carbon nucleus in the radiation capture reaction, then another 6 gamma rays can be excited. Thus, up to 13 responses of gamma-quanta arise from one incident neutron on carbon nuclei. Similarly, on potassium nuclei (see Table 2), a noticeable amount of gamma quanta is emitted from resonance and radiation capture reactions, which is confirmed by noticeable reaction cross sections reaching 2.098 bar (radiation capture reaction) and 1.8 bar (resonance capture) for ^{19}K. It should be noted that the energy of the upper boundary of the resonance region for ^{19}K is ~ 200 keV. In combination with a sufficiently high density of levels of the ^{19}K nucleus, this explains a significant amount (more than 300) of emitted gamma rays during neutron moderation in KDP: TL$^+$. For the ^{19}P nuclei the cross section of inelastic and resonance scattering is significantly low, so the obtained impulse response formed mainly by ^{19}K nuclei.

RESULTS

The measurement results of the counting efficiency of the KDP: TL$^+$ scintillator in mode of counting single photons (mode 7 ns, i.e., registration of single-photon signals in the interval of rise times about 7 ns) are shown in Table 3.

Table 3.

Registration efficiency of the fast neutrons and γ-quanta
by KDP: TL$^+$ and UPS-923A scintillators in a different filtration time

#	Scintillator	Size, mm	Mode	ε_n, imp/n	ε_γ, imp/γ	$\varepsilon_n / \varepsilon_\gamma$
1	Plastic UPS-923A	40×40×40	6.4 μs	0.24	0.071	3.42
	Plastic UPS-923A	40×40×40	1.0 μs	0.95	0.26	3.65
	KDP: Tl$^+$ (0.1 wt.% Tl)	18×18×42	6.4 μs	0.037	0.00024	154
	KDP: Tl$^+$ (0.1 wt.% Tl)	18×18×42	1.0 μs	0.09	0.00029	310
2	Plastic UPS-923A	40×40×40	7 ns	19.4	3.9	4.97
	KDP: Tl$^+$ (0.1 wt.% Tl)	18×18×42	7 ns	3.57	1.44	2.47
3	Plastic UPS-923A	Ø16×9	6 μs	0.30	0.071	4.2
	KDP: Tl$^+$ (0.1 wt.% Tl)	10×10×10	6 μs	0.124	0.004	31
	KDP: Ce^{3+} (0.01 wt.% Ce)	10×10×10	6 μs	0.162	0.006	27

For comparison purposes, the results of measuring the counting efficiency of the scintillator are given based on UPS-923A. In addition, all measurement results were obtained in the spectrometric signal counting mode with an integration time of 1 - 6.4 μs. It can be seen that the calculated efficiency for KDP upon transition from 6 μs to 7 ns (single-photon mode) increases by 3.57 / 0.09 = 40 times, i.e. In the photon counting mode, not only inelastic scattering is realized, but also resonance and radiation captures. A similar effect of an increase in the counted efficiency is also observed for UPS-923A - the counting efficiency increases from 1 μs to 7 ns (single-photon mode) by 19.4/0.95 = 20.4 times.

The measurement results of the KDP: TL$^+$ scintillator of small sizes (10x10x10 mm) [5] in the τ = 6 μs mode are consistent with the results of the KDP: TL$^+$ scintillator with dimensions of 18x18x42 mm in the τ = 6.4 μs mode adjusted for the size effect.

In this work, for the KDP: TL$^+$ and UPS-923A scintillators, the n/γ ratio was also determined (Table 3). It can be seen that the n/γ ratio for the KDP: Tl$^+$ of 10x10x10 mm size crystal measured in [5] is ~ 30, which is explained by the small crystal size. The registration in the photon counting mode with filtering time 7 ns provide 2.47 value for n/γ ratio of KDP: Tl$^+$. The registration in the filtration mode with filtering time 1 μs provide 310 value for n/γ ratio of KDP: Tl$^+$. In the present work, the path threshold selected at 1 μs that was about 25 keV energy region, which provide n/γ ratio of ~ 3.57. The efficiency of the UPS-923A scintillator measured in this work in the photon counting mode, was 19.4 pulses/neutron, and the n/γ ratio ~ 5.

Figure 6 shown bar diagram of counting efficiencies for KDP: TL$^+$ (a) and Plastic UPS-923A (b), obtained for ^{239}Pu-Be and ^{137}Cs sources for filtration times 7 ns and 1 μs.

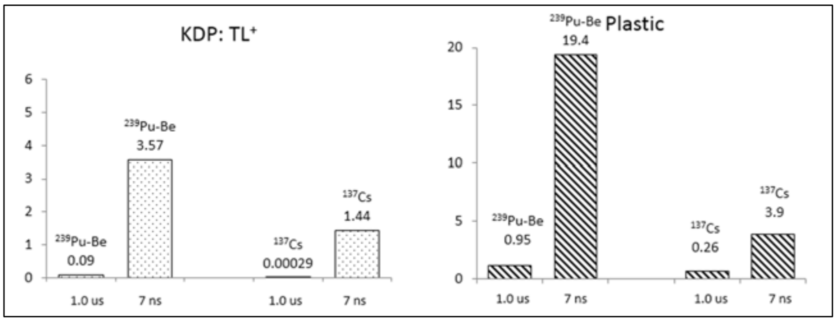


Figure 6. The counting efficiency for KDP: TL$^+$ and Plastic UPS-923A scintillators, obtained for ^{239}Pu-Be and ^{137}Cs sources for filtration modes 7 ns and 1 μs.

Figure 7 shows the n/γ ratio in bars representation for KDP: TL$^+$ and UPS-923A. Results are obtained for ^{239}Pu-Be and ^{137}Cs sources for 7 ns and 1.0 us filtration modes.

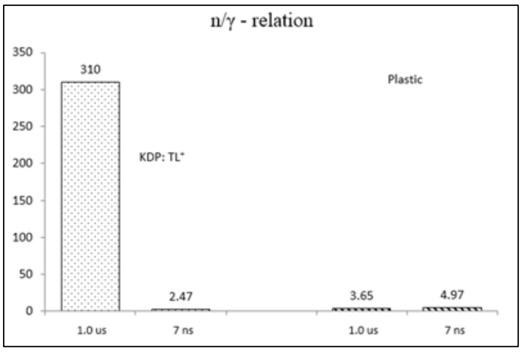


Figure 7. n/γ ratio for scintillators KDP: TL$^+$ and Plastic UPS-923A, obtained for ^{239}Pu-Be and ^{137}Cs sources for filtration modes 7 ns and 1.0 us

CONCLUSIONS

In this work, we calculated the counting efficiencies and n/γ ratios of KDP: TL$^+$ crystals and UPS-923A polystyrene when irradiated with fast neutrons and gamma rays from ^{239}Pu-Be and ^{137}Cs sources using a single-photon detection mode. The obtained efficiency values could be explained by the mechanism of inelastic scattering of fast neutrons (as the primary starting process), which, under certain conditions, can trigger for the process of resonance scattering and radiation capturing. In this case, excited states in the crystal nuclei generate cascades of gamma quanta with an energy in the range from high-energy values etc. E ~ 2-3 MeV and higher, to low-energy values, with an energy of few keV. Accordingly, three types of neutron interaction mechanisms contribute to the efficiency: inelastic scattering (n, n 'γ), resonant scattering $(n, n' \gamma)_{res}$, and radiation capture $(n, \gamma)_{cap}$. The counted detection efficiency of fast neutrons for KDP scintillation crystals with a thickness of 40 mm was about 3.57 pulse/particle in a photon counting mode. The ratio for neutrons and gamma reaches ~ 2.47. The counting efficiency of fast neutron registration for Plastic UPS-923A with a thickness of 40 mm was about 19.4 pulse/neutron. The ratio of the efficiencies for neutrons and gamma reaches ~ 4.97. The calculated statistical error with [17] approach for measurements of the neutron detection efficiency was about ~ 5%.

The obtained result of n/γ for KDP: TL$^+$ in a filtration mode with 1 us time filtration was about 310. That is mean that filtration registration mode can be used for the efficient detection of fast neutrons by the small size KDP: TL$^+$ scintillators with high n/γ ratio.

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ЛІЧИЛЬНА ЕФЕКТИВНІСТЬ ТА ГАММА/НЕЙТРОННЕ ВІДНОШЕННЯ ДЛЯ KDP: TL$^+$ ТА UPS-923A СЦИНТИЛЯТОРІВ В ОДНОФОТОННОМУ РЕЖИМІ ДЕТЕКТУВАННЯ

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Метою даної роботи є реєстрація швидких нейтронів детектором на основі неорганічного монокристала KDP: TL$^+$ (KH_2PO_4 дигідрофосфат калію) та пластику UPS-923A. Кристал детектора KDP: TL$^+$ вирощено з водного розчину методом зниження температури. Висока концентрація ядер водню в гратці KDP: TL$^+$ дає змогу реєструвати нейтронне випромінення з ефективністю, порівняною з полістирольними сцинтиляторами. Кристали KDP: TL$^+$ мають високу радіаційну стійкість (10^{10} нейтрон/см^2), що суттєво розширює спектр їх застосування в фізиці високих енергій, інтенсивних нейтронних полях. В роботі використана методика реєстрації відгуку детектора в режимі лічення фотонів та імпульсному режимі часової фільтрації. Оскільки детектор працює за принципом реєстрації гамма квантів з реакцій (n, n' γ), (n, n' γ)$_{res}$, (n, γ) та інших, це дає змогу, при певному виборі порогу реєстрації в режимі фільтрації, виділити складові частини каскадних процесів генерації в об'ємі детектора вторинних гамма квантів із збуджених станів компаунд-ядер. Гамма-кванти реакції непружного розсіяння (n, n'γ) для ядер сцинтилятора KDP: TL$^+$ є стартом каскадного процесу розрядки збуджених ізомерних станів вхідних, проміжних і кінцевих ядер. Виміри ефективності реєстрації швидких нейтронів здійснювалися кристалом KDP розмірами 18x18x42 мм в сферичній геометрії. Отримані відгуки детектора в однофотонному режимі, в одиницях імпульс/частинка для джерел та ^{239}Pu-Be та ^{137}Cs склали 3.57 та 1.44. При цьому був використаний широкополосний тракт з швидкодією 7 нс. Також одночасно проводилися виміри лічильної ефективності вузькополосним трактом з часом обробки 1 мкс та 6.4 мкс. Отримані відгуки KDP: TL$^+$ детектора в режимі 1 мкс (в одиницях імпульс/частинка) для джерел та ^{239}Pu-Be та ^{137}Cs склали 0.09 та 0.00029. При цьому відношення n/γ склало 310. Для порівняння наведені результати вимірів сцинтилятора на основі полістиролу розміром 40×40×40 мм. Отримані відгуки полістирольного детектора (в одиницях імпульс/частинка) в однофотонному режимі для джерел та ^{239}Pu-Be та ^{137}Cs склали 19.4 та 3.9. Також наведені коефіцієнти n/γ відношення для KDP: TL$^+$ – 2.47 і UPS-923A – 4.97. Статистична похибка вимірів ефективності реєстрації нейтронів склала ~ 5 %.

КЛЮЧОВІ СЛОВА: нейтрон, детектор, швидкі нейтрони, KDP: TL$^+$ кристал, ефективність реєстрації, поріг реєстрації, PX-5, швидкість лічення, радіаційний монітор

СЧЕТНАЯ ЕФФЕКТИВНОСТЬ И ГАММА/НЕЙТРОННОЕ ОТНОШЕНИЕ ДЛЯ KDP: TL$^+$ AND UPS-923A СЦИНТИЛЛЯТОРОВ В ОДНОФОТОННОМ РЕЖИМЕ РЕГИСТРАЦИИ

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Целью данной работы является регистрация быстрых нейтронов детектором на основе неорганического монокристалла KDP: TL$^+$ (KH_2PO_4 дигидрофосфат калия) и пластика UPS-923A. Кристалл детектора выращено из водного раствора методом снижения температуры. Высокая концентрация ядер водорода в решетке KDP позволяет регистрировать нейтронное излучения с эффективностью, сопоставимой с полистирольными сцинтилляторами. Кристаллы KDP: TL+ имеют высокую радиационную стойкость (10^{10} нейтрон/см^2), что существенно расширяет спектр их применения в физике высоких энергий, интенсивных нейтронных полях. В работе использована методика регистрации отклика детектора в режиме счета фотонов. Поскольку детектор работает по принципу регистрации гамма квантов из реакций (n, n' γ), (n, n' γ)$_{res}$, (n, γ)$_{cap}$ и других, это позволяет выделить составные части каскадных процессов генерации в объеме детектора вторичных гамма квантов с возбужденных состояний компаунд-ядер. Гамма-кванты реакции упругого рассеяния (n, n' γ) для ядер сцинтиллятора KDP: TL$^+$ являются стартом каскадного процесса разрядки возбужденных изомерных состояний входных, промежуточных и конечных ядер. Измерения эффективности регистрации быстрых нейтронов осуществлялись кристаллом KDP: TL$^+$ размером 18×18×42 мм в сферической геометрии. Полученные отзывы детектора в единицах импульс / частица для источников и ^{239}Pu-Be и ^{137}Cs составили 3.6 и 1.44. При этом был использован широкополосный тракт с быстродействием 7 нс. Также одновременно проводились измерения счетной эффективности узкополосных трактом со временем обработки 1 мкс и 6.4 мкс. Получены отклики KDP: TL$^+$ детектора в режиме 1 мкс (в единицах импульс/частица) для источников ^{239}Pu-Be и ^{137}Cs составил 0.09 и 0.00029. При этом отношение n/γ составило 310. Для сравнения приведены результаты измерений сцинтилятора на основе полистирола размером 40x40x40 мм. Полученный отклик полистирольного детектора (в единицах импульс/частица) в однофотонном режиме для источников ^{239}Pu-Be и ^{137}Cs составил 19.4 и 3.9. Также приведены коэффициенты n/γ отношения для KDP: TL$^+$ – 2.47 і UPS-923A – 4.97. Статистическая погрешность измерений эффективности регистрации нейтронов составила ~ 5%.

КЛЮЧЕВЫЕ СЛОВА: нейтрон, детектор, быстрые нейтроны, KDP: TL$^+$ кристалл, эффективность регистрации, порог регистрации, PX-5, скорость счета, радиационный монитор