ІНФОКОМУНІКАЦІЙНІ ТЕХНОЛОГІЇ ТА ЕЛЕКТРОННА ІНЖЕНЕРІЯ
INFORMATION AND COMMUNICATION TECHNOLOGIES, ELECTRONIC ENGINEERING

№ 3 (1), 2023

ЕЛЕКТРОНІКА ТА ІНЖЕНЕРІЯ

ANALYSIS OF THE RADIOISOTOPES RECOGNITION POSSIBILITY BY MEANS OF THE ABSORBED DOSE MEASUREMENT WITH DOSIMETRIC DETECTORS OF DIFFERENT DENSITY

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(Given 10 March 2023)

The work is devoted to the problem of identifying an unknown source of γ-radiation as a task of emergency dosimetry in the case of the use for terrorist purposes of the radiation-dispersive devices, known also as dirty bomb. The possibility of identifying an unknown γ-source is considered based on the energy dependence of the absorption of ionizing photon radiation, which in passive dosimetry manifests itself as dosimetric sensitivity. Radioisotope recognition is analyzed by the ratio of dosimetric sensitivities of heavy (with a high value of the effective atomic number Z_{eff}) and light (with a low Z_{eff} value) dosimetric detectors, for the values of γ-radiation energies of those radioisotopes that can probably be used to create a dirty bomb. As a light dosimetric detector, BeO ceramics is considered, and as a heavy one, a dosimetric detector based on single crystalline yttrium-aluminum perovskite ($YAlO_3$) or lutetium-aluminum perovskite ($LuAlO_3$). The influence of the accuracy of the absorbed dose measurement on the reliability of radioisotope identification is discussed and approaches for its practical implementation are proposed.

Key words: *emergency dosimetry; radiation dispersal device; dirty bomb; radioisotope identification; passive dosimetry; absorbed dose; dosimetric materials; optimal recognition; decision-making rule; error analysis.*

1. Introduction

The aggressive war, which was unreasonably and illegally started by the russian federation against Ukraine, creates a number of threats to the entire continent and has an impact on the whole world. Special concern causes the threat of criminal use of nuclear weapons against a non-nuclear state and the use of nuclear facilities such as nuclear power plants for terrorist purposes. Another type of threat, which is considered to be even easier for terrorists to create, is the ability to use a variety of radiation dispersal devices (RDD) [1–3], which are commonly named in media as a dirty bomb. Exactly the events of the last year in Ukraine have prompted again to speak about the reality of such threats and require the readiness to respond. The peculiarity of RDDs, unlike man-made radiation accidents, or terrorist use of industrial sources of ionizing radiation is that the radiation source is not known in advance, since there are in general many radioactive materials that can be used for radiation contamination of the territory, air, and water, as well for dangerous irradiation of a large number of people. Measures to respond to the factors of damage to the RDD use, and the scenario of elimination of consequences, including for the health and life of the

victims, depend significantly on the type of radioactive isotopes used [4–7]. Therefore, their earlier identification is one of the main problems of emergency dosimetry in the zone of the accident.

Although there are many methods of spectrometry of ionizing radiation, their prompt use directly at the place of a terrorist attack is not seen in a realistic scenario. The problem of identification of the source of dangerous radiation should be solved by the means that will be equipped with rescuers of Emergency Service and soldiers of the CBRN defense, which are the first who attend the radiation accident zone to respond to the threat.

In order to identify the unknown radioisotope the passive dosimetry of γ-radiation can be applied, which is usually used to control the danger of ionizing radiation for health and human life by the value of the absorbed dose. Usually, as detectors of passive dosimeters, one tries to use the so-called tissue-equivalent dosimetric material whose absorption ability is close to the tissues of the human body. This allows you to evaluate the dose absorbed by the human body as a dose absorbed in a dosimetric detector, and this ability is stored for various radiation energies. The absorption ability of the dosimetric detector depends significantly on the effective atomic number (Z_{eff}) of the dosimetric material, which determines the nature of elementary acts of the interaction of primary and secondary radiation particles with the matter. If the Z_{eff} of the dosimetric detector differs from the Z_{eff} of the human body, then it, after calibration at some energy of γ-radiation, will show the absorbed dose of the radiation of other energy, which differs from the dose got by the human body or the tissue equivalent detector. On the one hand, it is this difference that requires correction of the absorbed dose, measured by a non-tissue-equivalent detector. But from the other hand, it can be used to evaluate the energy of the source of γ-radiation and its identification.

The idea of ionizing irradiation source recognition utilizing measurements of absorbed dose using at least two different detectors of different effective atomic number Z_{eff} (and as a result the different specific density) was claimed in [8] and is based on the dependence of the amount of deposited energy upon the energy of radiation quanta. However, to date, this approach has not been implemented in practice mainly due to the lack of appropriate detectors made of high atomic number materials. Both dosimetric detectors should be placed in the same casing of wearable dosimeter and get irradiation in the same conditions. In this case, the detectors having different Z_{eff}, which have been calibrated for the same energy, for instance, using ^{137}Cs with γ-quanta energy 0.662 MeV, will demonstrate different absorbed doses, if the energy differs from 0.662 MeV. If the dependence of the absorbed energy upon the energy of irradiation quanta is known for both detectors, then the energy of the unknown γ-radiation source may be estimated from the difference in measured doses. In turn, the energy of registered irradiation identifies the unknown radioisotope as a radiation source.

The aim of this investigation is to analyze and establish a possibility to identify radioisotopes, which could be potentially used in RDD, employing the absorbed dose measurements of their γ-radiation with two detectors of different Z_{eff}. We'll consider as a "light" detector the beryllium oxide ceramics (BeO), which is tissue equivalent with Z_{eff} = 7.1 and is well known dosimetric material for thermally and optically stimulated luminescence dosimetry [9–12]. For usage as a "heavy" detector, two compounds will be considered – the yttrium aluminum perovskite (YAP) $YAlO_3$ with Z_{eff} = 31.4 and lutetium aluminum perovskite (LuAP) with Z_{eff} = 61.6. The first one activated with manganese (YAP:Mn), was investigated in detail in [13–16]. The second was not yet investigated and is considered as hypothetical material for dosimetry with very high Z_{eff}, because the (Y-Lu)AlO_3:Mn with partial substitution of Y with Lu demonstrated similar dosimetric properties [17].

2. The analysis of the energy dependence of dosimetric sensitivity

The dependences of deposited energy upon photons' energy were obtained in [8, 18, 19] using Monte-Carlo simulation of γ-quanta interaction with some materials of the 1 mm thickness which can be used for dosimetry. Some of them are presented in Fig. 1. The presence of an activator like Mn in YAP: Mn in amount much less than 1 at. %, doesn't influence the dependences presented in Fig. 1. It is necessary to emphasize that the experiments on the energy dependence of thermoluminescence dosimetry sensitivity of YAP: Mn fulfilled in [19, 20] with different radiation sources reliably confirmed the simulation results, which mean that our analysis can be based on simulation results [8, 18, 19] for other materials too.

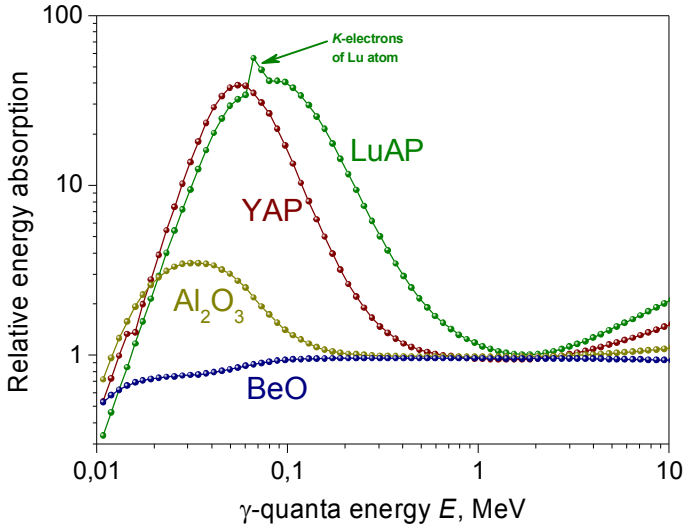

Fig. 1. Dependence of the irradiation absorption (energy deposition) upon radiation energy, obtained by Monte-Carlo simulation in [8, 18] for 1 mm thick dosimetric detectors based on BeO (Z_{eff} = 7.1), YAP (Z_{eff} = 31.4) and LuAP (Z_{eff} = 61.6), as well as Al_2O_3 (Z_{eff} = 11.1) given for comparison

The curves presented in Fig. 1 have can be considered as energy dependencies of relative dosimetric sensitivity $S(E)$. For two detectors calibrated for the same energy the measured (observed) values of absorbed dose for any other energy can be expressed:

$$D_1 = S_1(E) * D, \\ D_2 = S_2(E) * D.' \tag{1}$$

Then the true value of absorbed dose D and the energy E could be determined from the set of equations (1) if the functions $S_1(E)$ and $S_2(E)$ are known and the inverse function is unambiguous. Unfortunately, as one can see in Fig. 1, the sensitivity dependencies on energy are non-monotonic for all detectors besides BeO, and the determination of the energy from the sensitivity value is not unambiguous for them in the full range of energies. However from the point of view of practical implementation, it is necessary to consider only the energy range where the radioisotopes of interest are radiating.

3. The analysis of the energy range where the radioisotopes of interest can radiate

There were done a lot of investigations devoted to the possible scenarios of the hypothetical RDD terroristic usage events to propose the measures for readiness and response to the threats in such cases [1–7, 21, 22]. In particular, the possible use of various radioisotopes for the manufacture of RDD has been studied in some studies from the point of view of such aspects as the presence and availability of the required amount, the complexity of the technologies for the manufacture of dangerous substances, usability and effectiveness for achieving the goals of terrorists, etc. In conclusion, only a small number of radioisotopes from the huge variety of known radionuclides were considered [7, 23] as probable for use in the RDDs. They are listed in Table 1 together with some of their characteristics.

As can be seen from Table 1, radioactive isotopes 1–8 are sources of β- and α-particles and are relatively safe from the point of view of external irradiation since the corpuscular radiation has low penetration ability and is absorbed by air even at small distances from the source. Soft X-ray radiation, which accompanies the radioactivity of α-radiation sources 4–8 in Table 1 does not pose a great danger, since the activity of these isotopes is not high. All isotopes 1–8 in Table 1 pose a serious danger only in case of radiation pollution, getting on the skin or in the human body when they become sources of internal radiation. Sources of dangerous external γ-radiation can be only three radionuclides – Cesium ^{137}Cs, Iridium ^{192}Ir, and Cobalt ^{60}Co with radiation energies of 0.662, 0.820, and 1.250 MeV, respectively. Therefore, the task of identifying unknown γ-radiation in the case of terrorist use of RDDs in a certain simplification is reduced to distinguishing only these three sources of γ-radiation.

Table 1

Actual isotopes for use in RDD and their main characteristics after [23, 24]

No.	Isotope	Decay	Radiation energy, MeV	Radioactive half-life, year	Specific activity, Ci/g
1	Strontium (Sr-90)	β	0.2 (β)	28	140
2	Plutonium (Pu-239)	α	5.1 (α)	24 100	0.063
3	Polonium (Po-210)	α	5.3 (α)	0.4 (138.4 days)	4 500
4	Radium (Ra-226)	α, β, γ	4.8 (α), 0.0036 (β), 0.0067 (X)	1 602	1.0
5	Californium (Cf-252)	α, γ	5.9 (α), 0.0012 (X)	2.6	540
6	Curium (Cm-244)	α, γ	5.8 (α), 0.0017 (X)	18	82
7	Plutonium (Pu-238)	α, γ	5.5 (α), 0.0018 (X)	87.7	17
8	Americium (Am-241)	α, γ	5.5 (α), 0.0595 (X)	458	3.5
9	Cesium (Cs-137)	β, γ	0.19 (β), **0.6617 (γ)**	30	88
10	Iridium (Ir-192)	β, γ	0.22 (β), **0.82 (γ)**	0.2 (74 days)	9 200
11	Cobalt (Co-60)	β, γ	0.097 (β), **1.25 (γ)**	5.26	1 100

4. Analysis of the radioisotopes' identification possibility from the measurement of absorbed dose by two dosimetric detectors

Taking into account the dependences manifested in Fig. 1, the following analysis is narrowed only to the energy range where the energies of ^{137}Cs, ^{192}Ir and ^{60}Co radiation are located and where the corresponding dependences are monotonic. The case when both heavy and light detectors are calibrated for the ^{137}Cs radiation is considered and the corresponding dependencies shown in Fig. 1 were recalculated in the range 0.35–1.5 MeV to meet the unit sensitivity at the energy of the calibration source. They are shown in Fig. 2, a.

If the values of absorbed dose measured by two detectors $D_1 = D_{YAP}$ (or $= D_{LuAP}$) and $D_2 = D_{BeO}$ are known from the experiment then the energy of unknown radiation produced these values can be found from the set (1) by solving the equation

$$\frac{D_1}{D_2} = \frac{S_1(E)}{S_2(E)}, \tag{2}$$

Because the dependencies $S_1(E)$ and $S_2(E)$ are known, their ratio $R(E) = \dfrac{S_1(E)}{S_2(E)}$ is easy to calculate (see Fig. 2, b) and consider the equation (2) to be solved in the form:

$$R(E) = \frac{D_1}{D_2}, \tag{3}$$

To solve (3), the energy value can be estimated from the inverse dependence $E(R)$, which is easy to get from the numerical interpolation of the dependence $R(E)$ with any needed accuracy, and its argument $\mathrm{R} = \mathrm{D_1}/\mathrm{D_2}$ to be obtained from the measurement. If the energy of radiation $E\left(\mathrm{D_1}/\mathrm{D_2}\right)$ is determined, then the estimation of the true value of the absorbed dose can be found as an average value from the expression

$$D = \frac{1}{2}\left(\frac{D_1}{S_1(E)} + \frac{D_2}{S_2(E)}\right), \tag{4}$$

or using $R(E)$ instead of $S_1(E)$

$$D = \frac{1}{2}\frac{R(E)}{S_2(E)}\left(D_1 + D_2 R(E)\right). \tag{5}$$

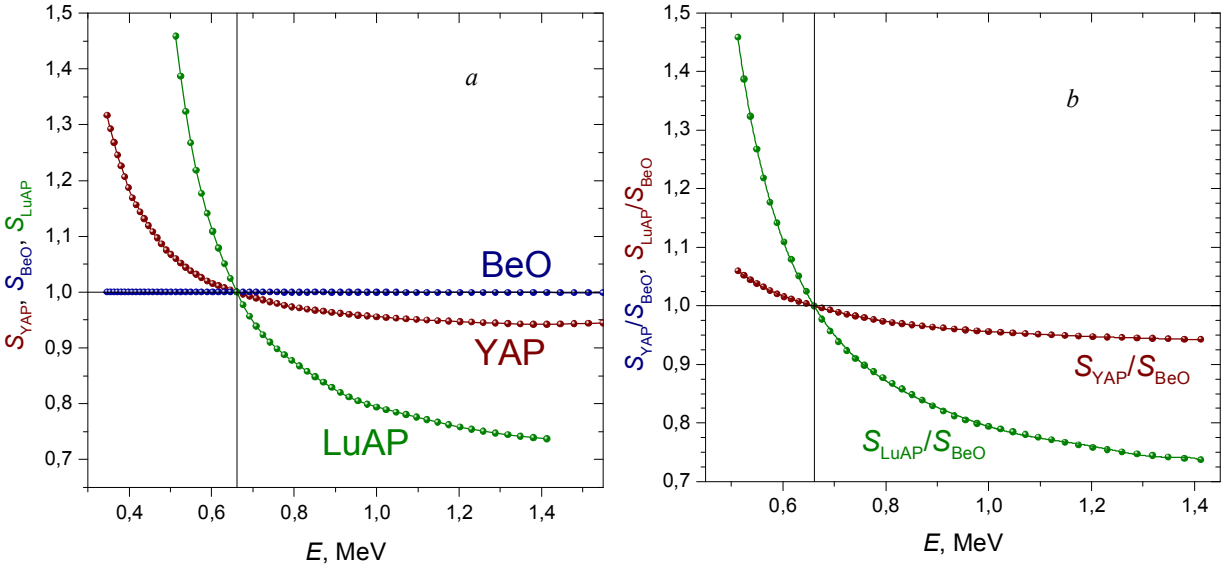

Fig. 2. Energy dependencies of relative sensitivity $S(E)$ *of the dosimetric detectors, based on YAP, LuAP and BeO (a) and their ratios* $R(E)=\frac{S_1(E)}{S_2(E)}$ *(b) for heavy and light detectors*

On the other hand, the averaging in (4) and (5) can clarify the central estimation of the true dose value D, but because of the adding the errors of measurements, the uncertainty of averaged D will increase. That is why taking into account that the $S_2(E)$ dependence in the energy range under consideration is very flat for the BeO detector, one can simply use the measured assessment D_2 as the true value of absorbed dose $(D \approx D_2)$. Then, there is no necessity to find the energy of the unknown radiation source from (1) or (3) at all, because the isotopes ^{137}Cs, ^{192}Ir and ^{60}Co can be identified only from the estimation of the ratio of measured dose $R = D_1 / D_2$.

Thus, the problem of recognition of unknown radiation from the series ^{137}Cs, ^{192}Ir and ^{60}Co is reduced to the recognition of the three discrete values of $R(^{60}\text{Co}) = R_1$, $R(^{192}\text{Ir}) = R_2$ and $R(^{137}\text{Cs}) = R_3$, which are dependent on the pair of detectors used. They are calculated from the dependencies given in Fig. 2, *b* and presented in Table 2. Of course, the measurements of D_1 and D_2 cannot be absolutely accurate. So, the R ratio obtained from measurements will be a continuous random quantity. To recognize the isotope, every value of R got from measurement has to be recognized as one of three discrete values using a decision-making rule, which is a general approach for recognizing the a priori known discrete signals.

Table 2

Ratios $R = D_1 / D_2$ **calculated from the dependence** $R(E)=\frac{S_1(E)}{S_2(E)}$ **for the γ-radiation energy of isotopes ^{137}Cs, ^{192}Ir and ^{60}Co as well as the ratio of** $\frac{\sigma_R}{\varepsilon_D}$ **(explanation see in the text)**

Isotope	Energy of g-quanta, MeV	YAP/BeO		LuAP/BeO	
		R	$\frac{\sigma_R}{\varepsilon_D}$	R	$\frac{\sigma_R}{\varepsilon_D}$
^{137}Cs	0.662	1	1.414	1	1.414
^{192}Ir	0.82	0.971	1.394	0.862	1.320
^{60}Co	1.25	0.946	1.377	0.751	1.251

The decision-making rule for isotopes recognition based on the R-value can be formulated as follows:

$$R = \begin{cases} R_1, R < r_{12}, \\ R_2, r_{12} < R < r_{23}, . \\ R_3, R > r_{23} \end{cases} \quad (6)$$

where the border quantities r_{12} and r_{23} should be found in the intervals $[R_1, R_2]$ and $[R_2, R_3]$ espectively using some criterion for optimal recognition. It is obvious that the decision-making rule has to take into account the peculiarities of the probability distribution.

To clarify the border quantities r_{12} and r_{23} in rule (6) let's assume that the absorbed dose value is measured with a stochastic error, which possesses a normal (Gaussian) distribution of probability characterized by the standard deviation σ_{D_i}. Then the standard deviation of the indirect measurement of the ratio $R = D_1 / D_2$ can be expressed:

$$\sigma_R = \left(\left(\frac{\partial R}{\partial D_1} \right)^2 \left(\sigma_{D_1} \right)^2 + \left(\frac{\partial R}{\partial D_2} \right)^2 \left(\sigma_{D_2} \right)^2 \right)^{1/2} = \sqrt{\frac{\left(\sigma_{D_1}^2 + R^2 \sigma_{D_2}^2 \right)}{D_2^2}} . \quad (7)$$

In assumption that $\sigma_{D_1} = \sigma_{D_2} = \sigma_D$ and $D \approx D_2$ (due to very flat dependence of $S_2(E)$ equation (7) can be rewritten in the form:

$$\sigma_R = \sqrt{1 + R^2} * \varepsilon_D , . \quad (8)$$

where $\varepsilon_D = \sigma_D / D$ is a relative error of measurement of absorbed dose. The values of σ_R / ε_D calculated for isotopes' energies are presented in Table 2. They allow considering the error probability distribution of the R_i estimations from measurements for the given quantity of relative dose measurement error. As an example the error probability density functions $w_i(R)$ of R_i estimations calculated for the relative measurement error $\varepsilon_D =$ 0.01 (1 %) are presented in Fig. 3. They demonstrate the probability of quantities of the R_i ratio obtained from measurements of the dose of isotopes' radiation absorbed by two dosimetric detectors YAP and BeO.

Fig. 3, *a* demonstrates an overlapping of the adjacent distribution tails which can result in errors in isotope identification when the pair of detectors YAP/BeO is used. The closer are the energies of isotopes, the closer are the ratio quantities, the larger is the area of overlapping and the bigger is the error, which may occur at isotope recognition. Minimal error will occur when the border quantities r_{12} and r_{23} will satisfy equations:

$$\begin{aligned} w_1(r_{12}) &= w_2(r_{12}), \\ w_2(r_{23}) &= w_3(r_{23}) \end{aligned} . \quad (9)$$

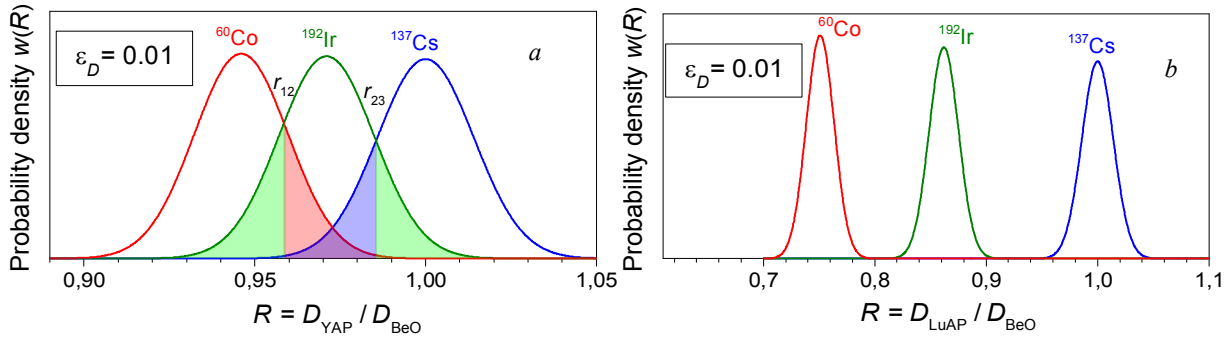

Fig. 3. The probability density distributions of estimated quantities R_i with parameters, presented in Table 2 for the detectors pairs YAP/BeO (a) and LuAP/BeO (b), in the assumption that the absorbed dose measurement possesses the Gaussian distribution of error and has a relative accuracy ε_D =0.01 (1 %)

If the obtained value of R_i will occur outside its own area of the highest probability, then the decision-making rule usage will result in the error. The error regions in Fig. 3, *a* are filled with the same colors that the main distribution curves $w_i(R)$. One can see that the ^{192}Ir identification error is practically twice bigger because its probability density function $w_2(R)$ overlaps with both adjacent functions and the filled "error area" is twice compared with the error for two other isotopes. The considered above approach allows estimating the probability of the identification error for each isotope as the filled area using the cumulative distribution function, which is the error function for the Gaussian distribution*, while the integral of probability density function in the infinite limits is equal to one. The error probabilities in identification of isotopes ^{137}Cs, ^{192}Ir and ^{60}Co can be expressed:

$$P_{Co} = P_R = \frac{1}{2} erf\left(\frac{r_{12} - R_1}{\sigma_1\sqrt{2}}\right), \tag{10}$$

$$P_{Ir} = P_G = \frac{1}{2}\left[erf\left(\frac{R_2 - r_{12}}{\sigma_2\sqrt{2}}\right) + erf\left(\frac{r_{23} - R_2}{\sigma_2\sqrt{2}}\right)\right], \tag{11}$$

$$P_{Cs} = P_B = \frac{1}{2} erf\left(\frac{R_3 - r_{23}}{\sigma_3\sqrt{2}}\right), \tag{12}$$

where subscripts *R, B,* and *G* correspond to the colors of curves and filling in Fig. 3, *a*.

All that was said in the two paragraphs above is also correct for Fig. 3, *b*, which regards using the pair of detectors LuAP/BeO. But the overlapping of the adjusting distributions here is negligible as well as the probability of isotopes' recognition error at $\varepsilon_D = 0.01$ (1 %).

Fig. 4 demonstrates dependencies of the identification errors probabilities $P_{Co}(\varepsilon_D), P_{Ir}(\varepsilon_D)$ and $P_{Cs}(\varepsilon_D)$ as functions of the relative error ε_D of the absorbed dose measurement using pairs of detectors YAP/BeO (*a*) and LuAP/BeO (*b*). They ground the requirements for dose measurement accuracy to use the isotope identification approach described above. In particular, it shows that even for very high accuracy of dose measurement when the relative error ε_D is equal to 1 %, the probability of the ^{192}Ir isotope identification in a single measurement using YAP/BeO detectors is close to 34 %, which cannot be considered reliable identification. For the lower accuracy of dose measurement, the identification cannot be considered satisfactory, because the probability of errors becomes quickly too high and the identification loses its meaning.

It looks problematic to improve the accuracy of measuring the absorbed dose by emergency dosimetry, so these results indicate that the pair of detectors with a higher difference of Z_{eff} can solve the problem while ε_D is not much higher than 2 % and Fig. 4, *b* clearly demonstrates that.

On the other hand for multiple measurements, *i.e.* using several dosimeters with pair of detectors YAP/BeO, and carrying out the isotopes identification by each of them independently and independently on dose got by each, the joint probability of wrong identification will drop down as an exponential function of number *n* of used dosimeters:

$$P_i(n) \sim P_i^n. \tag{13}$$

If the number *n* of used dosimeters is odd, then the recognition decision has to be made using well-known majority principle. For instance, using three dosimeters with YAP/BeO pair of detectors reduces the ^{192}Ir isotope identification error probability from 34 % to quite an acceptable level of 3.7 % at the same accuracy of dose measurement characterized by $\varepsilon_D = 0.01$ (1 %). This approach may be even more practical from the point of view that there may be several passive dosimeters irradiated by the same source in the zone of a radiation accident.

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* $erfc(x) = 1 - erf(x) = \frac{2}{\sqrt{\pi}}\int_x^\infty e^{-t^2} dt.$

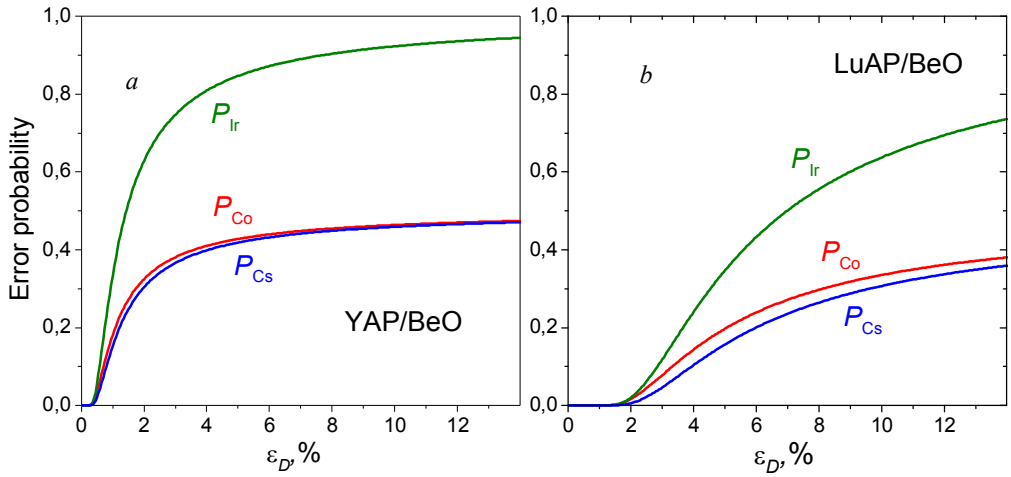

Fig. 4. Dependencies of the radioisotopes identification error probabilities P_{Co}, P_{Ir} and P_{Cs} upon the relative error if the absorbed dose measurement ε_D according to the decision-making rule (6) and absorbed dose measurement using detectors pairs YAP/BeO (a) and LuAP/BeO (b)

5. Conclusions

The analysis of the identification possibility of the unknown radiation source was performed in the context of emergency dosimetry in the case of hypothetical dirty bomb use by considering the problem recognition isotopes utilizing the absorbed doses' values measured by two dosimetric detectors, light BeO and heavy YAP: Mn or LuAP, taking into account the energy dependences of their dosimetric sensitivity and random errors appearing during measurements. According to the available sources, the number of radioisotopes which can be used by terrorists in RDDs is very limited, and only three isotopes ^{137}Cs, ^{192}Ir and ^{60}Co are dangerous from the point of view of external gamma-irradiation. In the case of RDD use with an unknown radiation source, the identification of these isotopes can be done based on the ratio of measured doses absorbed by two dosimetric detectors having a big difference in the effective atomic number Z_{eff}. The bigger is the slope of the energy dependence of the dosimetric sensitivity of the heavy detector in the energy range of interest, the easier is the recognition of isotopes. The performed analysis shows that the optimal identification of isotopes ^{137}Cs, ^{192}Ir and ^{60}Co using 1 mm thick dosimetric detectors based on YAP and BeO requires unusually high accuracy of measurements of absorbed dose or to use of a pair of detectors which have a bigger difference in observed absorbed doses ratio for the γ-radiation energy range of mentioned isotopes. The possible solution may be the usage of even heavier compounds like LuAP (Z_{eff} = 61.6) or others with higher Z_{eff} instead of YAP. On the other hand, a much easier and more feasible way to increase the reliability of isotopes' identification is to solve the recognition problem using several identical dosimeters which got irradiated by the same source owing to reducing the joint error probability with an increase of a number of independent identifications.

Acknowledgment

This work was supported by the NATO SPS MYP program (project G5647), the National Research Foundation of Ukraine (grant 2020.02-0373) and by the Polish National Science Centre (project 2018/31/B/ST8/00774)

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АНАЛІЗ МОЖЛИВОСТІ РОЗПІЗНАВАННЯ РАДІОІЗОТОПІВ ЗА ДОПОМОГОЮ ВИМІРЮВАННЯ ПОГЛИНЕНОЇ ДОЗИ ДОЗИМЕТРИЧНИМИ ДЕТЕКТОРАМИ РІЗНОЇ ГУСТИНИ

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Робота присвячена проблемі ідентифікації невідомого джерела γ-випромінювання як задачі екстреної аварійної дозиметрії у разі використання у терористичних цілях радіаційно-дисперсійних засобів відомих також як "брудна бомба". Можливість ідентифікації невідомого γ-джерела розглядається на основі енергетичних залежностей поглинання іонізуючого фотонного випромінювання, яка у пасивній дозиметрії проявляє себе як дозиметрична чутливість. Аналізується розпізнавання радіоізотопів за відношенням дозиметричних чутливостей важкого (з високим значенням ефективного атомного номера Z_{eff}) дозиметричного детектора та легкого (з низьким значенням Z_{eff}), для значень енергій γ-випромінювання тих радіоізотопів, які вірогідно можуть бути використані для створення брудної бомби. Як легкий дозиметричний детектор розглядається кераміка BeO, а як важкий – дозиметричний детектор на основі ітрій-алюмінієвого перовськиту ($YAlO_3$) або лютецій-алюмінієвого перовськиту ($LuAlO_3$). Обговорюється вплив точності вимірювання поглиненої дози на надійність ідентифікації радіоізотопу та пропонуються підходи для її практичної реалізації.

Ключові слова: *аварійна дозиметрія; радіаційно-дисперсійні засоби; "брудна бомба"; ідентифікація радіоізотопів; пасивна дозиметрія; поглинена доза; дозиметричні матеріали; оптимальне розпізнавання; віршувальне правило; аналіз похибок.*