ISSN 1027-5495. Functional Materials, 26, No.3 (2019), p. 648-655.
doi:https://doi.org/10.15407/fm26.03.648

Forecasting of scintillation equipment development for anticipatory standartization

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Received June 11, 2019

The level of innovation in the five main industries of application for scintillation equipment (geology, dosimetry, high energy physics, medicine, radiation monitoring) has been evaluated in the article. A method for analytical forecasting of the development of these industries, based on presented equivalent effectiveness of innovation and its components (economic, social, technical and environmental), for the purpose of anticipatory standardization development was proposed. The data of such a forecast has been given; and the degree of its reliability has been provided, which enables to discuss the possibility of anticipatory standard development.
Keywords: innovation, scintillation equipment, analytical forecasting, anticipatory standard.

Проведена оценка степени инновационности сцинтилляционной техники, применяемой в основных областях (геология, дозиметрия, физика высоких энергий, медицина, радиационный мониторинг). Предложен метод аналитического прогнозирования развития степени инновационности сцинтилляционной техники с учетом приведенной эквивалентной эффективности инноваций и ее составляющих (экономической, социальной, технической и экологической). Приведены данные такого прогноза, показана степень его достоверности, что позволяет говорить о возможности создания опережающего стандарта.

Прогнозування розвитку сцинтиляційної техніки для створення випереджувальних стандартів. *Ю.Даниленко, Б.Гриньов, В.Любинський, А.Мезеря, Р.Тріщ.*

Проведено оцінку ступеня інноваційності п'яти основних галузей застосування сцинтиляційної техніки (геологія, дозиметрія, фізика високих енергій, медицина, радіаційний моніторинг). Запропоновано метод аналітичного прогнозування розвитку цих галузей з урахуванням приведеної еквівалентної ефективності інновацій та її складових (економічної, соціальної, технічної та екологічної) з метою створення випереджувальної стандартизації. Наведено дані такого прогнозу, показано ступінь його достовірності, що дозволяє говорити про можливість створення випереджаючого стандарту.

1. Introduction

Scintillation method is one of the priority methods for X-ray and gamma radiation registration, based on conversion of ionizing radiation into UV visible radiation. Scintillation materials have a wide range of applications due to the variety of their properties. Application of such materials increase at a rapid rate, that helps find their new properties, improve their existing characteristics and discover new areas of scintillation equipment application [1].

Standardization, which can be considered as a means of ensuring compatibility, interchangeability, unification, reliability of

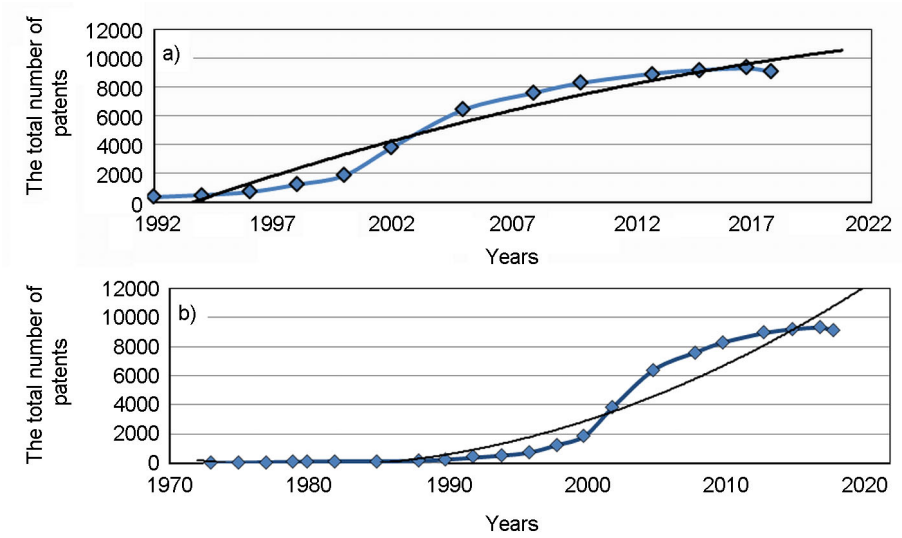

Fig. 1. The evaluation of the level of innovative of development for scintillation equipment of medicine (a). The accumulative value of the development for scintillation equipment of medicine (b).

equipment and information networks, safety standards and environmental requirements, unity of characteristics and properties, quality of products, works and services, plays a special role. It sets up direction that must be considered by manufacturers' of scintillation equipment improving their technology. Standards can serve as a source of information for innovation, along with other sources such as databases, scientific publications, intellectual property, which together create the necessary informative space for innovation and contribute to a more diffuse distribution of innovation [1].

Due to development of science and technology, the lead time between the scientific discovery and its mass production, which used to reach up to several years, has been reduced. Therefore, the standardized parameters of products should be revised more frequently, considering the development forecasting in the industry and the growth rate of scientific and technological progress.

Patent information is one of the significant factors of scientific and technical growth. The number of obtained patents per year can indicate at the rate of technical development of the industry. To predict electronics [2] the author used the method of anticipatory forecasting of research topics development based on the quantitative and dynamic analysis of the time series in US patents within a certain period formed by specific groups, subgroups of International Patent Classification, keywords and phrases.

The goal of this article is to develop the analytical methods for forecasting of scintillation equipment to enable the creation of anticipatory standards.

2. Exploring

One of the indicators of the company innovation activity is the number of obtained patents. This means that each patent carries a certain efficiency of innovation, namely, it corresponds to the unit of relative innovation. The following dependences were found: the number of patents obtained in the world for the industry over an appointed period of time, using an open global cyber infrastructure [3].

The five main industries of application of scintillation equipment: geology, dosimetry, high energy physics, medicine, radiation monitoring were reviewed.

To evaluate the level of innovative of development of one of the scintillation industry (medicine), Microsoft Excel graphic dependences were built. The approximation of the curve in Fig. 1a was carried out by a polynomial of the second degree: $E(t) = 3.9t^2 + 330.6t - 920.7$. The value of the probability of approximation (R^2) is 0.9.

The accumulative value of the development of scintillation equipment for medicine is built as a function of all patents obtained in the world within a certain industry to a certain year: $E_{ac}(t) = 7.5t^2 - 29725t + 3E{+}07$ where $R^2 = 0.94$.

As can be seen from Fig. 1a, even though scintillation materials in medicine (scintigraphy and single-photon emission computed tomography) has been starting to develop recently, a large number of patents being obtained in recent years indicates that application of scintillation equipment in this area is innovative and attractive. The

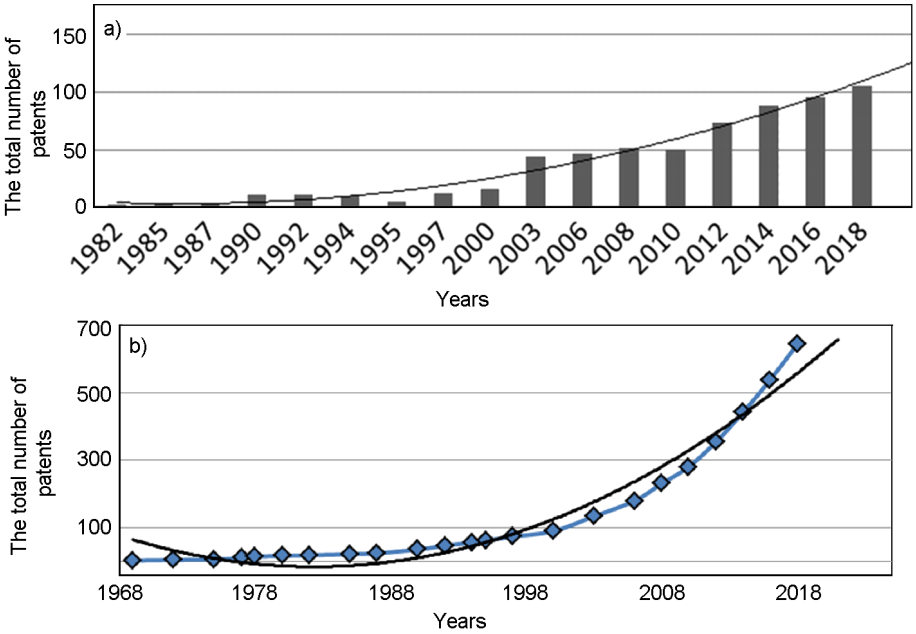

Fig. 2. The evaluation of the level of innovative of development for scintillation equipment of dosimetry (a). The accumulative value of the development for scintillation equipment of dosimetry (b).

probability is that the number of patents will increase in the next 1–2 years is 0.9. Long-term prediction is non-relevant due to the influence of the general external factors. This assumption is also supported by the accumulated value of its development.

The obtained dependences enable to predict the development of innovations of scintillation materials in medicine (Fig. 1a, Fig. 1b). For other applications of scintillation equipment, the assessment of the degree of innovative development and the accumulative value of development was conducted analogously.

Another important application of scintillation materials is dosimetry (the measurement of the exposure dose of photon radiation, the absorbed dose and the equivalent dose of photon or neutron radiation, as well as measurement of the radiation power of these quantities).

Fig. 2a shows the number of patents relating to the use of scintillation materials in dosimetry for the registration of ionizing radiation (α-, β-, γ-, X-ray radiation and neutrons) between 1980 and 2018. This dependence is approximated by a polynomial of the second degree: $E(t) = 0.5t^2 - 2.32t + 5.7$. The value of the probability of approximation is 0.97. The accumulative value of the development of scintillation equipment for dosimetry is shown in Fig. 2b. It is approximated by a polynomial of the second degree:

$E_{ac}(t) = 0.5t^2 - 1787.9t + 2E{+}06$ where $R^2 = 0.96$.

The stated dependences (Fig. 2a, Fig. 2b) give a possibility to predict that the usage of scintillation materials in dosimetry will increase over the next three years. Long-term prediction is non-relevant due to the influence of the general external factors.

Radiation-resistant single-crystal scintillators and inexpensive scintillation plastics with luminescent impurities, which operate under ultra-large fluxes conditions of ionizing radiation, are used in high-energy physics experiments. Fig. 3a shows dependence of the number of world patents of scintillation materials using in high-energy physics experiments over time. The given curve is approximated by a polynomial of the second degree: $E(t) = -5.7458t^2 + 391.23t - 10060.47$. The value of the probability of approximation is 0,9. The accumulative value of the of scintillation equipment development for dosimetry is shown on Fig. 3b. It is described by a polynomial of the second degree: $E_{ac}(t) = 40.4t^2 - 160095t + 2E{+}08$ where $R^2 = 0.98$.

As it can be seen on Fig. 3a and Fig. 3b, since 2010 more than four thousand patents have been received annually in this industry. In addition, we can conclude that the number of patents will grow over the next

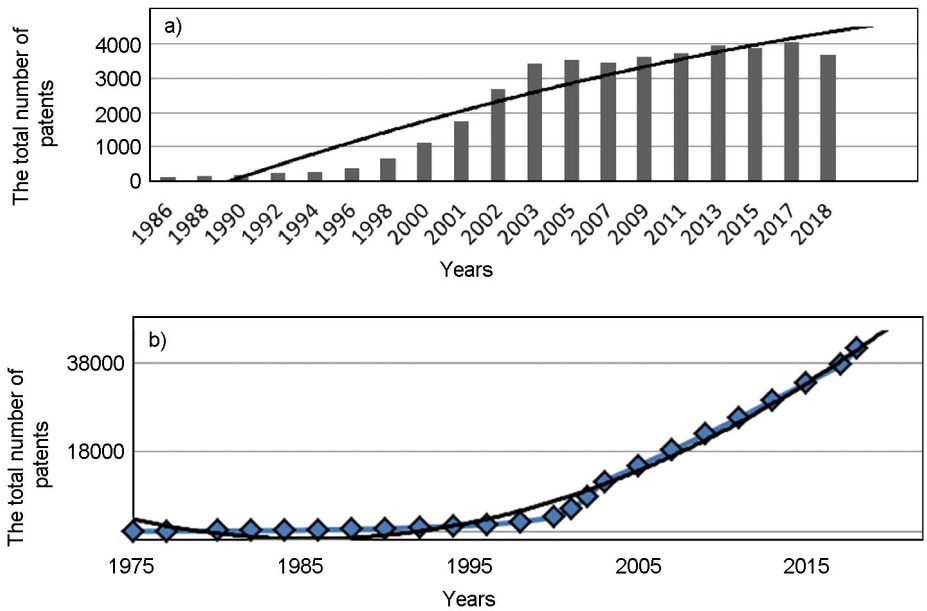

Fig. 3. The evaluation of the level of innovative of development for scintillation equipment of high energy physics (a). The accumulative value of the development for scintillation equipment of high energy physics (b).

two to three years with a probability of 0.9–0.98. Long-term prediction is non-relevant due to the influence of the general external factors.

In geology scintillation detectors are successfully used to detect gamma and X-ray doses for radiation logging in wells, however they have a number of specific limitations that can limit their usage, for example: the effectiveness of the scintillation detector depends on the operating temperature and the vibration resistance of the recording device.

Fig. 4a shows the dependence of the number of world patents relating to the usage of scintillation materials in geology over time, is approximated by a third-degree polynomial: $E(t) = 0.12t^3 - 2.1t^2 + 12.3t - 8.83$. The value of the probability of approximation is 0.7. The accumulative value of the development of scintillation equipment for geology is shown on Fig. 4b. It is described by a polynomial of the second degree: $E_{ac}(t) = 0{,}142t^2 - 565.72t + 560883$ where $R^2 = 0.98$.

As it can be seen on Fig. 4a, the innovation of the scintillation materials usage is less than in other applications that is associated with the particularities of these materials application in geology. Because the probability of approximation is only 0.7, it is impossible to predict the development of this industry for more than a year, but according to the obtained dependency, the number of patents in this area would increase. On the contrary, using the method of function for the accumulative value of development allows us to predict the development of this industry over the next three years with a probability of 0.98.

Portal monitors for radiation monitoring are intended for non-destructive testing and measurement of nuclear, radioactive materials, ionizing radiation sources and are used for radiation monitoring systems and systems, in dosimetric customs services for solving nuclear safety problems. This application has emerged recently with the advent of international terrorism. Fig. 5a shows the dependence of the number of world patents of scintillation materials using in radiation monitoring over time. It is approximated by a polynomial of the second degree: $E(t) = -3.4t^2 + 99t - 254.8$. The value of the probability of approximation (R^2) is 0.7. The accumulative value of the development of scintillation equipment for radiation monitoring is shown on Fig. 5b. It is described by a polynomial of the second degree: $E_{ac}(t) = 6.5t^2 - 25697t + 3\text{E}{+}07$ where $R^2 = 0.96$.

As it can be seen on Fig. 5a, the coefficient of approximation probability is low, which indicates that it is impossible to reliably predict how the use of scintillation materials will develop in this industry for more than a year and whether the number

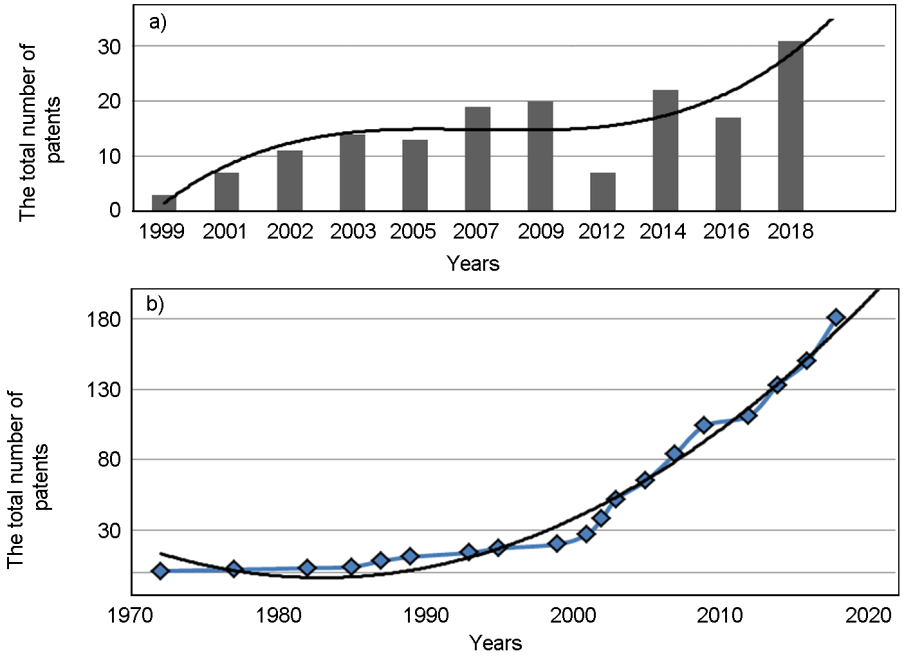

Fig. 4. The evaluation of the level of innovative of development for scintillation equipment of geology (a). The accumulative value of the development for scintillation equipment of geology (b).

of patents will decrease. Also, despite the fact that there is some downward dynamics in the number of intellectual property, spectrometric portals are still under development and existing portals are still unable to meet the customers' requirements for such products. Despite this, the radiation monitoring industry is innovative and will constantly develop in the future. On the contrary, using the method of function for the accumulative value of development allows us to predict the development of this industry over the next three years with a probability of 0.96.

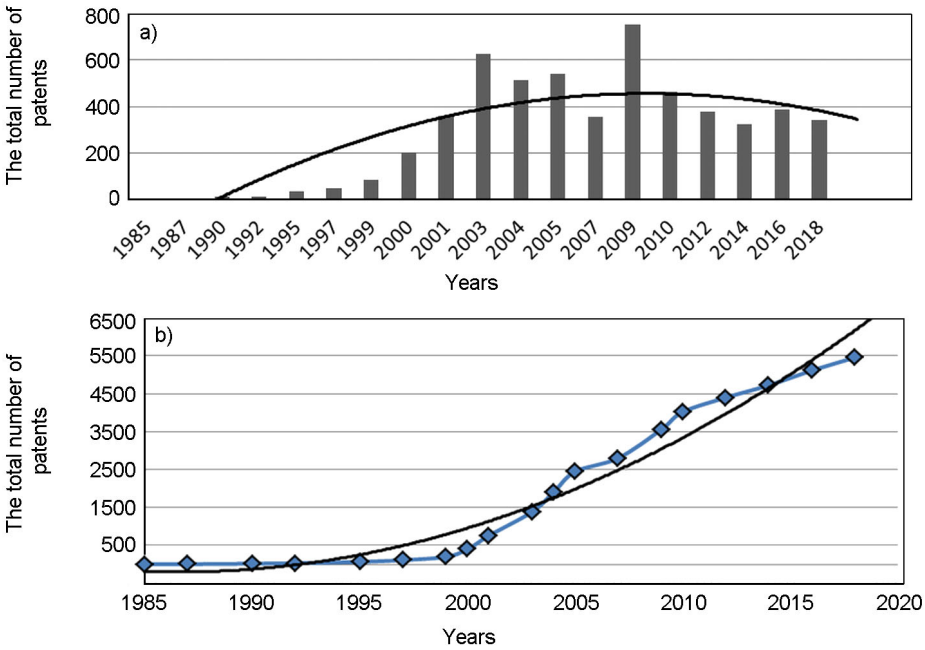

Fig. 5. The evaluation of the level of innovative of development for scintillation equipment of radiation monitoring (a). The accumulative value of the development for scintillation equipment of radiation monitoring (b).

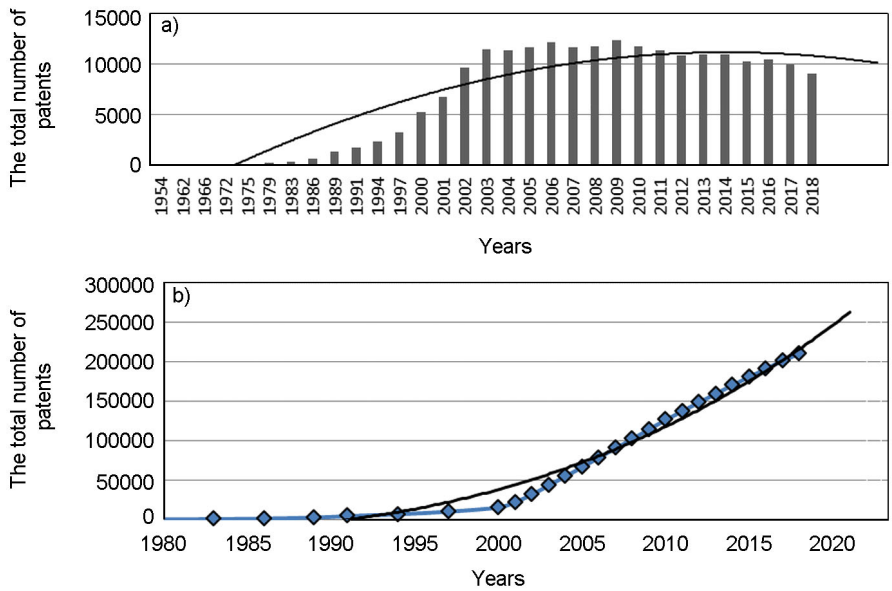

Fig. 6. The evaluation of the level of innovative of development for scintillation equipment (a). The accumulative value of the development for scintillation equipment (b).

A similar study to find dependences and predict the development of the scintillation equipment was also performed.

The obtained dependence of the number of world patents of scintillation materials over time shown on Fig. 6a is approximated by a polynomial of the second degree: $E(t) = -21.6t^2 + 1172.7t - 4710.3$, $R^2 = 0.85$. The accumulative value of the development of scintillation equipment is shown on Fig. 6b. It is approximated by a polynomial of the second degree $E_{ac}(t) = 1.7t^3 - 9917.4t^2 + 2\text{E}{+}07t - 1\text{E}{+}10$ where $R^2 = 0.98$.

It enabled to predict the overall development of scintillation equipment. Fig. 6a shows, the peak in the development of scintillation materials was between the years of 2003 to 2011. The conclusion is that there might be a slight decline in the activity of development of scintillation materials over the next two years with a probability of 0.85, but getting of 10,000 patents in the scintillation industry per year indicates that it remains innovative and will continue to evolve. Along with that, the method which evaluates the function of the accumulative value of the development of scintillation equipment allows to predict the development of this industry for the next three years with a probability of 0.98.

The conducted research of existing world patents enabled to allocate the main components of efficiency for scintillation equipment: economic, technical, social and ecological. For each of these components, dependences similarly to the previous research were obtained.

The energy resolution of the scintillation device makes a significant contribution to the technical component of innovation. Fig. 7a shows the dependence of the number of patents obtained between 1960 and 2018, which are aimed at increasing the efficiency in technical component of the scintillation technology. The given curve is approximated by a polynomial of the second degree: $E_t(t) = -0.01t^2 + 138.09t - 235867.5$, where the correlation coefficient is 0.92.

During the study of the economic component (Fig. 7b) in the scintillation equipment, the number of patents which are aimed at the price reduction of the scintillation device between 1971 and 2018 was considered. The given curve is approximated by a polynomial of the second degree: $E_e(t) = 2.16t^2 - 8514.5t + 8406136.7$ the correlation coefficient was 0.96.

To find the environmental component in scintillation equipment, the number of world patents between 1972 and 2017 which are aimed at the safety of the scintillation device was studied. The given curve (Fig. 7c) is approximated by a polynomial of the second degree: $E_{ec}(t) = 1.7t^2 - 6717.03t + 6627227.7$, the correlation coefficient was 0.97.

To find the social component in scintillation equipment, the number of world patents between 1973 and 2017 which are aimed at the reliability of the scintillation device was studied. The given curve (Fig. 7d) is approxi-

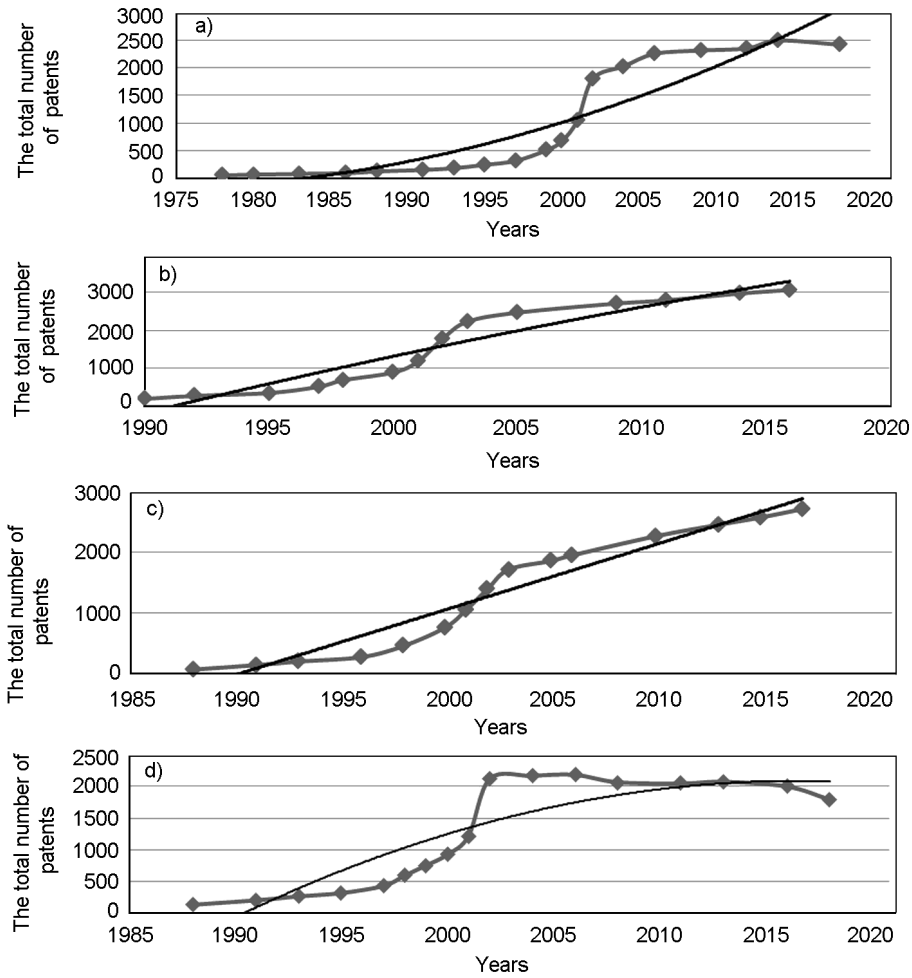

Fig. 7. The component of innovation: a) technical; b) economic; c) ecologic; d) social.

mated by a polynomial of the second degree $E_s(t) = -0.3t^2 + 1306.2t - 1377250$, the correlation coefficient was 0.87.

The industries where scintillation devices are used leave an imprint on effectiveness criteria of their usage. The main industries where scintillation equipment is being currently used are geology, dosimetry, high energy physics, medicine, radiation monitoring. The impact of various components of innovation — economic, technical, social and environmental on these industries of scintillation technology was obtained by Delphi method.

In the framework of this method, an expert survey was conducted, where the experts using the score method would fill in the coefficients for each application of the scintillation material, depending on the efficiency components, namely: technical, economic, social and environmental. The obtained weight coefficients were added up for each industry and should be equal to 1 (one). Seven people were acting as experts who are leading specialists in their relevant field, both in Ukraine and abroad. The results are presented in Table. The equivalent efficiency for each industry was estimated by identifying superpositions of innovation individual components for each industry.

3. Results and discussion

Taking into account the influence of individual components of efficiency, based on expert survey, and obtained efficiency dependence for different industries, a formula to determine the reduced equivalent effectiveness of innovation was built:

$$E_{in} = E_t(t) \cdot k_1 + E_e(t) \cdot k_2 + E_{ec}(t) \cdot k_3 + E_s(t) \cdot k_4, \quad (1)$$

By using the formula 1 and the values of the reduced equivalent innovation efficiency were obtained for each application:

Geology:

$E_{in} = 0.56t^2 - 2161.1t + 2064704.6$

Dosimetry:

Table. Results of expert estimation.

Components of innovation	The coefficients for each application depending on the efficiency components				
	Geology	Dosimetry	High Energy physics	Medicine	Radiation monitoring
Technical, k_1	0,6	0,3	0,5	0,6	0,5
Economic, k_2	0,2	0,3	0,3	0,1	0,2
Ecological, k_3	0,1	0,2	0,1	0,1	0,1
Social, k_4	0,1	0,2	0,1	0,2	0,2
Total	1	1	1	1	1

$E_{in} = 0.92t^2 - 3595.1t + 35001076.3$

High Energy physics:

$E_{in} = 0.79t^2 - 3026.4t + 2928905.1$

Medicine:

$E_{in} = 0.52t^2 - 1981.4t + 1886813.75$

Radiation monitoring:

$E_{in} = 0.74t^2 - 2846.6t + 2751014.2$

Dependency graphs of the reduced equivalent efficiency E_{in} for each application of scintillation technology on the time (Fig. 8) are shown below.

The following has been obtained during the research:

— dependency of reduced equivalent efficiency for each application of scintillation technology: geology, dosimetry, high energy physics, medicine, radiation monitoring;

— dependency of innovation process impact on the efficiency of the individual components of the scintillation technology: economic, technical, social and environmental;

— equations that describe these dependences, allowing to analytically predict the development of scintillation technology and its individual elements in the future.

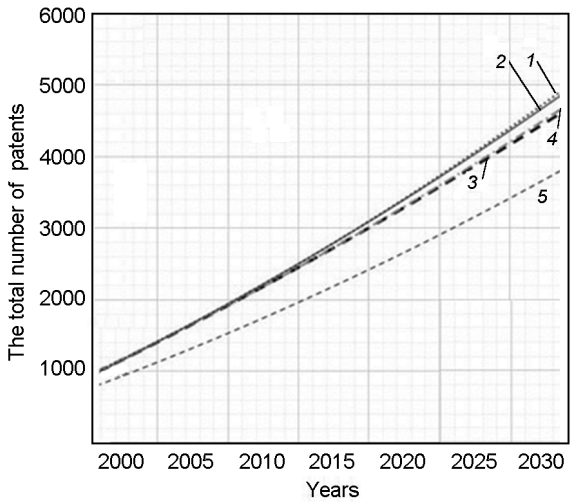

Fig. 8. Dependency graphs of the reduced equivalent efficiency for each application of scintillation technology on the time: *1* — radiation monitoring, *2* — high energy physics, *3* — medicine, *4* — geology, *5* — dosimetry. X axis — the total number of patents. Y axis — Years.

4. Conclusions

As a result of the performed research it can be concluded that the obtained dependences allow to develop an anticipatory standard aimed at determination of the parameters of scintillation equipment or it's certain applications, taking into account possible development of this equipment in the future.

It has important practical implications, because anticipatory standard can stimulate the innovation activities of the research institutes.

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