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DEPARTMENT OF PHYSICS

Methodical instructions to perform laboratory works

R1"INTRODUCTION TO THE BASICS OF RADIATION SAFETY"
and R6 "DOSIMETRY OF IONIZING RADIATION"

Brest 2014

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Methodical instructions to perform laboratory works R1"introduction to the basics of radiation safety" and R6 "Dosimetry of ionizing radiation". – Brest, BrSTU, 2014.

Methodical instructions drawn up in accordance with a model program of radiation safety course for engineering majors.

The guidance given necessary for explaining the principle of operation of devices and equipment used, describes a technique experiments, are tasks for independent work. Given control questions and a list of recommended reading.

Methodical instructions to carry out the laboratory work designed for foreign students BrGTU all technology sectors and forms of education.

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LABORATORY WORK R1

"INTRODUCTION TO THE BASICS OF RADIATION SAFETY"

1. GOAL

Studying the law of radioactive decay.

2. ORDER OF PERFORMANCE

1) In a radioactive substance with the decay constant **λ** and the half-life $T_{1/2}$ **k** is the proportion of decayed nuclei of their initial value decay for a time **t**. The average lifetime of a radioactive nucleus is **τ**. Find the unknown quantities, according to the number of your options in **Table 1**.Use the formulas**(1)**, **(2)**, **(3)** of the **THEORY** for your calculations.

Try all your calculations result in the same units as specified in the table (these values need to check on your computer).

2) The nucleus of the radioactive element having undergone a number of transformations, lost **n** αparticles and **m** βparticles and became the nucleus of another element. According to the version numbers in **Table 2**:

Write the general equation for α and βdecays. Find the resulting element if the source is known, or, conversely, get the original item, if known formed.

3. THEORY

3.1. The law of radioactive decay

Spontaneous decay of atomic nuclei is subject to radioactive decay law:

$$N = N_0 \cdot e^{-\lambda t}, \qquad (1)$$

in which $\mathbf{N_0}$ – the number of nuclei in a given volume of the substance at the initial time; **N** – the number of nuclei in the same volume at time t; $\boldsymbol{\lambda}$ – the decay constant (measured in [s^{-1}] and decay probability characterized of one nucleus in a second).

Then the number of decayed nuclei is given by $\mathbf{N_d = N_0 - N}$, and the proportion of decayed nuclei, respectively, $\mathbf{k = N_d/N_0}$. After some simple mathematical transformations can get the connection values **k,** $\boldsymbol{\lambda}$ and **t.** Make it your own.

To characterize the radioactive elements introduce the concept of half-life $\mathbf{T_{1/2}}$. Half-life is the time during which decays half initial amount of nuclei. The link between the half-life $\mathbf{T_{1/2}}$ and the radioactive decay constant $\boldsymbol{\lambda}$ is given by:

$$T_{1/2} = \frac{ln2}{\lambda} \qquad \textbf{(2)}$$

The reciprocal of the decay constant λ iscalled average lifetime of the radioactive nuclei $\boldsymbol{\tau}$:

$$\tau = \frac{1}{\lambda}. \qquad \textbf{(3)}$$

3.2. Alpha decay

Alpha decay is a type of radioactive decay in which an atomic nucleus emits helium nucleus ($_2\mathbf{He}^4$). The transformation of one element into another is as follows:

$$_ZX^A \rightarrow {}_{Z-2}Y^{A-4} + {}_2He^4$$

Alpha decays observed only in heavy nuclei, in which the charge number Z > 82. For example:

$$_{92}U^{238} \rightarrow {}_{90}Th^{234} + {}_2He^4.$$

Because of their relatively large mass, +2 electric charge and relatively low velocity, alpha particles are very likely to interact with other atoms and lose their energy. Their forward motion is effectively stopped within a few centimeters of air.

3.3. Types of radioactive decay with the emission of βparticle

Nuclei with proton number is less than the number of neutrons decay with the emission of a negatively charged β^-particle (electron $_{-1}e^0$), and the nuclei with neutron number is less than the number of protons decay with the emission of a positively charged β^+particle (positron $_{+1}e^0$). The positive charge of the positron is the electron charge, and its mass is the mass of an electron. The positron is the antiparticle of the electron.

Depending on the scheme β-decay be emitted neutrinos (ν) or antineutrinos ($\tilde{\nu}$). The neutrino is a neutral particle with negligible mass. Neutrinos are usually denoted $_0\nu^0$. Designation antineutrinos – $_0\tilde{\nu}^0$.

If $_ZX^A$ – nucleus undergoes decay and $_{Z'}Y^A$ – newly formed nucleus, the scheme β^-decay can be written as follows.

When β^-decay: $_ZX^A \rightarrow {}_{Z+1}Y^A + {}_{-1}\beta^0 + {}_0\tilde{\nu}^0$ nucleus is formed with the same mass number, but with a larger charge number.

When β^+decay: $_ZX^A \rightarrow {}_{Z-1}Y^A + {}_{+1}\beta^0 + {}_0\nu^0$new nucleus has the atomic number is one less.

Thus, knowing the reaction scheme and using the data table of isotopes can be determined element formed after disintegration. For example:

$$_{29}Cu^{66} \rightarrow {}_{30}Zn^{66} + {}_{-1}\beta^0 + {}_0\tilde{\nu}^0.$$

4. CONTROL QUESTIONS

1) Formulate the law of radioactive decay.
2) Which means the decay constant, the half-life, the average lifetime.
3) How to determine the proportion of decayed nuclei.

5. LITERATURE

1) Русаков К.И., Ракович Ю.П., Кушнер Т.И., Русакова З.В., Пинчук А.И. Радиационная безопасность. Конспект лекций и лабораторный практикум: Пособие. Брест: Издательство БрГТУ, 2012 – с.144.

Table 1.

Number	λ	$T_{1/2}$	t	k	τ
1	0.0546 s^{-1}	? s	10 s	? %	? s
2	? $year^{-1}$	? days	? days	26.2 %	65.8 days
3	0.0565 s^{-1}	? s	? s	36.36 %	? s
4	? $\cdot 10^{-3}$ $year^{-1}$	5.26years	4 year	? %	? years
5	?$\cdot 10^{-3}$ $year^{-1}$	86 years	? years	43.12 %	? years
6	?$\cdot 10^{-3}$ $year^{-1}$	? years	16 years	? %	25.4 years
7	? $year^{-1}$	? days	1 year	64.46 %	? days
8	0.3466 s^{-1}	? s	2.5 s	? %	? s
9	? $year^{-1}$	? days	? days	43.73 %	43.3 days
10	0.0433 s^{-1}	? s	? s	47.77 %	? s
11	?$\cdot 10^{-3}$ $year^{-1}$	5730years	3000 years	? %	? years
12	?$\cdot 10^{-3}$ $year^{-1}$	17.6 years	? years	44.62 %	? years
13	?$\cdot 10^{-3}$ $year^{-1}$	? years	10^4 years	? %	34625years
14	? $year^{-1}$	? days	100 days	43.75 %	? days
15	0.1318 s^{-1}	? s	5 s	? %	? s
16	?$\cdot 10^{-3}$ $year^{-1}$	? years	? years	51.71 %	5.5 years
17	$8.06 \cdot 10^3$ s^{-1}	?$\cdot 10^{-6}$s	?$\cdot 10^{-6}$ s	53.50 %	? 10^{-6} s
18	?$\cdot 10^{-3}$ $year^{-1}$	30 years	25 years	? %	? years
19	?$\cdot 10^{-3}$ $year^{-1}$	12.7years	? years	58.26 %	? years
20	? $year^{-1}$	? days	100 days	? %	105.3 days
21	? $year^{-1}$	? days	200 days	38.63 %	? years
22	0.2666 s^{-1}	? s	3 s	? %	? s
23	? $\cdot 10^{-3}$ $year^{-1}$	? years	? years	51.32 %	8266.6 years
24	0.025 s^{-1}	? s	? s	52.76 %	? s
25	?$\cdot 10^{-3}$ $year^{-1}$	16 years	20 years	? %	? years
26	?$\cdot 10^{-3}$ $year^{-1}$	2.6 years	? years	60.67 %	? years
27	? $year^{-1}$	? days	200 days	? %	238 days
28	? $year^{-1}$	? days	300 days	49.66 %	? years

Table2.

Number (variant)	The original nucleus	n	m	The product nucleus
1	$_{92}U^{238}$	1	2	?
2		3	2	?
3		5	2	?
4		6	3	?
5	?	5	4	$_{82}Pb^{206}$
6	?	2	4	
7	?	2	3	
8	?	1	2	
9	$_{90}Th^{232}$	1	2	?
10		3	2	?
11		5	2	?
12		5	3	?
13	?	6	3	$_{83}Bi^{209}$
14	?	4	3	
15	?	3	2	
16	?	1	2	
17	$_{92}U^{235}$	2	2	?
18		5	2	?
19		6	3	?
20		7	4	?
21	?	5	3	$_{82}Pb^{208}$
22	?	4	2	
23	?	3	2	
24	?	1	2	
25	$_{93}Np^{237}$	3	1	?
26		3	2	?
27		6	2	?
28		7	3	?

LABORATORY WORK **R6**

"DOSIMETRY OF IONIZING RADIATION"

1. GOAL

Studying of techniques for measuring the exposure dose by dosimeter and evaluation of other doses of radiation exposure.

2. INSTRUMENTS AND ACCESSORIES

Dosimeter РКСБ-104 РАДИАН.

3. INSTALLATION DESCRIPTION

Dosimeter РКСБ-104 РАДИАН is designed to monitor radiation situation on the ground, in houses and workplaces. It can function radiometer register gamma radiation with an energy in the range of 0.06÷1.25 MeV and beta radiation energy 0.5÷3 MeV. Detection of radiation occurs in two gas-discharge counters in parallel. Gas-discharge is converted into an electrical signal and transmitted to the pulse counter. The measurement results aredisplayed on a liquid crystal display indicator. The end of the measurement is accompanied by an audible signal.

For measurements:

1) slide the switch left white dosimeter in the up position;

2) put right white switch to the **«Раб»(«Norm»)**;

2) turn the red switch in the up position **«Вкл»(«On»)**;

3) wait for the sound of the completion of the measurement (about 30 seconds after switching on) and appearing in the lower right corner of the symbol **F**.

4) write the number (usually two digits) without standing in front of zeros. This number corresponds to the exposure dosage rate $\mathbf{P_{ex}}$ measured in μ**R/h** (micro-roentgen per hour).

4. ORDER OF PERFORMANCE

1) Measure exposure dosage rate of gamma radiation **P_i 7-10 times** by the dosimeter.

2) Determine the average value of the exposure dosage rate **P_{ex}** as follows:

$$P_{ex} = \frac{1}{n}\sum_{i=1}^{n} P_i ,$$

where n – the number of measurements.

3) Calculate the exposure dose X for the calendar year, using the formula:

$$X = P_{ex} \cdot t$$

At the same time, **t (year)** must be converted to **hours**. The resulting value **X** write to micro-roentgen(**μR/h**).

4) Calculate the absorbed dose **D** of external exposure to human tissue averaged over the year, using the following relations: **1 μR = 96.5·10^{-10}Gy.**

5) Calculate the dose equivalent **H** external exposure **in Sievert** for the averaged human tissue for the calendar year, using the formula:

$$H = D \cdot w_R ,$$

where D – the absorbed dose from external radiation; w_R – weighting factor corresponding to radiation or particles, for which the absorbed dose is determined. W_R ratio for gamma equal to 1 and alpha radiation – 20. Neutrons as a function of their energies correspond to the coefficients of 5 to 20.

6) Determine the external irradiation dose **E** for all organs and tissues listed in Table.1.The effective dose is determined by the formula:

$$E = H \cdot W_T ,$$

where H – equivalent dose of external radiation received by the body as a whole for year; W_T – tissue weighting factors. Use the data in 2008.

Table.1.

Organs	Tissue weighting factors		
	ICRP30(136) 1979	**ICRP60(13) 1991**	**ICRP103(16) 2008**
Gonads	0.25	0.20	0.08
Red Bone Marrow	0.12	0.12	0.12
Colon	-	0.12	0.12
Lung	0.12	0.12	0.12
Stomach	-	0.12	0.12
Breasts	0.15	0.05	0.12
Bladder	-	0.05	0.04
Liver	-	0.05	0.04
Oesophagus	-	0.05	0.04
Thyroid	0.03	0.05	0.04
Skin	-	0.01	0.01
Bone surface	0.03	0.01	0.01
Salivary glands	-	-	0.01
Brain	-	-	0.01
Remainder of body	0.30	0.05	0.12

7) Calculate the equivalent internal dose received by the Cs-137. For the calculations you can use the formula below, where $\mathbf{H_{in}}$ will be determined by substituting the values **mSv** exposure rate of $\mathbf{P_{ex}}$ in **μR/h**.

$$H_{in} = A_0 + A_1 \cdot P_{ex} + A_2 \cdot P_{ex}^2,$$

where $\mathbf{P_{ex}}$ - the average exposure rate in **μR/h;**

A_0, A_1 and A_2 - the coefficients are equal: $A_0 = 5.46 \cdot 10^{-2}$ mSv; $A_1 = 4.41 \cdot 10^{-2}$ mSv·h/μR; $A_2 = 3.15 \cdot 10^{-7}$ mSv·h²/μR².

Because of the smallness of the last term can be neglected. Thus, we obtain

$$H_{in} = A_0 + A_1 \cdot P_{ex} .$$

Constant A_0, A_1 and A_2 are determined based on the average European factors of radionuclides Cs-137 in the chain *soil → plants → animals* and secondary standards of nutrition in the year (milk - 332 kg, bread and cereals - 133 kg, vegetables - 37 kg, root vegetables and fruits - 118 kg, meat - 63 kg).

8) Calculate the total equivalent dose (external and internal), the average dose from natural and artificial sources of radiation. Make a conclusion about the background radiation in the area.

The total equivalent dose from natural and artificial sources of radiation on average **(2.3 ÷ 2.8)mSv/year**.

5. CONTROL QUESTIONS:

1) How to measure exposure dosage rate of gamma radiation by dosimeter.
2) How to calculate the radiation absorbed dose.
3) How to determine the equivalent internal dose received by the Cs-137.

6. LITERATURE

1) Русаков К.И., Ракович Ю.П., Кушнер Т.И., Русакова З.В., Пинчук А.И. Радиационная безопасность. Конспект лекций и лабораторный практикум: Пособие. Брест: Издательство БрГТУ, 2012 – с.

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