"The study of SaproSORB properties as a natural sorbent for radionuclide removal from the organism"

Report
on the applied research work performance under contract 0407.11 dated 04.05.2011
Abstract

The experiment on SaproSORB as a natural sorbent for radionuclide removal from the organism was conducted on laboratory mice in the special vivarium of the Department of Radiobiology.

4 groups of mice were gathered for the experiment, 7 mice in the group. The mice were similar in their age, sex and BW, one of the group was control.

All the groups were fed daily feed stuff impregnated in the working solution of ^{137} CsCl (100 BgmL).

The experimental groups were fed SaproSORB. The controls were treated the same, but they were not fed the preparation.

The mice were slaughtered to assess the effects of the preparation on the distribution and the removal of radiocaesium from mice. To detect the specific activity of the organs was used a radiometric device with software “Progress – 320”.

Results:

1. It is possible to use SaproSORB as the sorbent to remove radionuclides from the organism
2. SaproSORB has a high rate of radiocaesium removal from animals being fed with

radiocaesium together or even after the feeding ended.

3. Being fed with radiocesium together, SaproSORB decreases the distribution of radiocaesium in animals. SaproSORB removes radiocaesium from animals in two times faster if it is fed to animals after radiocaesium feeding ended.

Introduction

Caesium – 137 is with the half-life of 30 years the most widespread isotope today. After the Chernobyl disaster caesium contamination was the most large-scale. That is why the maps of the contaminated areas of Russia, Ukraine and Belorussia are based on the data of caesium – 137 concentration.

High concentration of radionuclides in mushrooms, barriers, fish and wildfowl, radioactive contamination of herbs and hay which feed cows which give milk are the main ways of radionuclide transfer to the food. It is possible to decrease the contamination of meat and milk using safe feed (hay) and feed additives (sorbents), and also through reducing the time of pasture.

The Chernobyl disaster has highlighted the principal problem of the XX century: the progress of science and technologies is more and more often associated with negative “aftereffects” of extensive and intensive exploitation of the nature – radionuclide contamination, transfer of heavy metal salts to the ground, water and atmosphere pollution. One of the topical problems in medicine is now seeking after effective means for prevention and pathogenetic therapy of radioactive affections of the organism. There is increasing quantity of those who undergo the effects of ionizing radiation and there are practically no effective antiradiation drugs.

The purpose: to study the efficiency of SaproSORB using as the sorbent for caesium – 137 removing from animals.

Problems:

- To detect the rate of caesium – 137 removal from the mice
- To study the evolution of accumulation and removal of caesium – 137 from the mice fed SaproSORB

Chapter 1. Literature review

1.1 Enterosorption

It is effective to use in diets feed additives which combine selectively radionuclides in the gastrointestinal tract of animals to decrease radiostrontium contamination of animal produce. Those additives are different substances capable of fixing radionuclides in the gastrointestinal tract. Though, the substances preventing radionuclides to be absorbed are called sorbents.

At present it is rather topical to search for optimum methods capable of general detoxification of organisms of animals to normalize the state of their health on the one hand and to tear the vicious circle of transition and cumulation of toxicants in “animal – animal produce – human” system.

The most adequate method for solution detoxification problems and the least traumatic is enterosorption method contained in peroral injection of some adsorbents – substances, which are capable of holding toxic chime components on their surface or in their crystalline structure. Fixed substances remove from the organism mixed with stool excepted from adsorption and circulation processes. In the opinion of many authors, enterosorption is the most physiological method which does not cause complications and considerable money costs. In the basis of enterosorption application lies the opportunity for radionuclides to move from the blood into the bowels being sorbed then and removed.

Shalimov S.A. and co-authors (1988) suppose that in the basis of enterosorption lies a few stages permitting to decrease the concentration of toxic substances and metabolites in the organism: combining toxic substances moving to the lumen of the intestine from the blood and prevention thereby their reabsorption.

The enterosorbent, except adsorption of intestine substances, extract them from the blood by means of osmosis and diffusion, evacuates the digestive juice carrying a considerable amount of toxins; changes lipid and amino acid spectrum of intestine contents; removes toxic substances in the intestine.

In the basis of modern classification of sorbents lies several principles: the structure, the nature of the material, the kind of interaction between the material and the sorbed substance.

Qualitative criterions for enterosorbents are their nontoxity, they do not harm mucous membranes, they provide a good evacuation of sorbent from the intestine, high sorption capacity, favorable effects or absence of effects on the secretion, etc. Enterosorbents are subdivided on origin (natural and artificial sorbents) and the range of actions (selective, which are capable of combining the fixed radionuclides and broad spectrum, combining a few radionuclides at a time).

Natural sorbents are clay, zeolites, bentonites, humolits, vermiculites and other.

Artificial sorbents are ferrocyanide agents.

The betweennes group contents the sorbents extracted and concentrated from the natural sources. First of all, they are alginic acid derivatives, obtained from seaweeds and also pectins obtained from vegetable products rich with these substances (apples, some alga species, etc), chitosan obtained from crab shell.

It should be noted that natural sorbents are not effective in ruminant animals as a rule, because of digestion peculiarities.

At present it is popular to use processing products of wood (lignin, cellulose, absorbed carbon) and minerals (alumosilicates, zeolites), etc.

Due to development of new sorbing materials a detailed rating of properties of the new enterosorbents tends to be especially topical today, as well as the analysis of the relief, and a possibility of fixing and removing the end products of metabolism. It should be noted that the question of effects of the digestive juice (saliva; gastric juice; pancreatic juice, etc.) on enterosorbents was never examined before.

The whole classes of enterosorbents were developed and introduced into the industry and medicinal practice. The following enterosorbents became popular in veterinary: medical lignin (polyphepan), absorbent coal, chitin and chitosan, alumosilicates – kaolin, enterosorbent-B, etc.

Each adsorbent has a row of unique properties depending on its chemical nature. Adsorption properties of sorbents depend on the developed porous structure with active surface, which is capable of holding gases, vapor, liquids or dissolved substances.

There is a classification by M.M Dubibin and co-authors, according to which absorbent coals are adsorbents, containing pores of all types; zeolites are micro porous, alumosilicates are meso-macroporous and adsorbents on basis of cellulose are macroporous. The role of macro pores (K > 200 nm) in adsorption processes increases with an examination of fixing of microorganisms, viruses and other particles on adsorbents.

Thereby, Russian and foreign literature have rather broad theoretical and experimental experience in the questions of application of different kinds of adsorbents in enterosorption practice in veterinary and medical practice. Negative effects of adsorbents show generally in prolonged enterosorption courses. It may cause unbalancing of mineral substances and microelements, the content of the other nutrients (protein, lipids, carbohydrates, vitamins, ferments) may tend to decrease. Particularly, the usage of high hydrophilic enterosorbents may cause intestinal stasis. It is necessary to take these facts into account prescribing enterosorption medicines to animals, or prescribing efficient treatment terms or improving diets with additional nutrients. The analysis of medicinal and preventive effects of enterosorption method as the easiest way for sorbtion detoxification of the organism and its usage in veterinary predicts a promising future to it.

1.2 Radionuclide intakes of animals

Radioactive substances may pass into the organism of an animal through the lungs by inhaling polluted air; through the digestive system with feed and water, containing radioactive substances; through intact skin, mucous membranes and wounds.

The type of distribution of radionuclides in the organism depends on the main chemical properties of an element, the form of the injected compound, the way it passes through and the physiological state of the organism.

The type of adsorption of radioactive substances in the organism of an animal depends on many factors: the way of the intake, physicochemical properties of radionuclides, species, age and physiological state and etc.

The most significant place of active adsorption is the gastrointestinal tract, and lungs, if substances pass through them.

Monogastric animals have a higher rate of resorption than animals with multi-chambered stomach.

Absorbed into blood radioactive isotopes take part in metabolism as well as stable isotopes of the element.

The heavier is an animal, the slower is the procession of radionuclide absorption.
Warm-blooded animals have higher rates of metabolism to compensate warmth losses as a result of the increasing relative body surface.

Growing animals have higher rates of radionuclide absorption than the adults. Age is the main factor, which changes the rate of gastrointestinal absorption. New-born animals have several times higher rates of radionuclide absorption.

The rate of absorption considerably depends on the quantity of taken substances. The more quantity comes in, the smaller percent will be absorbed.

The efficiency of radionuclide absorption depends also on the species of the taken substances. Strontium, barium, radium and other elements contained in the milk diet increase (twice) the absorption, what can be caused by the presence of lactose and lysine in milk.

1.3 □□□□□□□ Stable caesium

Stable caesium was discovered in 1860 by R. V. Bunsen and G. R. Kirchhoff. The chemists found the metal through a spectroscopic analysis of *mineral water* from *Durkheim*, Germany. Cs (lat. caesius – sky-blue) by two bright lines in the blue part of the spectrum. Metal Cs was eventually isolated by the Swedish chemist Carl Setterberg. In 1882, he produced caesium metal by electrolyzing a liquefied mixture of CsCN and Ba.

Caesium is a chemical element with symbol Cs and atomic number 55. It is a soft, silvery-gold alkali metal. Natural caesium consists of the one stable isotope – 133Cs. There are 23 radioactive isotopes with the mass number 123-132 and 134-144.

Radioactive caesium isotopes are produced from nuclear fission in a nuclear reactor or in a nuclear explosion and also in a particle accelerator. Radioactive explosions and radiation accidents caused the main part of environmental radiation contamination.

Radioactive caesium isotopes fallout on the land in nuclear weapon tests and nuclear fallouts are the main source of pollution and radioactive effects performed on humans.

Cs is of particular importance as it has high fission yields and a half-life about 30 years, high migration capability and toxicity. It is one of the main radionuclides of radioactive fission products.

There were hundreds of radiation accidents, but only some of them caused nuclear pollution. A mistake in the operation of the nuclear reactor in Windscale (1957) caused fuel overheating and a three-day fire. There were released 12 PBq of radionuclides in the surrounding area including

^{131}I – 740 TBq,

^{137}Cs - 44 TBq,

^{106}Ru - 12TBq. The Chernobyl accident (1986) was the biggest radioactive accident. There were released 1.85 EBq of radionuclides. Radioactive caesium-137 was released in the amount of 270 PBq. The special feature of the Chernobyl accident is extremely heterogeneous contamination caused by 10 days of radionuclide release and changed weather (precipitations and changed wind directions).

There were two huge accidents in the Urals. From 1949 to 1959 there had been dumped radioactive waste from “Mayak” factory into the water of Techa River. 102 PBq of radionuclides had been dumped including 12.4 PBq of ^{137}Cs. In 1951 the levels of ^{90}Sr and ^{137}Cs and ^{89}Sr in the Upper Techa exceeded the permissible levels two or three thousand times and 100 times, respectively. There was another accident in Kyshtym in 1957 when radionuclides with the total activity of 74 PBq (2 MKu) were released in the surrounding area, including ^{137}Cs. 15000 km^2 were contaminated.

Thus, ^{137}Cs contamination was of a global nature. The territories of the former USSR and also the whole Northern Hemisphere were contaminated after the Chernobyl accident. The other accidents caused generally only a local contamination.

1.4 Intakes and behaviors in the body

Radioactive caesium is the main source of the external and internal explosion of the body. Each human has radiocaesium in different quantities. Adsorption, accumulation in the organs and tissues, its removal from the organism are caused by its physicochemical data. The absorption of the soluble forms of the radionuclide reaches almost 100%. Adsorption process is intensive. Radiocaesium was detected in blood after a few minutes of the intake. Intact skin doesn`t adsorb the nuclide (0.007%). Injured and burn skin, wounds absorb caesium very active.

After a peroral intake of caesium it secrets into the intestine and then reabsorbs in the descending intestine. Reabsorption rate differs in different animals.

A human breathes in 0.25% of the taken with food caesium. Caesium distributes rapidly through organs and tissues. Muscle caesim content is higher than in any other organ during the period of the establishment of a dynamic equilibrium.

Animal tests proved that during this period critical organs are gonads and marrow. The concentration of ^{137}Cs in the gonads of dogs is 2-2.5 times lower than it is in muscles.

1.5 Cs toxicity

Radioactive caesium was the major dose contributor of irradiation of population in nuclear tests and radiation accidents. The expected irradiation dose of the world population after nuclear tests is 540 Sv, and the collective dose is $220*10^4$ person-Sv. Irradiation doses in the local radiation releases were much larger. There was observed an acute radiation syndrome in a number of cases.

Radiocaesium uniformly radiates organs and tissues due to high penetrating power of gamma-quanta of its daughter nuclide ^{137m}Ba (E_{γ} = 0,662 MeV), which is about 12 cm. Uniform distribution of the radionuclide in an adult person with the specific activity of 1 Bq / (kg of the BW) causes from 2.14 to 3.16 mcg/year (average 24 mcg/year) of the absorbed dose. That is why ^{137}Cs biological efficiency of external and internal exposure is practically the same.

Caesium in living organisms is a permanent chemical element of plants and animals.

Radioactive caesium is highly toxic substance practically independent of nuclide intake. Biological radiocaesium effects is rather good examined on different animals. Rats have acute (SD $_{50/30}$), subacute and chronic affections after nuclide injection of $8*10^5$; $6,5*10^5$ and $3,7*10^5$ Bq/ g. Highly effective doses caused the rats` death in 2-3 weeks by the moment they had 30g in their organisms.

The decease had a lot of common with the acute radiation syndrome with an external γ-irradiation. The decease caused depression, weakness, BW losses, diarrhea, haemorrhage of the subcutaneous tissue and internal organs. At the quantity of $7,8 – 12,6*10^4$ Bq ^{137}Cs it does not effect on the rat lifetime.

Dogs need doses 5-6 times less. It is enough to cause a radioactive syndrome of a human after 2 or 3 times less dose, compared to dogs. Mild moderate and severe radioactive exposures are expected after the intake of 148, 370 and 740 MBq/organism. Absorbed doses may be 2.5 and more Gy.

1.6 Radionuclide removal from the living organism

The problem of radionuclide removal became of a great importance after the Chernobyl accident. A complete restoration takes a lot of time, so it is necessary to adapt to the life in radioactive area and try to make the life conditions the safest.

It is necessary to limit radionuclide intake with food and take measures to remove radionuclides from the organism.

Sorbents decrease radiation contamination of animal produce. They selectively bound radionuclides in the GIT.

Sorbents are subdivided by the origin (natural and artificial sorbents) and by the effect (selective and broadspectrum). Natural sorbents are clay, zeolites, bentonites, vermiculite and other. Artificial sorbents are ferrocyanide-containing elements.

^{137}Cs removal is generally performed through kidneys. In the first month urine removes in 6-8 times more than faeces. After a single intake of ^{137}Cs urine and faeces remove in average 0.57% of the whole radionuclide content in the organism. In the case of chronic intakes urine and faeces remove ^{137}Cs permanently.

1.7 Biological effects of ^{137}Cs

Caesium isotopes join in biological rotation and migrate through different biological chains. At present ^{137}Cs is to be found in animals and humans. It should be noted, that human and animal organisms contain stable caesium at 0.002 to 0.6 mkg per 1 g of the soft tissue.

Absorption of ^{137}Cs in animal and human GIT is 100%. There are different rates of caesiuim absorption in different parts of the GIT. In an hour after caesium injection 7% of ^{137}Cs absorbs the intestine, 77% absorbs the duodenum, 76% absorbs jejunum, 78% - ileum, blind gut absorbs 13%, transverse colon absorbs 39% of the injected dose.

A human breathes in 0.25% of the taken with food caesium. After a peroral intake of caesium it secrets into the intestine and then reabsorbs in the descending intestine. Reabsorption rate differs in different animals.

L.A. Buldakov and G.K. Korolev suppose that the main accumulation of caesium isotopes is mainly performed in muscles. According to U.N. Moscalev, ^{137}Cs removes rapidly from the blood after an intravenous injection. In the first 10-30 minutes the maximum concentration of caesium is performed in kidneys (7-10% per 1 g of the tissue). Then it redistributes and the main quantities – 52.2% - stay in muscles.

Chapter 2. Own research

2.1 Materials and methods, the research design

The research on SaproSORB efficiency as an enterosorbent was conducted in the Department of Radiobiology and Biophysics.

There were gathered groups of 7 mice similar in the BW and the age; one group was control.

All the groups were fed the feed stuff impregnated with the working solution of $^{137}CsCl$ (100Bk/mL).

Each group was fed SaproSORB. The controls were treated the same but were not fed the sorbent.

The mice for gamma-spectrometric analysis were slaughtered on the 1, 3, 7, 9 day. Table 1 shows the design of the experiment.

Table 1

Group	Caesium-137 (100Bk) per day	SaproSORB (250mg / 1kg of the feed)
1	Feeding caesium-137 during 14 days	Was not given
2	Feeding caesium-137 in the first part of the experiment	The feed was given in the second part of th
3	Feeding caesium-137 in the second part of the experiment	SaproSORB was given in the second part
4	Feeding caesium-137 during 14 days	SaproSORB was given during 14 days

2.2 Facts about the preparation under consideration

SaproSORB and its derivatives is a mineral substance of the natural origin. It is generated on the bottom of water basins from organic remains. It is used in medicine and cosmetology in the form of a medical mud, in agriculture in the form of a fertilizer and a feed additive for many species of livestock.

Average content of organic substances: (% of the dry substance)

Crude protein – 6.0 %

Fat – 0.19 %

Ashes – 50%

Phosphorus – 0.1%

Calcium – 0.8%

2.3 Feed with a radiation label

The cooked feed stuff was grinded into powder. The grinded feed stuff was weighed in the Petri dishes calculating 5 g per one mouse multiplied by the quantity of the mice in the group. Then there was cooked feed from the grinded weighed feed stuff. We added water, mixed it all together and made briquettes. The feed was dried in the thermostat. After the feed had been cooked we added a radioactive tracer calculating 0.5 mL per 1g of the feed. Then the feed was dried at a draught and given to the mice.

2.4 Feed with preparations

The grinded feed stuff foe each group was weighed in the Petri dish calculating 5f per a mouse. Then the necessary dosages of preparations (powder, if necessary) were mixed properly. We added water to the mixture and mixed it, then made briquettes. The feed was dried then and given to a group once day at the same time. The feed was cooked every day.

2.5 Gamma-spectrometric method

We used a gamma-spectrometric tract with a scintillation detection unit (DB) to register gamma radiation of the counting sample. It contains a scintillator (NaI (TI) crystal), a photomultiplier tube with high voltage divider and impulse amplification block. The DB lies in a protective lead case with wall thickness of 50 mm to protect it from the external gamma radiation. We used an Analogue-toDigital converter (ADC) to convert the analogue spectrometric signal from the detector output to digital. It is made in a form of a built-in a PC card. Control of the ADC spectrum processing and calculations of errors and activities are performed on a PC using “Progress 3.2” software package.

Technical data

Crystal size	63x 63 mm

Energy range, MeV	0.03 - 3.0
Basic error of measurement, %, not more	30
Standard time of exposure of the sample counting	1800 sec

Features of the software package “Progress 3.2”

- Automatic calculation of the density of the calculating sample
- Automatic calculation of errors
- The possibility of placing the results in a database

The measurement method of the calculating samples

- Switching on and heating the equipment for 30 min
- Automatic energy calibration of gamma-spectrometric tract of the tops of the peaks of the total absorption of Cs-137 and K-40 radionuclides in the spectrum of two-component calibration source for 150 sec
- Gamma-background measurement
- Direct measurement of the calculating sample for 1800 sec

2.6 Calculating method

1. The calculation of radiocaesium absorption from the mice

$100 - A/A_0 * 100$

A – activity of a mouse (Bk) during the last 24 hours of the experiment

A_0 – activity of a mouse (Bk) right after the feeding

2.7 Statistical analysis of the result

The statistical analysis of the results was made through EXEL. For the indexes, received by reiteration of the same measuring were calculated mean values and mean-square declinations of the mean using the formula

$$\mathbf{M = \sum x_i / n}$$

где x_i – отдельные значения измеряемых показателей

$$\mathbf{m = \sqrt{\sum (x_i - x_i) / n (n - 1)}}$$

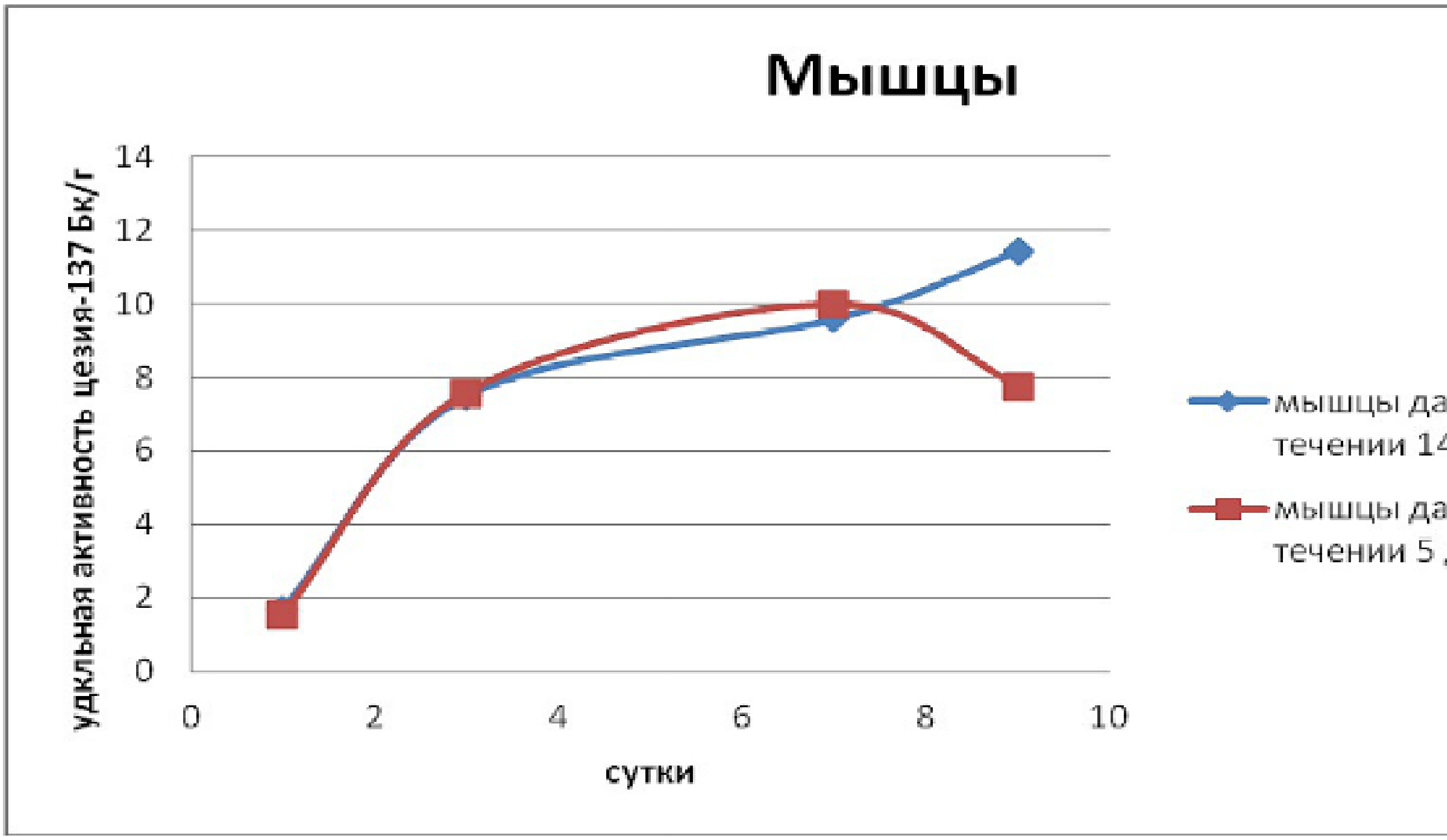
Затем для этих значений рассчитывали доверительный интервал по формуле: $\boldsymbol{\alpha = 0.5 * (M \pm t * m / \sqrt{n})}$

Chapter 3. The results and discussion of the own study

3.1 The evolution of accumulation and removal of cesium -137

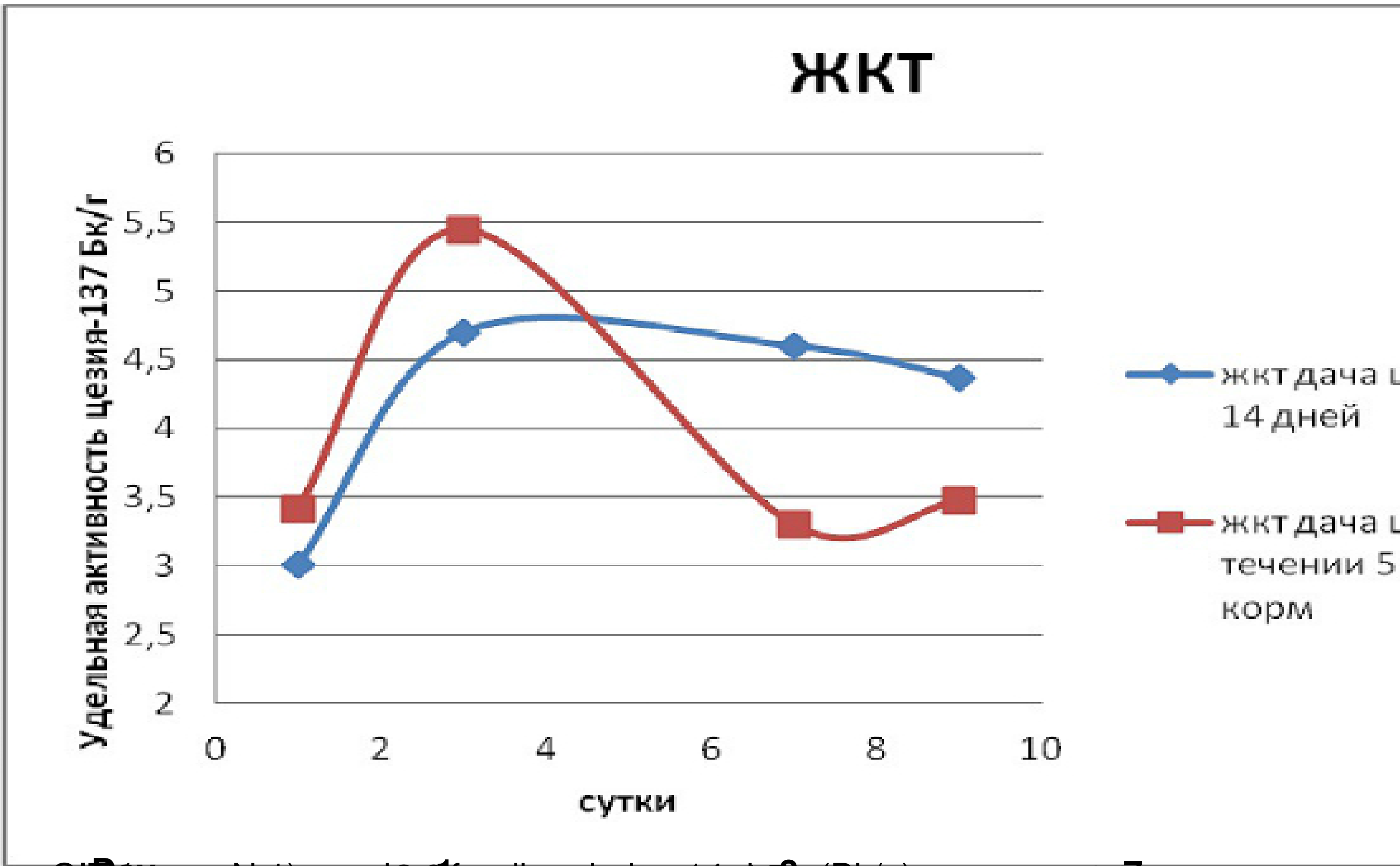
Group 2. Caesium-137 during 7 days, then the feed.

Muscles

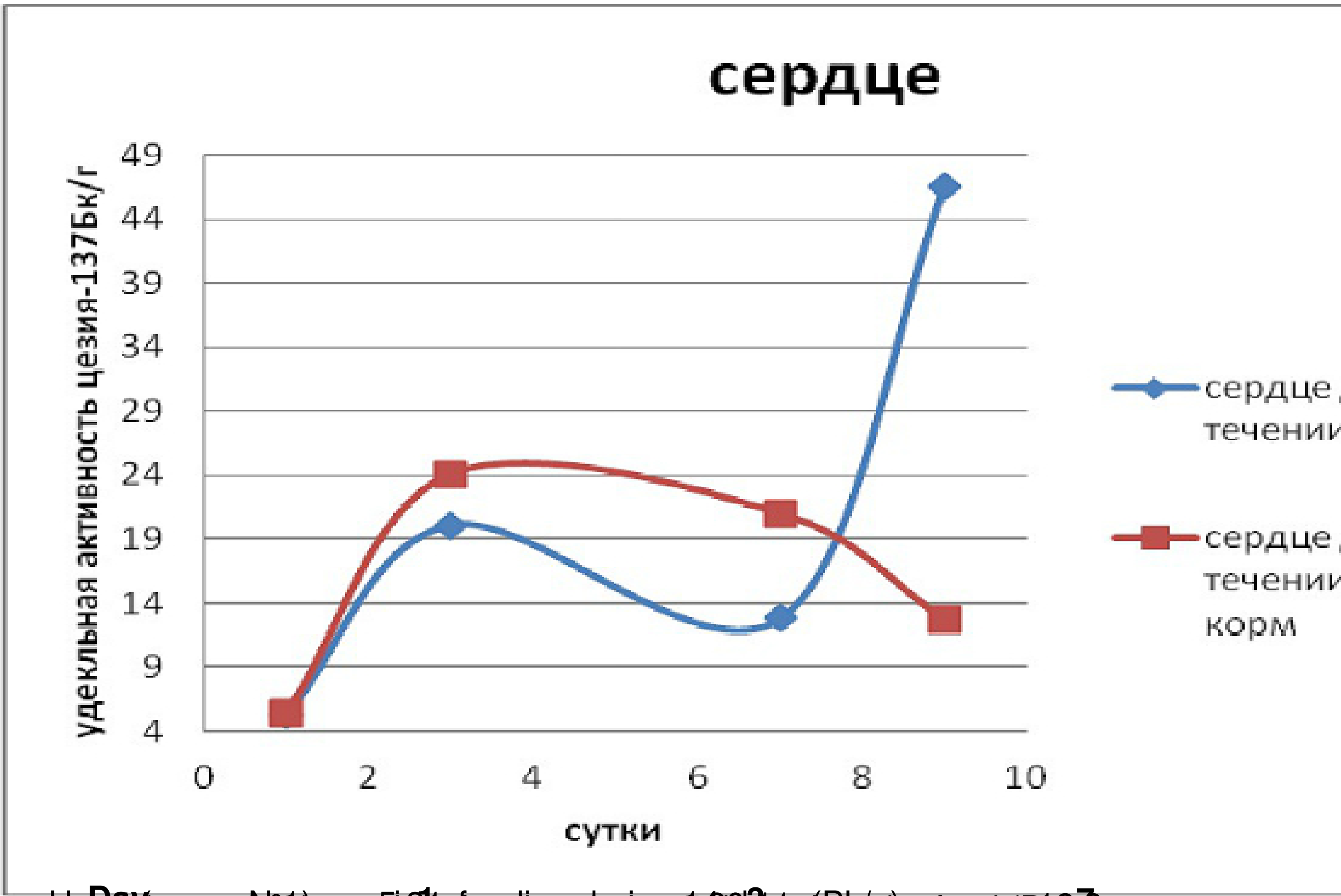


Day	1	3	7
Muscles (group №1) caesium feeding during 14 days (Bk/g)	1.7	7.5	9.6
Muscles (group №2) caesium feeding during 5 days, then the feed (Bk/g)	1.53	7.57	9.97

GIT



Heart
GIT
Day
(group №1) caesium feeding during 14 days (Bk/g)
(group №2) caesium feeding during 5 days, then the feed (Bk/g)


сердце
удекльная активность цезия-137Бк/г
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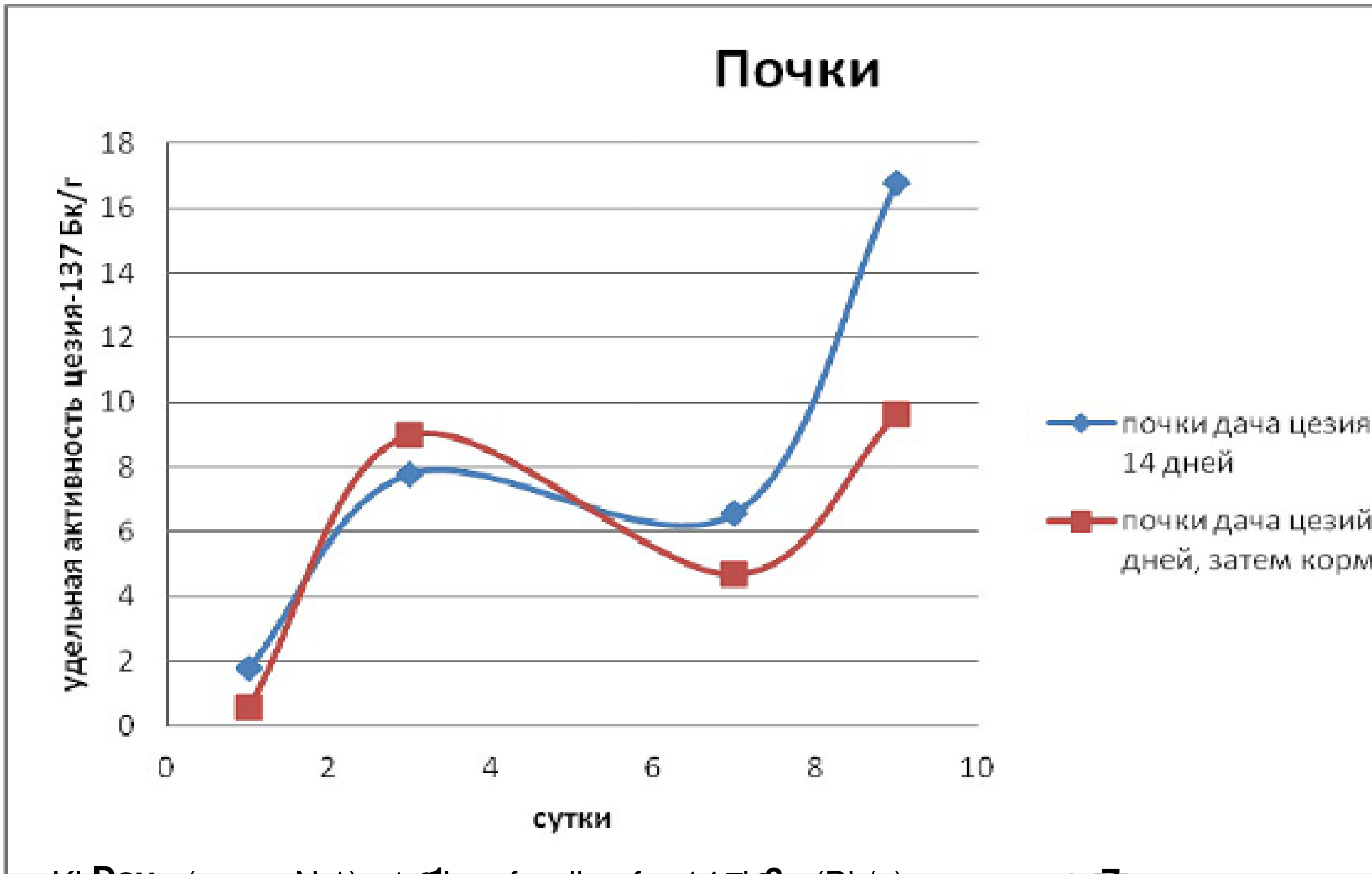
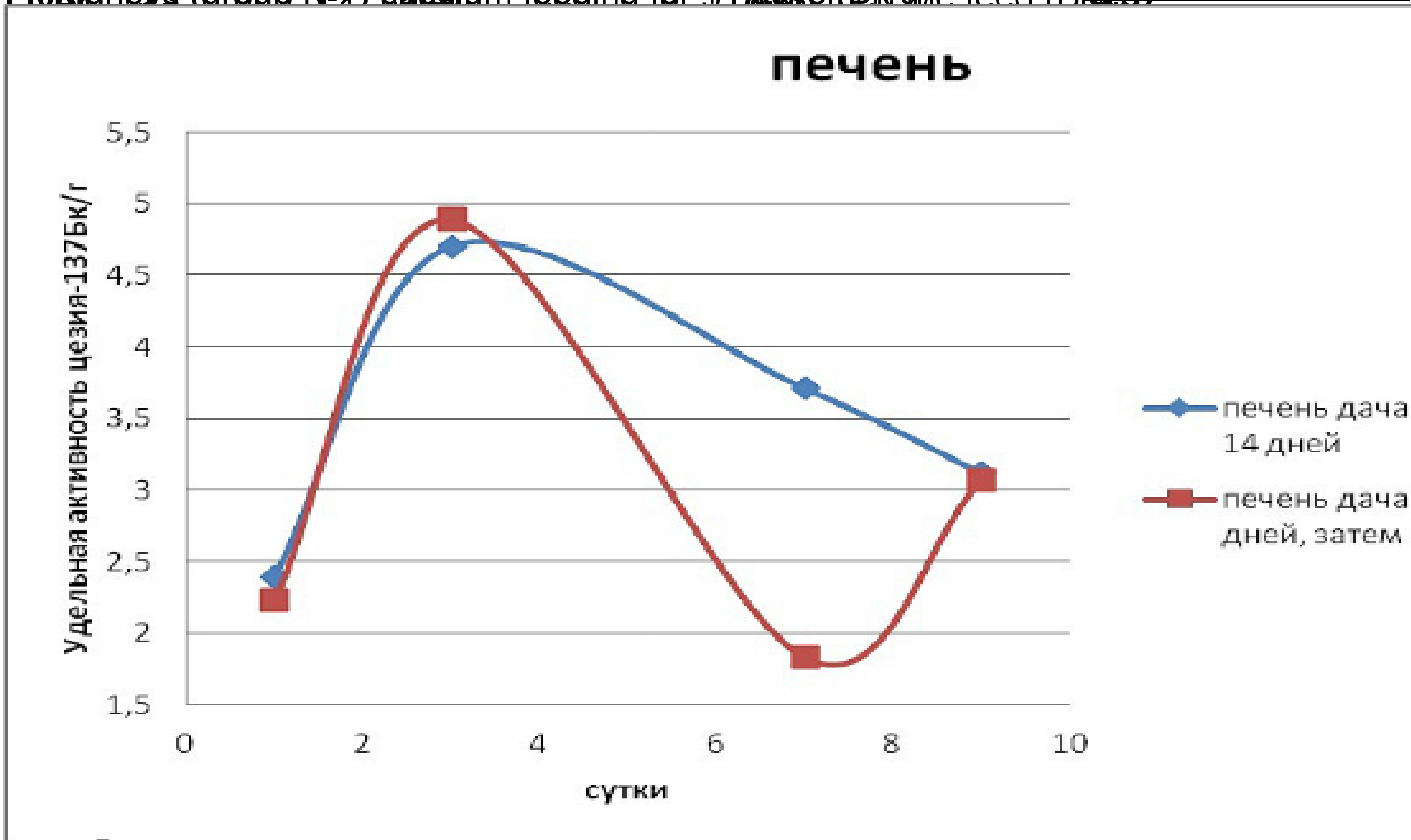
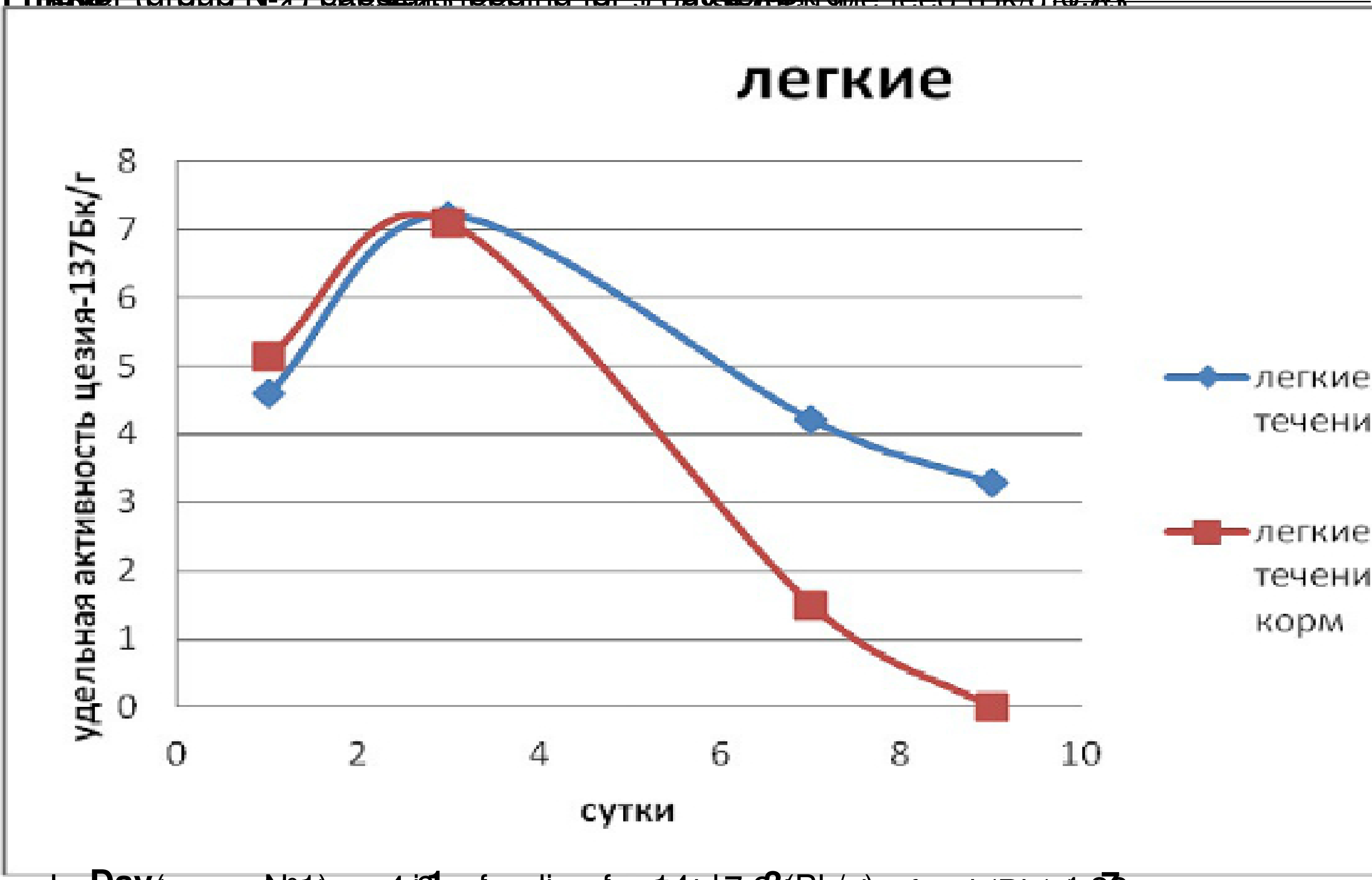


Kidneys (group №1) caesium feeding for 14 days (Bk/g)
Kidneys (group №2) caesium feeding for 5 days then the feed (Bk/g)
Day 1 3 7 9 6.57



Day


легкие
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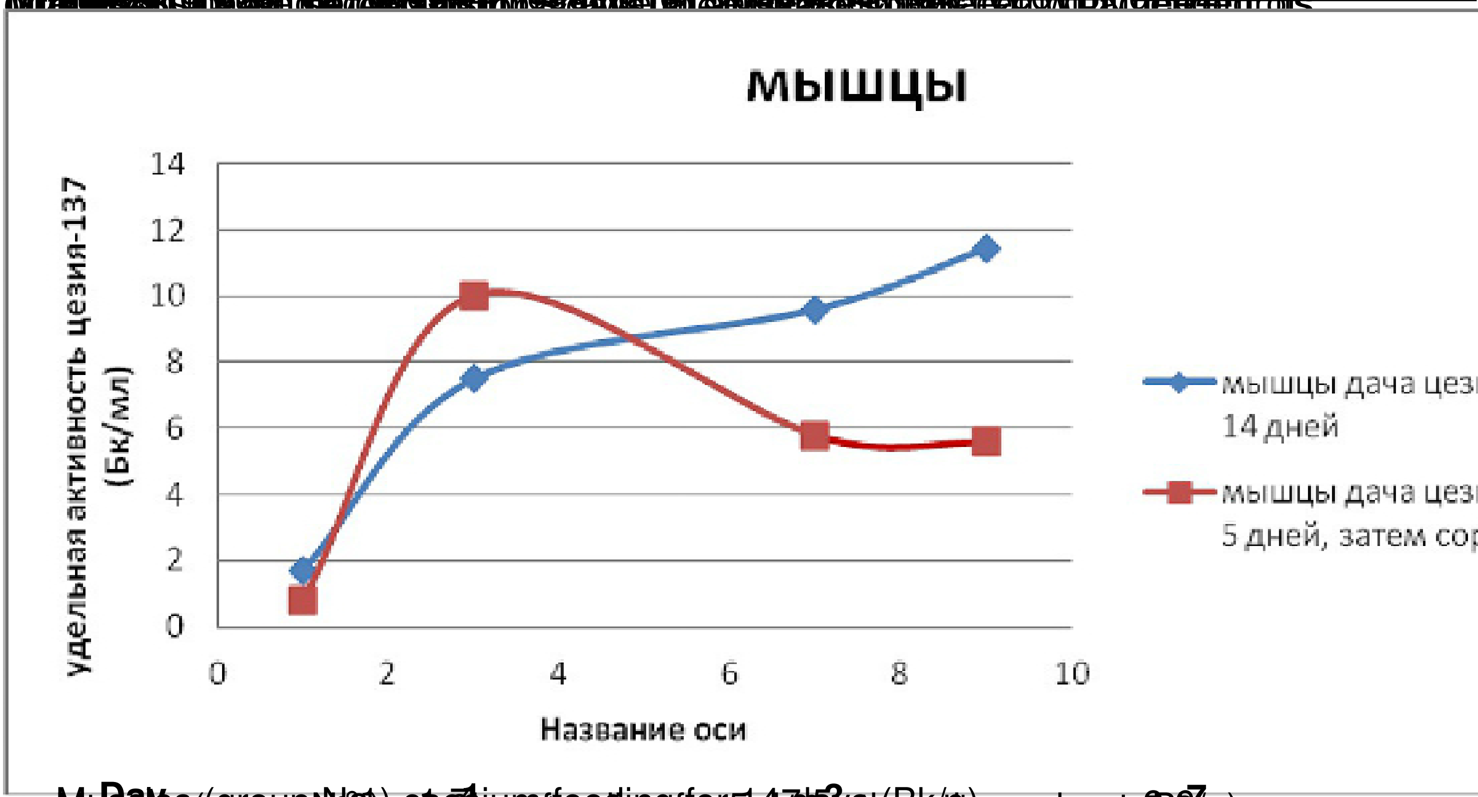
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(Бк/мл)
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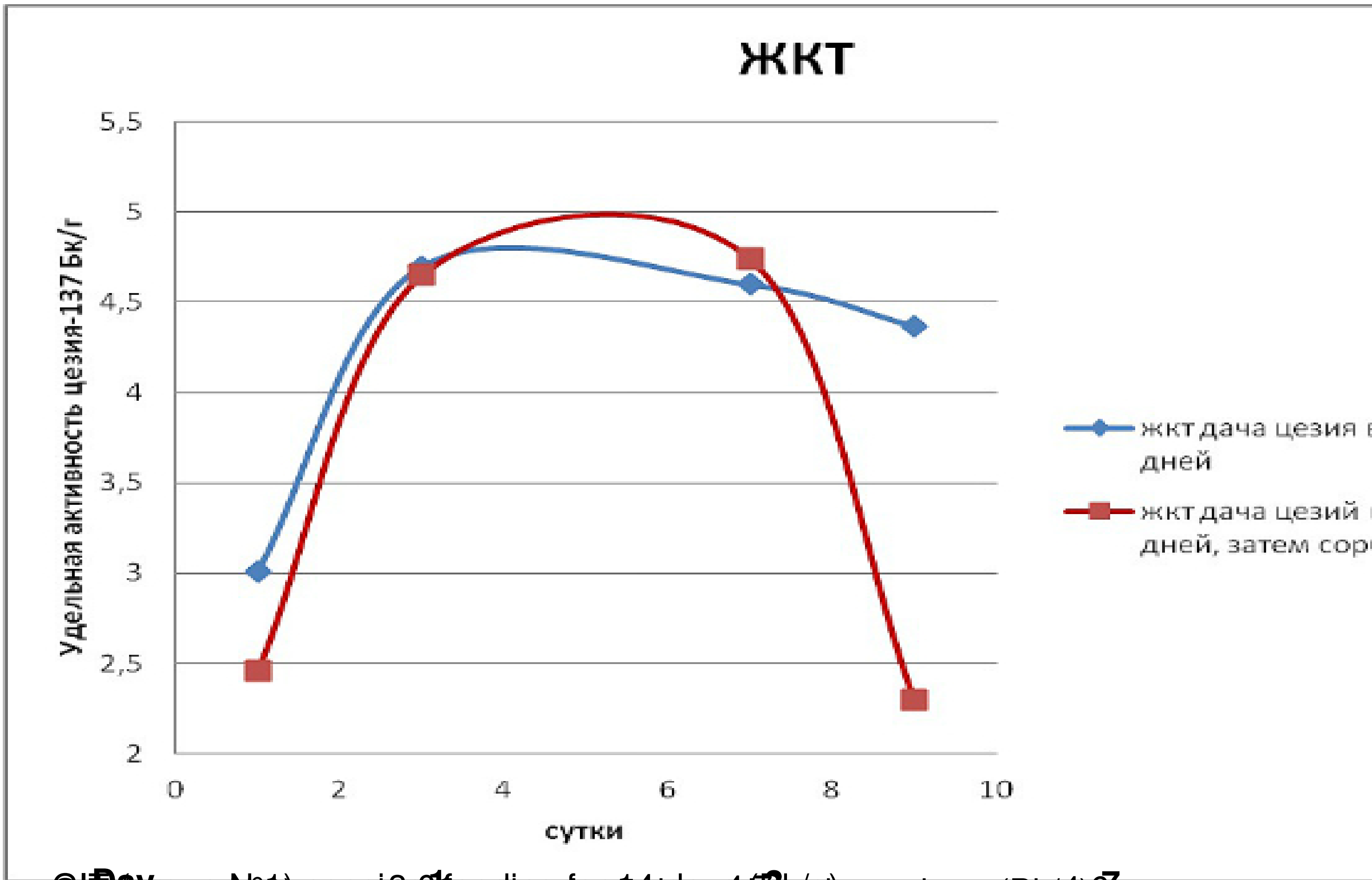
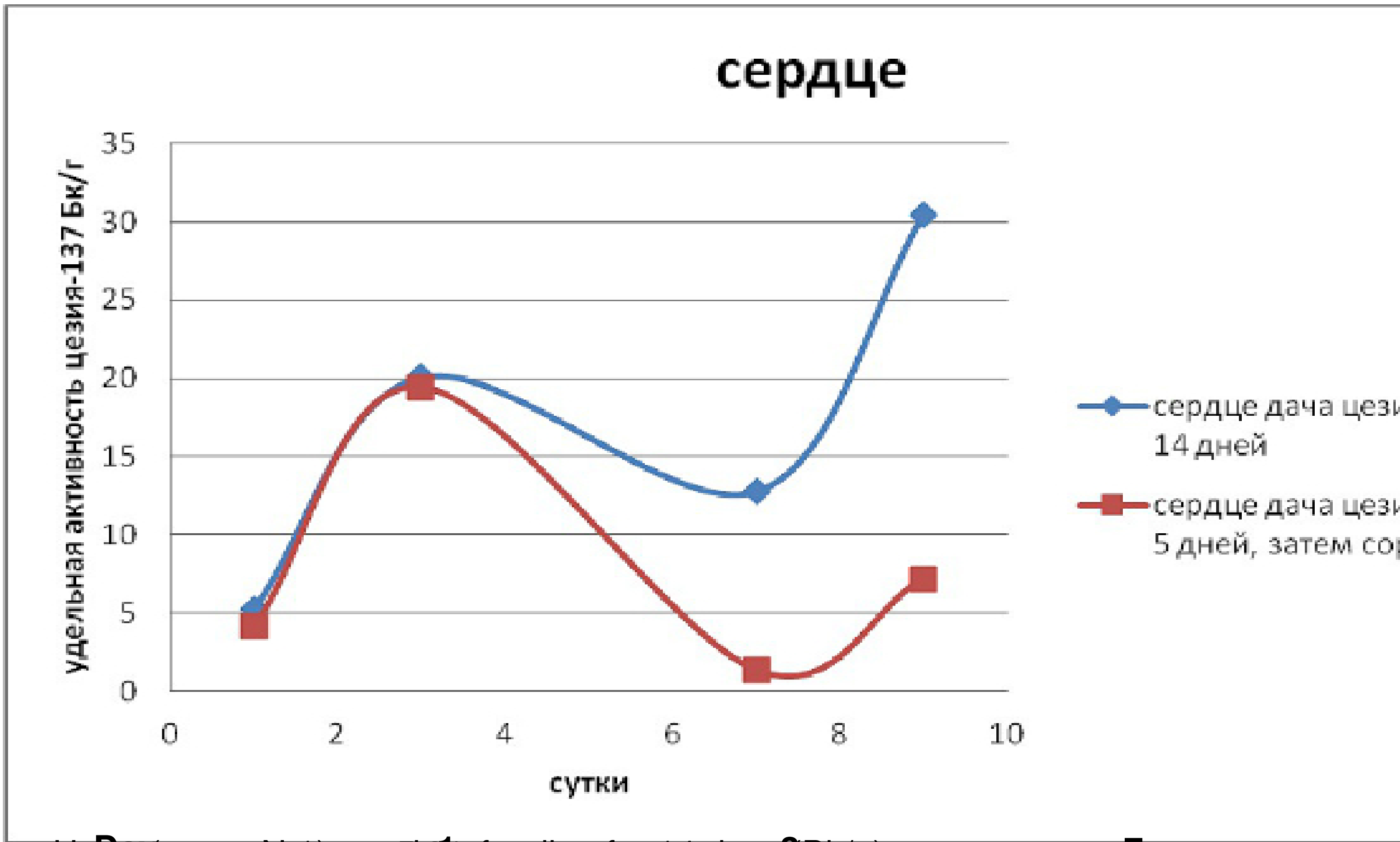


Heart

Day 1 3 7

GIT (group №1) caesium feeding for 14 days (Bk/g)

GIT (group №3) caesium feeding for 5 days, then the sorbent (Bk/g) 2.46 4.63 4.74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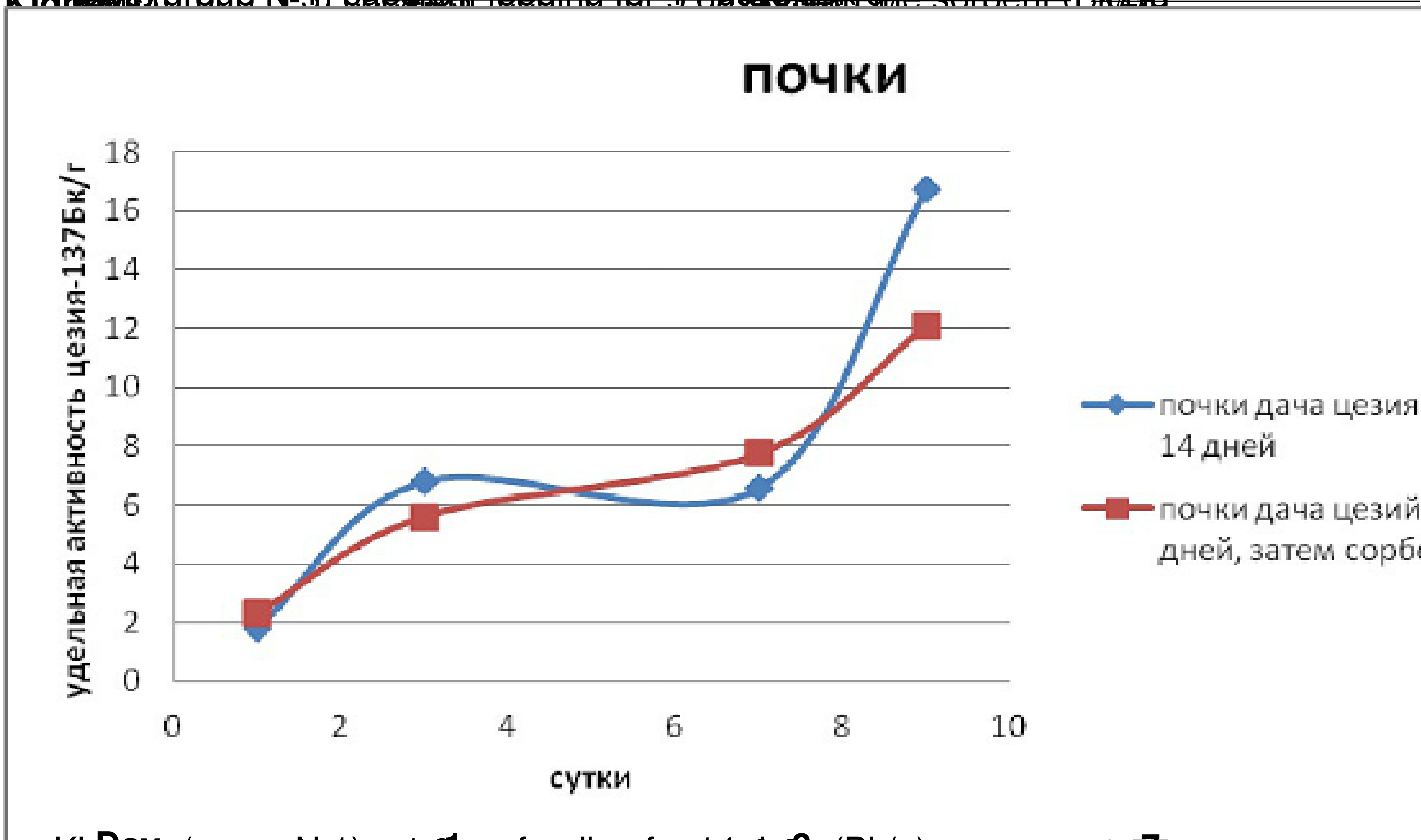
5 дней, затем сор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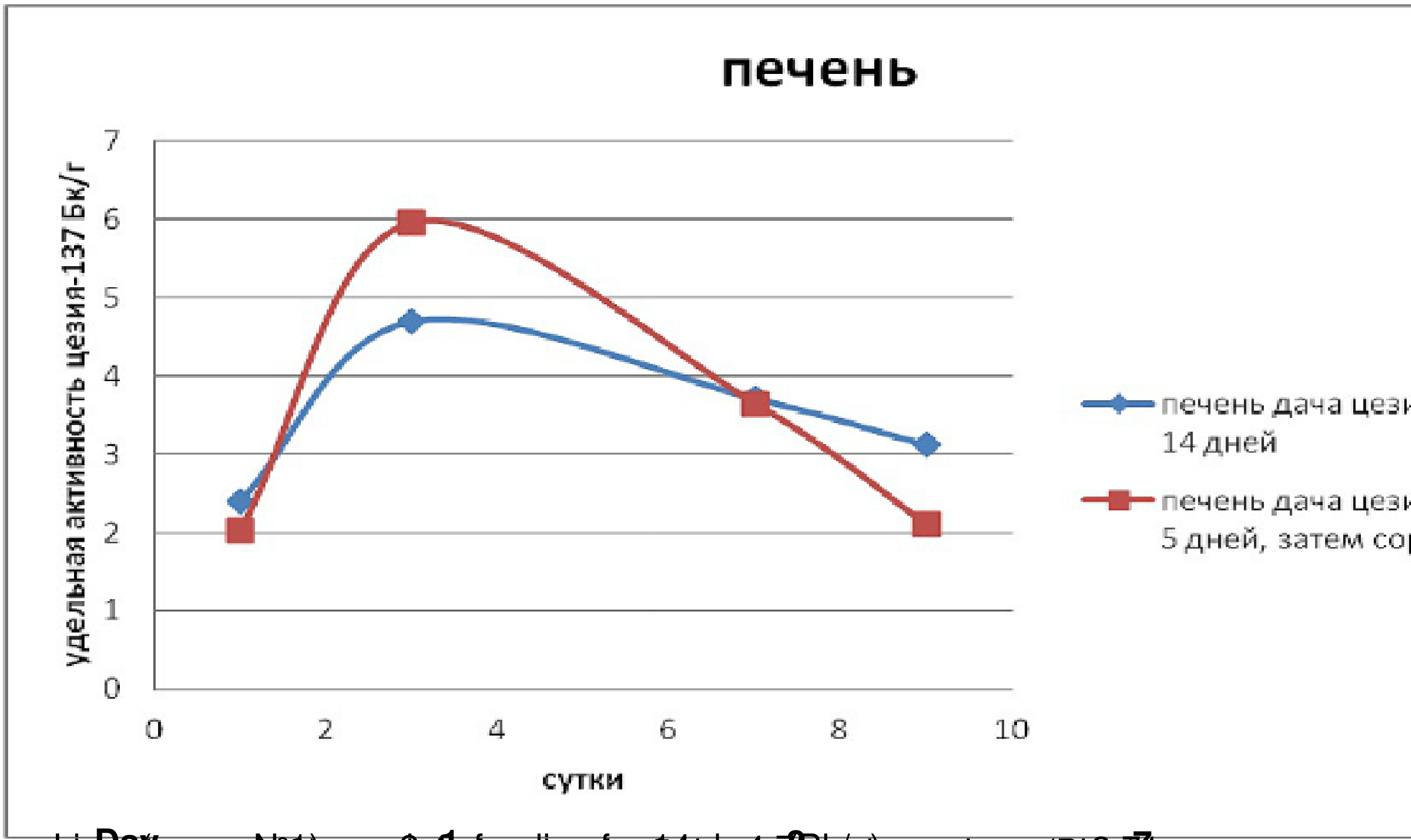
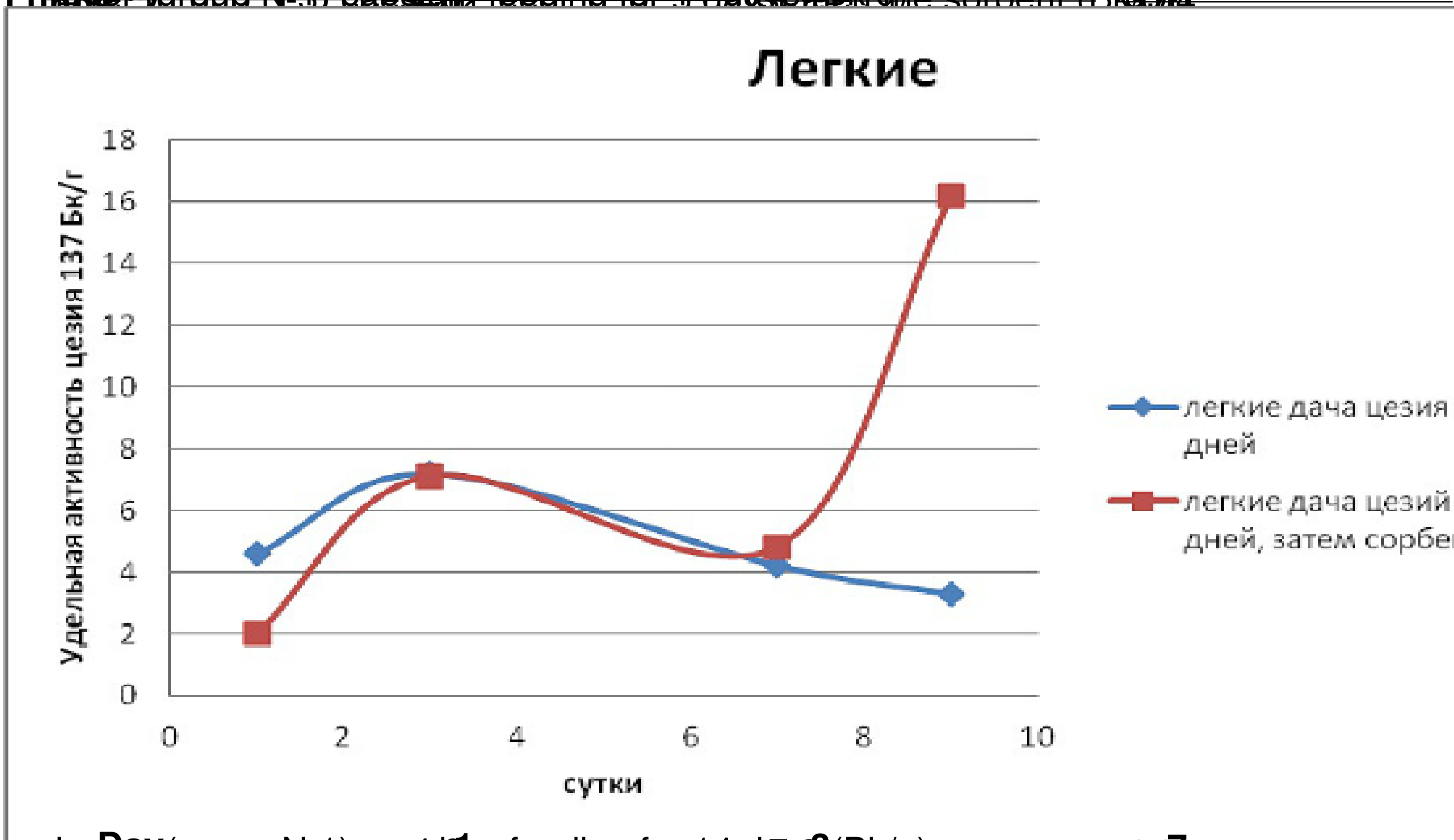


Liver (group №1) caesium feeding for 14 days (Bk/g)

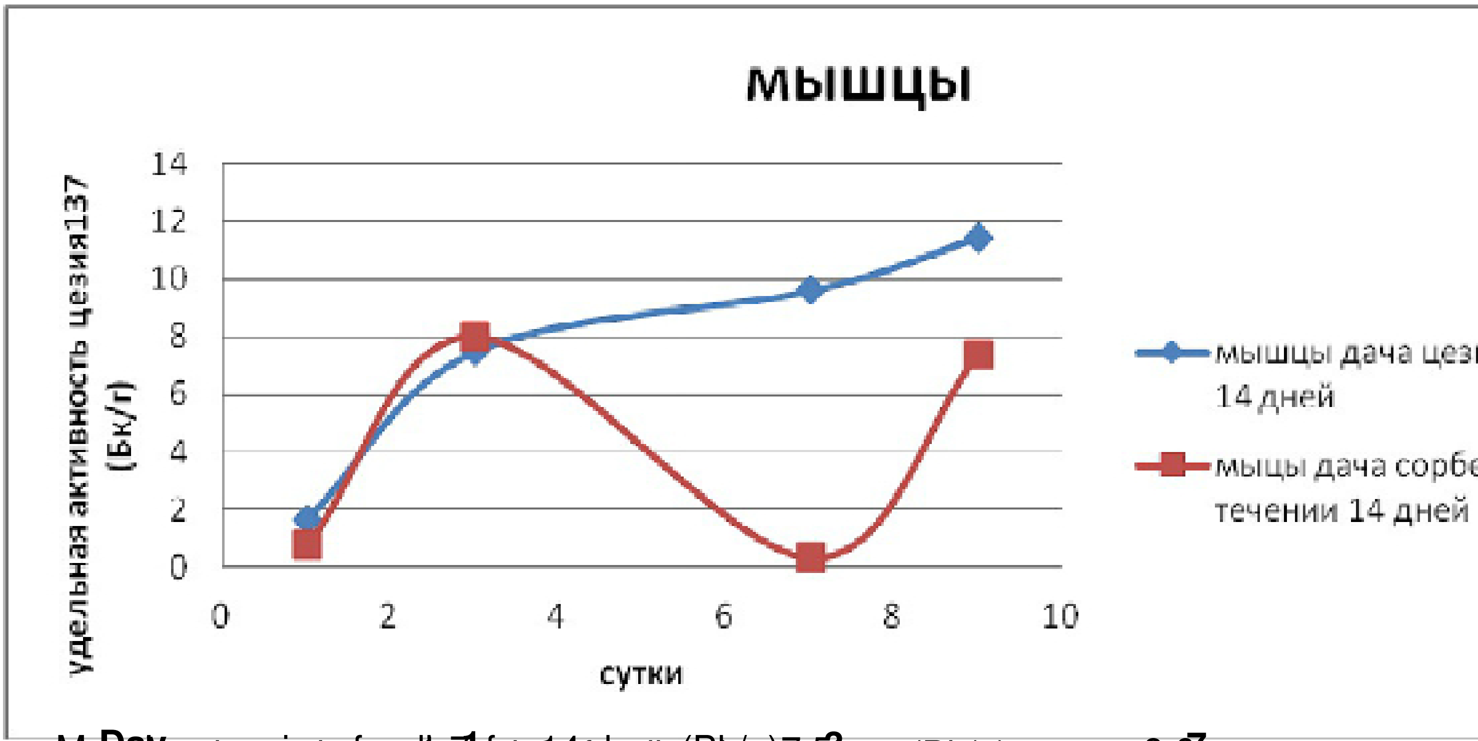
Liver (group №3) caesium feeding for 5 days, then the sorbent (Bk/g)

Day



Lungs (group №1) caesium feeding for 14 days (Bk/g)

Day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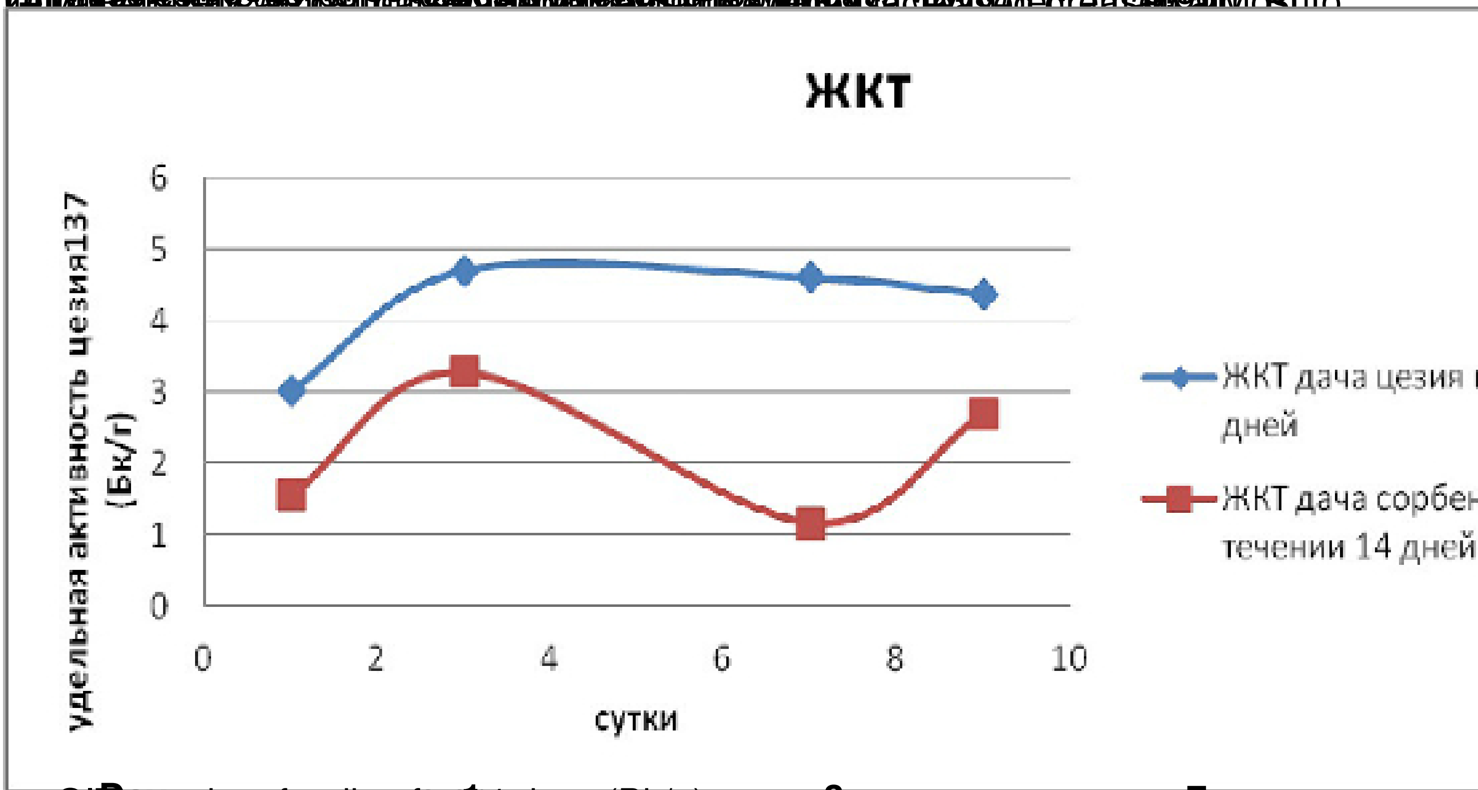
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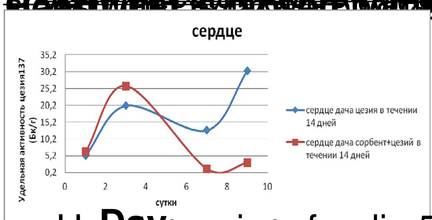
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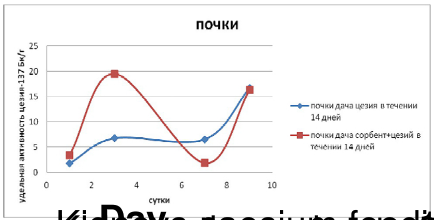
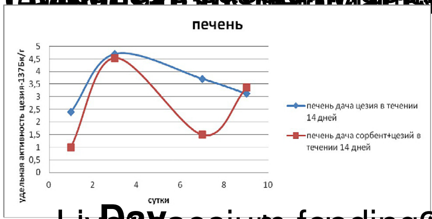
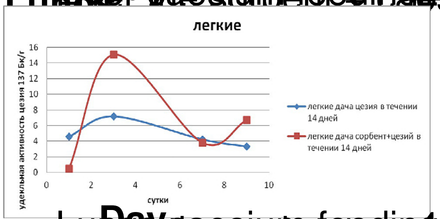
Удельная активность цезия137 (Бк/г)
сутки
сердце дача цезия в течении 14 дней
сердце дача сорбент+цезий в течении 14 дней

Kidneys







3.2 The detection of the removal percent of cesium-137 from the mice bodies

This figure shows us the values of caesium-137 removal percent from the mice

Table № 2

Group №	Caesium-137 removal percent
1 (control)	0 %
2	33 %
3	64%
4	85 % on the 5 day; 47% on the 9 day

The data show that the greatest caesium-137 removal percent is in group № 3 and № 4.

In group № 4 (caesium-137 + SaproSORB) there are 2 biological periods of caesium-137 removal from the mice.

The possibility of SaproSORB usage for radioisotopes removal from the organism is likely caused by some amino acids. Cystine and methionine contain sulphur atoms in the structure. Due to that they are applied in radiobiology for preventing radiation affections of an organism.

SaproSORB has the high rate of radiocaesium removal from the animals both by giving it together with caesium and after caesium feeding.

The results of group № 4 show that SaproSORB giving together with caesium-137 decreases the accumulation of the latter in animals. The results of group № 3 show that SaproSORB giving after caesium-137 diet was ended twice increased the removal of radiocaesium from the organism.

Deductions and practical suggestions

1. SaproSORB sorbing properties performed in group № 3 and № 4.

- After the beginning of SaproSORB giving in group № 3 we can observe a decrease of caesium-137 specify activity on the 1st-2nd day almost in two times, compared to the controls.

- In group № 4, where the mice were fed SaproSORB together with caesium-137, we can observe that caesium-137 specify activity gradually decreased and its removal periods increased twice, compared to group № 3 and 2.

2. There is a high rate of caesium-137 removal in group № 3 and № 4.

- 64% in group № 3
- In group № 4 the rate is 85% on the 5 day and 47% on the 9 day. There are 2 biological periods of caesium-137 removal.

Practical recommendations

1. SaproSORB can be applied as a natural sorbent for radionuclide removal from the organism both in the areas of extreme animal breeding with a heightened radiation background and in farms which buy feed from the areas with high environmental caesium-137 concentration.
2. we recommend to feed animals with SaproSORB mixed with feed or in the form of a paste bolus.