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FOREST FIRES IN THE CHERNOBYL EXCLUSION ZONE AND CHILDREN'S HEALTH

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This book is dedicated to the effect of forest fires in the Chernobyl Exclusion Zone on health of children living in the nearest populated localities. A blood level of homocysteine, a product of the essential amino acid methionine, was used as an integrative indicator reflecting the development of pathological processes in children. We also present results of analysis of the association of hyperhomocysteinemia with

In addition, considering the genetic system of the folate cycle, our analysis on the result of the relationship among the state of hyperhomocysteinemia, thyroid dysfunction and mineral metabolism are presented.

This book was written for medical doctors of all specialties, ecologists, scientists, specialists in the field of radiation protection, and for anyone involved in the consequences of the accident at the Chernobyl nuclear power plant.

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Книга присвячена впливу лісових пожеж у Чорнобильській зоні відчуження на стан здоров'я дітей, які проживають в найближчих населених пунктах. При цьому представлені матеріали про вміст радіоактивних елементів в ґрунті і лісових деревах Чорнобильської зони відчуження і прилеглих до неї районів.

Як інтегративний показник, що відображає розвиток патологічних процесів в дитячому організмі, використовувався рівень гомоцистеїну в крові — продукту незамінної амінокислоти метіоніну. Проведені дослідження показали після лісових пожеж у Чорнобильській зоні відчуження підвищення рівня гомоцистеїну в крові в групі дітей підліткового віку в 79,8 % випадків. Приріст випадків гіпергомоцистеїнемії в окремих підгрупах дітей, сформованих з урахуванням генотипів фолатного циклу, становив 10,8 — 35,3 % (в загальній групі 22,6 %). Результати досліджень зміни рівня гомоцистеїну в крові у одних і тих же дітей узгоджуються з результатами порівняльного змісту гомоцистеїну в крові дітей двох районів до і після пожеж у Чорнобильській зоні відчуження.

Представлені відомості про те, що найбільший рівень гомоцистеїну і найменший рівень фолієвої кислоти в крові визначалися у дітей при гомозиготному носійстві алелі ризику Т генетичного поліморфізму MTHFR:677, що контролює синтез метилентетрагідрофолатредуктази. Однак більш виражена реакція на лісову пожежу реєструвалася у дітей з генотипом, складеним з нейтральних алелей С/С даного поліморфізму. Робиться висновок про те, що збільшення концентрації гомоцистеїну в крові дітей після пожеж у Чорнобильській зоні відчуження, пов'язане з радіоактивними агентами, що розповсюджуються з повітряними потоками.

У книзі наводяться результати аналізу зв'язку стану гіпергомоцистеїнемії з порушенням функції щитовидної залози і мінерального обміну з урахуванням генетичної системи фолатного циклу.

Виходячи з отриманих результатів, можна обгрунтовано стверджувати про негативний вплив пожеж лісу в Чорнобильській зоні відчуження на обмін гомоцистеїну, а значить і метіоніну, в організмі дітей, які проживають в прилеглих населених пунктах. Наслідком цього є розвиток важких захворювань, що призводять до інвалідності та смертності населення.

У зв'язку з високими рівнями забруднення території радіонуклідами і внаслідок цього небезпекою для здоров'я людей Чорнобильська зона відчуження не може бути використана для проведення туристичних та розважальних заходів.

Книга призначена для лікарів усіх спеціальностей, екологів, науковців, фахівців в області протирадіаційного захисту, всіх, хто пов'язаний з наслідками аварії на Чорнобильській атомній електростанції.

Ключові слова: гомоцистеїн, діти, лісові пожежі, Чорнобильська зона відчуження, радіонукліди, фолатний цикл, генотип.

CONTENTS

PREFACE

The accident at the Chernobyl nuclear power plant in 1986 created a threat to the existence of many generations of people on the Earth, especially those who, due to various life circumstances, are forced to live near the territory contaminated with long-lived radioactive elements. These people are abandoned by state structures to fend for themselves and are forced to survive on their own. Scientific medical organizations, funded by the International Atomic Energy Agency (IAEA) also turned away from them. At the same time, information about the health status of these "hidden" victims of the Chernobyl tragedy is extremely important in the development of measures for the prevention and treatment of a number of serious diseases.

Particular attention should be paid to the state of health of children living from the moment of birth under conditions of constant radiation exposure. A growing organism is unusually sensitive to the effects of external factors, and therefore, it can be considered an indicator of the state of the environment. During the period of antenatal ontogenesis, organs and systems are formed at all levels of structural organization: cellular, tissue, and organ. In this regard, the environmental factor can cause severe structural changes in organs — congenital anomalies and congenital malformations. However, one should not think that this does not disturb the tissue structure of the organ and does not affect the metabolism in cells. As a rule, the environmental factor disrupts interorgan regulatory relationships not only in the developing organism, but also in the mother-fetus system. As a result, metabolism is disturbed, which is manifested in the form of specific diseases at various stages of postnatal ontogenesis. In this case, in most cases, the genetic factor plays a key role. Thus, the formation of a pathological process, in most cases, occurs under the influence of a provoking factor of the external environment, in the presence of a certain genetic predisposition.

At present, a great danger to the health of adults and children living in the territory affected by the accident at the Chernobyl nuclear power plant is represented by the forest, which has accumulated a huge amount of radioactive elements during the post-accident period. The so-called "gifts of the forest" — forest mushrooms and berries contain, huge amounts of radionuclides in most cases. When consuming these products, people are exposed to radiation toxic effects. This is due to difficult social conditions, as well as due to lack of information.

The factor of forest fires in areas affected by the accident at the Chernobyl nuclear power plant, including in the exclusion zone, cannot be ignored when assessing the humanitarian consequences of the Chernobyl disaster. However, its effect on human health has hardly been studied.

This book presents the results of a study of the metabolism of the sulfur-containing amino acid homocysteine, which reflects the development of pathological processes in the body, taking into account the state of the genetic system of the folate cycle, in children from the settlements of Polessky district of Kyiv region of Ukraine before and after forest fires in the Chernobyl exclusion zone.

CONTAMINATION OF FORESTS BY RADIATION AGENTS AFTER THE ACCIDENT AT THE CHERNOBYL NUCLEAR POWER PLANT

The question of how much radioactive agents were released into the atmosphere and how much remained in the reactor as a result of the accident at the 4th power unit of the Chernobyl nuclear power plant (ChNPP) in 1986 is controversial [1]. Professor N. I. Sanzharova and co-authors believe that $1.85 \cdot 10^{18}$ Bq of radioactive substances were released into the environment, including $8.5 \cdot 10^{16}$ Bq of ^{137}Cs (half-life 30.17 years), ^{134}Cs – $4.7 \cdot 10^{16}$ Bq (half-life 2.06 years), ^{90}Sr- $2.3 \cdot 10^{17}$ Bq (half-life 28.79 years), ^{131}I – $2.7 \cdot 10^{17}$ Bq (half-life 8 days). $^{238-241}Pu$ and ^{241}Am are recorded in the area adjacent to the ChNPP site [2].

3.2 % of the territory of the former USSR is contaminated by ^{137}Cs radionuclides with a density above 37 kBq/sq.m (1 Ci/sq.km) [3]. 64 TBq, or ~ 1.7 MCi of ^{137}Cs fell on the territory of Europe, while 18 % — on the territory of Ukraine, 23 % — the Republic of Belarus, 30 % — the Russian Federation [4]. In 1996, the area of soil contamination with ^{137}Cs, with a density of more than 37 kBq/sq.m was about 145 thousand sq.km, or 14.5 million hectares [4].

As of January 1, 2011, in Ukraine, the total area of the territory contaminated with radionuclides was 5.35 million hectares, while the area of forests occupied 2.54 million hectares [5]. 2151.8 thousand people lived on this territory in 2293 settlements, of which 498.1 thousand were children under the age of 17 inclusive [6].

As of January 1, 2012, the territory of radioactive contamination of the forest fund of the Republic of Belarus was 1.8 million hectares or 18.8 % of the total forest area of the republic. The largest part of the forest fund — 1.055 million hectares (70 % of the contaminated area) is located on the territory with a soil contamination density of ^{137}Cs from 37 to 185 kBq/sq.m (1-5 Ci/sq.km) [2].

Contamination of forest ecosystems with technogenic radionuclides ^{137}Cs and ^{90}Sr is 25-200 % higher in comparison with open landscapes, including agricultural ones [7].

The accumulation of ^{137}Cs radionuclides by forest trees depends on the structure of the soil on which they grow. Woody plants accumulate more ^{137}Cs in wood 1.5-2.5 times, leaves (needles) 2-4 times, 1 and 3-year-old shoots — 1.5-6 times on hydromorphic soils (soils with increased moisture), in comparison with automorphic soils (soils that are not subject to water saturation). An example of this is black alder [8].

Forested areas of the Belarusian-Ukrainian Polesie are located mainly on acidic, hydromorphic soils with a small humus content, on which the migration capacity of radionuclides in trophic chains is maximum [7].

Different types of forest trees have a different ability to accumulate radiation elements. Conifer species (spruce, pine), as well as common alder, accumulate ^{137}Cs less than other forest species (aspen, birch, oak). At the same time, spruce accumulates less than pine. The main accumulator of radionuclides in the aerial part of forest are tree stems.

Since ^{137}Cs is strongly sorbed by the soil, it, in relatively smaller quantities, passes into the woody part of plants through the root system. At the same time, when it ends up on the top of trees, it quickly passes to the wood. ^{90}Sr, being in the soil, easily passes into the wood through the root system [9].

Trees self purification occurs due to the decay of these long-lived radionuclides, therefore, the radiation situation in forests changes extremely slowly. Forests firmly hold the fallen out radionuclides and, thereby, prevent their removal outside the contaminated areas. However, this is a source of radiation hazard, first of all, during forest fires, as well as when using wood in living conditions [10].

A common feature of radioactive contamination of forests is its mosaic pattern, in which the difference between the minimum and maximum densities of soil contamination in the same taxation quarter or department is quite typical, which significantly complicates the organization of radiation control and the use of forestry products [11].

Forests are a direct and indirect traditional source of many food products, the beginning of numerous food chains that lead directly to humans. Despite some improvement of the the radiation situation over time, forest ecosystems remain critical from the point of view of the formation of human radiation dose [7].

CHERNOBYL EXCLUSION ZONE

The Chernobyl exclusion zone — the area around the ChNPP, has a total area of 259,799.8 hectares (in Kyiv region — 259403.7 hectares and Zhytomyr region — 396.1 hectares). The length of the perimeter of the Chernobyl exclusion zone (ChEZ) is 441.2 km, while 154.5 km is the border with the Republic of Belarus [12].

This territory received the status of an exclusion zone due to the fact that the largest amount of radionuclides, including transuranium elements (^{137}Cs – 4.4 PBq, ^{90}Sr – 4.0 PBq, $^{239\text{-}241}$Pu – 32 TBq) [13]. 30 years after the accident at the ChNPP, the soils of the exclusion zone contain long-lived radionuclides: ^{137}Cs, ^{90}Sr, ^{241}Am (half-life 432.6 years, ^{239}Pu (half-life 24110 years) [2]. In 2017, the levels of radionuclide contamination of the most contaminated territories of the ChEZ reached 100 MBq/sq.m for ^{137}Cs; 50 MBq/sq.m for ^{90}Sr, and 1 MBq/sq.m for $^{239\text{-}240}$Pu [14].

The forest fund of the exclusion zone includes 211.4 thousand hectares of forest land (87.9 %) and 29.2 thousand hectares of non-forest land (12.1 %). Twenty years after the accident at the ChNPP, the spread of forest on the territory of the exclusion zone reached 57.8 % [15], and 30 years later — 62.8 % [10]. In the forests of the ChEZ, coniferous trees cover 89.9 thousand hectares, or 59.5 % of the territory, deciduous trees — 61.1 thousand hectares, or 40.5 %. Common pine, common oak, drooping birch, black alder and sedge are the most common, with middle-aged trees predominating. This means there is a high concentration of aboveground forest fuels that can be used in upper fires [10].

In the ChEZ, the radionuclides mainly fell out on the territory occupied by the forest, and therefore, the radioactive contamination of soils under the forest tracts was greater than in the unforested areas. The area covered with forest vegetation with radioactive contamination levels > 15.0 Ci/sq.km is 31.1 % [10].

RADIOACTIVE FOREST FIRES IN THE CHERNOBYL EXCLUSION ZONE

Forest fires are quite frequent phenomena in areas of radioactive contamination [16]. 1566 fires occurred in the ChEZ for the period 1993-2018 [10]. One of the largest forest and meadow fires in the ChEZ over the past 25 years (its extent was 10127 ha) occurred on 26/04 – 29/04/2015 [17]. In addition, during the period 29/06 – 05/07/2015 a forest fire occurred on an area of 130 hectares [16]. The epicenters of these fires were located on the border with the territory of Polessky district (Fig. 1) [10]. The maximum density of contamination of the territory in areas of ground forest fire in individual sectors of Lubyansky forestry division was 1040 kBq/sq.m for ^{137}Cs; 368 kBq/sq.m for ^{90}Sr; 11.4 kBq/sq.m for $^{238-240}Pu$ and 14.4 kBq/sq.m for ^{241}Am [17].

It is known that the combustion of 1 ton of forest plant mass leads to the release of 125 kg of carbon monoxide, 12 kg of hydrocarbons (including carcinogens), 2 kg of nitrogen oxides, 22 kg of solid particles [18].

Forest and meadow fires in the ChEZ lead to the formation of an aerosol-gas mixture in the air, including CO, CO_2, NO_2, SO_2, acrolein, acetaldehyde, water vapor of the smallest solid particles of soot, ash, and tar droplets, 90 % of which are less than 0.1 μm [19].

The total concentration of radionuclides exceeded the maximum permissible level in the air of forest fires near the ChNPP. This is due to the fact that undissolved highly active micron-sized particles of irradiated nuclear fuel have been preserved in the soils of this zone (^{90}Sr — $6 \cdot 10^8$ Bq/g; ^{238}Pu — $6 \cdot 10^6$ Bq/g; ^{239}Pu — $5 \cdot 10^6$ Bq/g; ^{240}Pu — $8 \cdot 10^6$ Bq/g; ^{241}Am — $3 \cdot 10^7$ Bq/g) [19].

^{137}Cs, ^{90}Sr, $^{238-241}Pu$ were recorded in quantities exceeding permissible levels in the surface atmospheric layer in the composition of smoke aerosols [20]. Smoke aerosols, including mainly ^{137}Cs, travel long distances with wind currents. The duration of their existence in the lower troposphere (height up to 1.5 km) is less than a week, in the upper troposphere — about a month, in the stratosphere — 1-3 years. The deposition of radioactive combustion products occurs in areas with the status of "clean" ones [20].

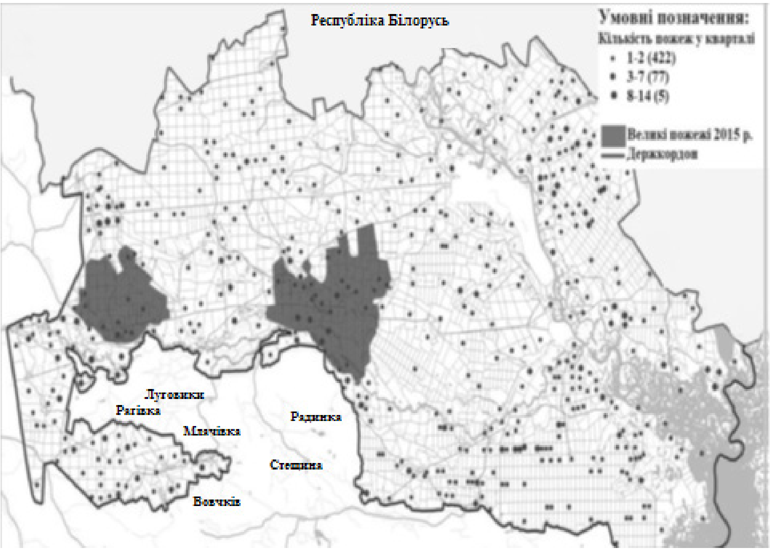

Fig. 1. Localization of large fires in the Chernobyl exclusion zone in 2015 (10).

The penetration into the body with air of fine particles 0.1–2.5 μm in size (PM2.5), including black carbon, causes cardiometabolic disorders leading to fatal outcomes [21, 22, 23]. This condition is associated with the development of oxidative stress, which occurs due to an increased levels of the sulfur-containing amino acid homocysteine in the blood, in the presence of a certain genetic effect [24].

USE OF THE CHERNOBYL FOREST FOR ECONOMIC PURPOSES AND IN HOUSEHOLD USE

Depending on the radiation contamination of forest areas, state bodies distinguish the following zones of economic activity:

Zone of sanctuary regime with the level of contamination by ^{137}Cs > 3700 kBq/sq.m, ^{90}Sr > 370 kBq/sq.m, ^{239}Pu > 11.1 kBq/sq.m.

Zone of limited forest management with a level of ^{137}Cs = 1480–3700 kBq /sq.m, ^{90}Sr = 111– 370 kBq/sq.m, ^{239}Pu = 3.7–11.1 kBq /sq.m.

Zone of unlimited forest management with a level of ^{137}Cs < 1480 kBq /sq.m, ^{90}Sr < 111 kBq/sq.m, ^{239}Pu < 3.7 kBq/sq.m [15].

The ChEZ is distinguished by a high level of contamination of the territory, therefore, all wood must undergo radiation control and be accompanied by a radiation study protocol for the content of technogenic radionuclides in it with recommendations on possible options for its use.

In Ukraine, there are hygienic standards for the maximum permissible content of ^{137}Cs and ^{90}Sr in wood and wood products.

If for ^{137}Cs maximum permissible levels are given for various types of products from forest trees, then for ^{90}Sr these restrictions are absent. The limiting level was noted only for fuel wood (Table 1) [25].

The use of firewood with ^{137}Cs and ^{90}Sr concentrations exceeding the permissible level will cause contamination of the stoves, and the ash used as fertilizer in the personal plot causes additional soil contamination, which will increase levels of these radionuclides in cultivated crops [26].

It must be remembered that when burning wood contaminated with radionuclides, there is a concentration of radioactive substances in the mineral part of the waste (ash) with an increase in the specific activity of ash by several tens of times — to a dangerous level of radioactive waste — 10,000 Bq/kg (RW), compared with the specific activity of the original wood [27].

In this regard, the deforestation in areas of radioactive contamination should be carried out only after radiation monitoring of wood and the compliance with the permissible level. In forest areas contaminated with radionuclides, cones should not be harvested for use as fuel.

There is a constant risk of deterioration of the radiation situation in the house and in the personal plot in the event of uncontrolled and unauthorized procurement of firewood for the local population, who live in radioactively contaminated areas and use firewood as fuel.

The wood used by the residents of Ivankovsky district adjacent to the ChEZ is a source of radioactive elements. As confirmation, we present an analysis of the specific activity of ^{137}Cs and ^{90}Sr of wood used by residents of six settlements in Ivankovsky district of Kyiv region for domestic needs, in particular, for heating houses.

Table 1

Hygienic standard for the specific activity of ^{137}Cs and ^{90}Sr in wood and wood products

Forestry products	Radionuclide content standard, Bq·kg^{-1}	
	^{137}Cs	^{90}Sr
1. Wood in the rough		
1. Roundwood		
– raw material for plywood production, raw materials for the production of veneer	1000	—
– timber for industrial construction and temporary structures	1500	—
– wood balances	1500	—
– raw materials for fastening works (mining risers)	3000	—
2. Wood for technological needs	1500	—
2. Wood treated		
– uncut lumber	1000	—
– sawn lumber	740	—
– bar	740	—
– parquet	740	—
– sawn workpieces, including for the production of furniture	740	—
– sawn pieces for Euro pallets	1500	—
– tare board, tare bar	1000	—
3. Cultural and household and household products		
– fuel wood *, fuel bundles	600	60
– fence	1000	—
– souvenir products	740	—
– household and household products (cuttings, kitchen boards, etc.)	740	—

Note. * — ash must be collected and buried at a depth of at least 0.5 m. It is recommended to choose a dry and elevated place outside the settlement for ash burial.

A total of 266 wood samples were studied. If the specific activity of ^{137}Cs in wood samples in most cases was 1.2-20 times lower than the maximum permissible level established by state services in Ukraine (600 Bq/kg), then with regard to ^{90}Sr, the situation is completely different.

The specific activity of this isotope in the wood samples under study varied from 21 Bq·kg^{-1} to 1146 Bq·kg^{-1} (Table 2). The specific weight of samples in which ^{90}Sr did not exceed the established hygienic standard (60 Bq/kg) was 53.7 %. The share of samples exceeding the hygienic standard of specific activity of ^{90}Sr accounted for 46.3 % (Fig. 2).

Table 2

Characteristics of radioactive contamination of soil and fuel wood with ^{90}Sr in the settlements of the Ivankovsky district (2017–2018)

No	Settlements	Specific activity ^{90}Sr in fuel wood, Bq/kg			Density of contamination soil ^{90}Sr, kBq/m^2	
		N[1]	Min	Max	Min	Max
1	Zhereva village	7	40	105	0.8	1.5
2	Leonovka village	63	41	262	7.5	10.8
3	Makarovka village	41	43	194	6.2	9.6
4	Oran village	59	159	1146	2.3	35.1
5	Rozvazhev village	28	36	54	2.0	16.9
6	Fenevichi village	68	21	211	3.8	11.6

Note. [1] – number of fuel wood samples tested.

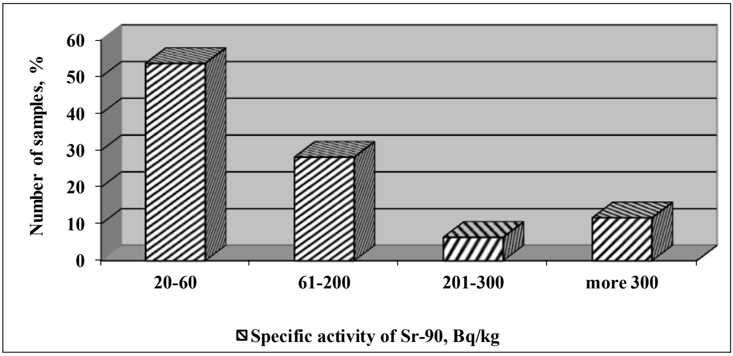

Fig. 2. Fuelwood distribution by specific gravity of samples containing ^{90}Sr.

The largest proportion of wood samples, in which the ^{90}Sr level exceeded the normative value was recorded in the village of Oranoe, located near the border with the ChEZ (Fig. 3).

According to the radiometric laboratory of the communal institution of Ivankovsky District Council “Ivankov Central District Hospital”, when analyzing 14 ash samples obtained from the stoves of residents of Ivankovsky District for the period 16/02/2017 – 14/06/2017, the maximum specific activity of ^{137}Cs and ^{90}Sr was 3430 and 13100 Bq/kg respectively.

It should be noted that the contamination of wood by ^{90}Sr reflects, to a greater extent, the contamination of the soils by this isotope of the studied settlements of Ivankovsky district, as evidenced by the results of work carried out in 2013-2014 by the staff of the Ukrainian Institute of Agricultural Radiology under the leadership of Professor Kashparov within the framework of the European Commission project «Health and environmental programs associated with the Chernobyl exclusion zone. Preparation, training and coordination of health projects» (Fig. 4).

During the period 2013-2016, projects of the European Commission and the Regional Council of Rhône-Alpes (France) were implemented in Ivankovsky and Polessky districts. They included the determination of the health status of children living under conditions of constant radiation exposure. One of their areas was the assessment of the state of metabolic processes associated with the amino acids methionine and homocysteine in adolescent children.

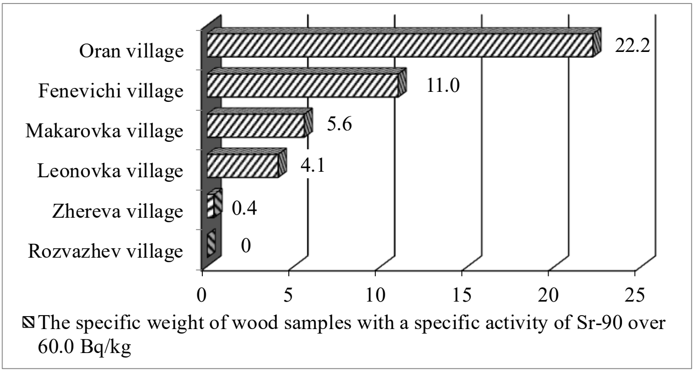

Fig. 3. The proportion of wood samples with a specific activity of ^{90}Sr > 60 Bq/kg, used by residents of certain settlements of the Ivankovsky district in 2017-2018.

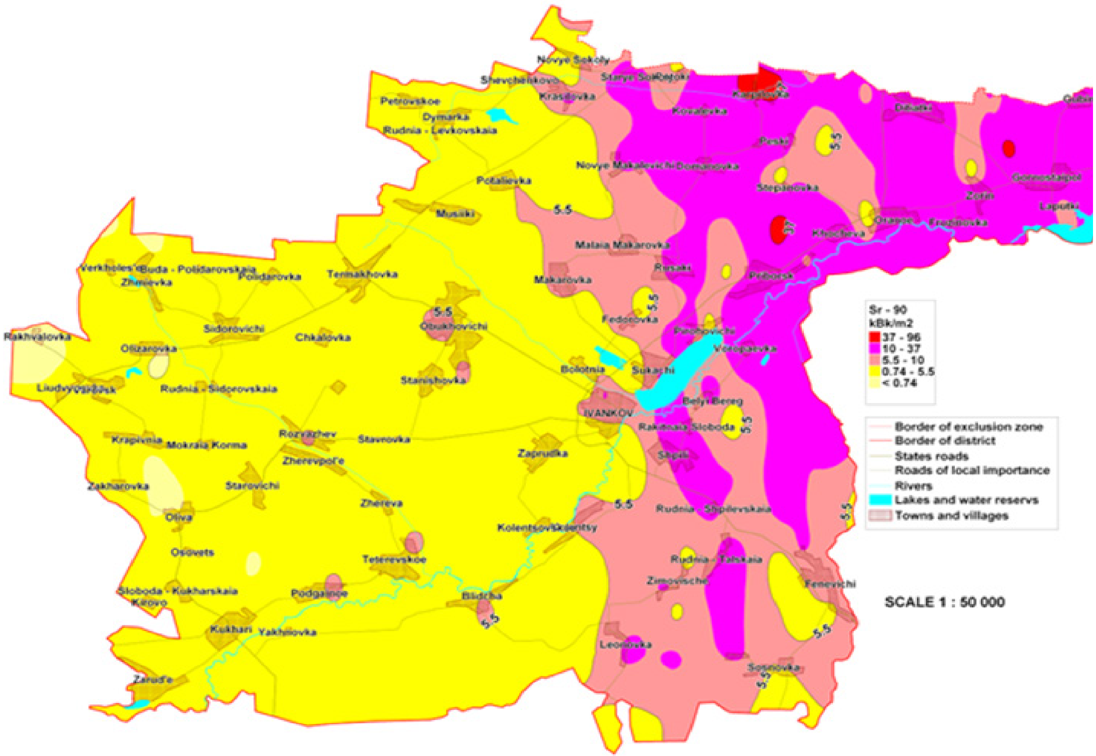

Fig. 4. Cartogram for density of soil contamination with ^{90}Sr in Ivankov region, 2014. Scale 1: 50 000 (without halftones).

HOMOCYSTEINE AS A MARKER OF CHILDREN´S HEALTH

Modern research suggests that the level of homocysteine in the blood is an indicator of the health status of the human body. Its relationship to the diseases of the cardiovascular system, congenital malformations, oncological and mental diseases is known [28].

Homocysteine (H_{cy}) is a sulfur-containing amino acid, a product of the essential amino acid methionine. Modern research shows the link of H_{cy} with a number of biochemical reactions, and therefore, the level of this amino acid in the blood is a marker of the state of metabolism in the body.

It is believed that after activation by adenosine triphosphate (ATP) methionine is converted to S-adenosylmethionine (S-AM), which is a donor of methyl groups for nucleic acids, hormones, and lipids [29]. In this case, one should lay the emphasis on the reaction of transformation of guanidinoacetate into creatine with the participation of S-AM catalyzed by guanidinoacetate N-methyltransferase (GAMT), at which about 75 % of the total amount of H_{cy} is formed [30].

There are three main pathways for biochemical transformations of this amino acid. The process of homocysteine remethylation to methionine associated with the folate cycle occurs in the cells of most tissues. Its main participants are the enzymes methylenetetrahydrofolate reductase and B_{12} methionine synthase associated with vitamins B_9 and B_{12} [31].

5-methyltetrahydrofolate, formed as a result of the activity of methylenetetrahydrofolate reductase, is a substrate for B_{12} methionine synthase, which remethylates H_{cy} to methionine.

The resynthesis of methionine from H_{cy} is also possible when betaine synthesized from choline is the donor of the methyl group. At the same time, under the influence of betaine-homocysteine S-methyltransferase, betaine is converted into dimethylglycine. The remethylation of H_{cy} using betaine was detected only in the liver, kidneys and lens of the eye [28].

The third pathway of utilization of H_{cy} is called trans-sulfuration, whereby H_{cy} is converted to cysteine. At the first stage of this process, the vitamin B_6-dependent cystathionine β-synthase mediates the reaction between H_{cy} and serine, resulting in the formation of cystathionine. At the second stage, cystathionine is converted into the amino acid cysteine, which forms taurine, participates in the synthesis of direct anticoagulants — heparin, heparan sulfate, and chondroitin sulfate, enters into composition of glutathione, which protects cells from oxidative stress.

In the course of the trans-sulfuration process associated with the exchange of sulfur-containing amino acids, the H_2S gas transmitter is formed, which, along with NO and CO, regulates the physiological functions of the body [28]. It is known that S-adenosylmethionine is a regulator of the metabolic pathways of H_{cy} transformation. In particular, it acts as an activator of cystathionine-β-synthase, and as an allosteric inhibitor of methylenetetrahydrofolate reductase [31].

It is important to note that in the cells of the central nervous system and myocardium, as well as in endothelial cells, the enzyme cystathionine-β-synthase is absent, and therefore, they are incapable of utilizing H_{cy} using the trans-sulfuration reaction. These cells possess only the system of H_{cy} remethylation with the help of the folate cycle, and therefore they are the most vulnerable in the presence of the increased formation of this metabolite [28, 32].

H_{cy} is capable of forming compounds with proteins, altering their structure and, consequently, their function. The severity of the process of homocysteinylation, a post-translational modification of proteins, is in direct proportion to the concentration of H_{cy} in the blood plasma. In the presence of hyperhomocysteinemia, modifications are made to fibrinogen molecules, low and high density lipoproteins, albumin, hemoglobin, and ferritin. As a result, an autoimmune process and thrombosis develop.

The oxidative stress of the endoplasmic reticulum, based on the inactivation of free amino groups [33], is associated with the formation of hydrogen peroxide (H_2O_2) and superoxide anion radicals that stimulate lipid peroxidation [28]. The formation of NO, the main gaseous regulator of endothelial homeostasis, is impaired [34].

Homocysteinylation, which causes the formation of reactive oxygen species, leads to the oxidation of proteins, lipids, carbohydrates, and nucleic acids. In this regard, endothelial damage and proliferation of smooth muscle cells occur in the walls of blood vessels. The process of thrombus formation based on platelet hyperaggregation and activation of plasma proteins (factor V) underlies the development of ischemic stroke [35].

Thus, increased concentrations of H_{cy} in the body have an atherogenic and thrombovascular effect. Experimental studies have shown damage to cardiomyocytes in the presence of hyperhomocysteinemia [36]. Even with short-term exposure, homocysteic acid at concentrations characteristic of the state of hyperhomocysteinemia induces cell apoptosis [37].

An important property of H_{cy} is its ability to interact with glutamate receptors present on the membranes of body cells, including synapses of neurons, myocardiocytes, and hepatocytes. The excitatory transmitter of this receptor is glutamic acid (glutamate) [37, 38, 39, 40].

With the help of these receptors, the regulation of many processes in the central nervous system is carried out, including during the period of intrauterine development of the embryo, and the processes of neuronal differentiation and the formation of neuronal connections are ensured [38].

The most studied receptors are N-methyl-D-aspartate (NMDA) receptors. At rest, the ion channel of these receptors is blocked by the Mg^{2+} ion.

Under physiological conditions, exposure to glutamate lasting several milliseconds leads to depolarization of the postsynaptic membrane (from -50 to -30 mV) and opening of the channel, as a result of which K^{+}, Na^{+}, Ca^{2+} ions penetrate into the cell [38].

Glutamate can also cause over-activation of NMDA receptors. In this case, Ca^{2+} ions enter the cell through receptor channels in large quantities, which leads to an increase in the activity of proteases, kinases, endonucleases, lipoxygenases, phospholipase A_2, uncontrolled action of free radicals, and as a result, damage to mitochondria and suppression of ATP synthesis [38].

Thus, the toxic effect of glutamate is associated with the entry of Ca^{2+} ions into the cell through the channels of NMDA receptors [41].

The development of convulsive states is associated with the superactivation of glutamate receptors in the structures of the brain. The ability of H_{cy} to induce overexcitation of N-methyl-D-aspartate receptors in the cells of the central nervous system, resulting in an increase in the amount of intracellular ionized calcium [36] and reactive oxygen forms [42]. A similar effect of H_{cy} was noted with respect to immunocompetent cells [39]. Under its influence, hypothalamic regulation of reproductive function is disrupted [44]. However, H_{cy} is defined as a weak neurotoxin, since it does not induce massive influx of extracellular Ca^{2+} into neurons [43].

Thus, the sulfur-containing amino acid H_{cy} in amounts exceeding physiological levels has a toxic effect on metabolic processes in the cells of the nervous system and internal organs. Its ability to interfere with the mechanisms of regulation of cellular and intercellular relationships makes it one of the most important indicators of health.

The physiological concentration of H_{cy} in the blood for adolescent children should not exceed 5-6 μmol/L [45]. For adults, hyperhomocysteinemia is determined when the concentration of this metabolite in the blood exceeds the level of 10 μmol/L [35].

The causes of hyperhomocysteinemia can be endogenous and exogenous factors, and more often both.

The endogenous factors, first of all, include mutations of genes responsible for the synthesis of enzymes of the folate cycle. The following allelic variants are currently most frequently studied: C677T and A1298C of the MTHFR gene (synthesis of the methylenetetrahydrofolate reductase enzyme), A2756G of the MTR gene (synthesis of the B_{12}-dependent methionine synthase enzyme), and A66G of the MTRR gene (synthesis of the methionine synthase reductase enzyme).

When examining 479 children aged 12-17 years, permanently living in the Ivankovsky and Polessky districts 30 years after the accident at the ChNPP, the absence of risk alleles for all the studied polymorphisms of the folate cycle was found in 2.09 % of cases.

Carriers of the risk allele of one of the studied polymorphisms were detected in 15.66 % of cases, two of the studied polymorphisms — in 44.05 %, three — in 31.94 % of cases. Children carrying risk alleles of all four studied polymorphisms of the folate cycle were found in 6.26 % of cases. The MTHFR: C677T and MTR: A2756G polymorphisms are of the greatest scientific and practical importance.

The MTHFR:677 genetic polymorphism controls the synthesis of methylenetetrahydrofolate reductase, the enzyme responsible for the synthesis of 5-methyltetrahydrofolate, the main carrier of methyl groups in the H_{cy} remethylation cycle. Carriership of the T risk allele of this polymorphism creates essential preconditions for an increase in the level of H_{cy} in the blood [46]. The largest number of cases of hyperhomocysteinemia was reported with a homozygous T/T variant. However, hyperhomocysteinemia occurred in children from Polessky district even in the absence of this allele (Table 3).

The MTR:2756 genetic polymorphism controls the synthesis of B_{12}- methionine synthase, an enzyme that transfers the methyl group from the 5-methyltetrahydrofolate molecule to the H_{cy} molecule with the help of cobalamin (vitamin B_{12}). Both enzymes are closely related to S-adenosylmethionine, which regulates the process of H_{cy} remethylation.

Increased concentrations of S-adenosylmethionine inhibit the activity of methylenetetrahydrofolate reductase, and hence the production of 5-methyl tetrahydrofolate. In this case, there occurs the activation of trans-sulfuration reactions, as a result of which H_{cy} is converted into cysteine.

Table 3

Dynamics of cases of hyperhomocysteinemia in subgroups of children with different genotypes

Subgroup / Genotype	Number of cases	Hyperhomocysteinemia					
		Measurement 1		Measurement 2		Increase	
		Abs.	%	Abs.	%	Abs.	%
A/A MTR:2756	57	35	61.4	47	82.5	12	21.1
A/G MTR:2756, G/G MTR:2756	27	13	48.2	20	74.1	7	25.9
A/A MTHFR:1298	47	26	55.3	41	87.2	15	31.9
A/C MTHFR:1298, C/C MTHFR:1298	37	22	59.5	26	70.3	4	10.8
C/C MTHFR:677	44	20	45.5	31	70.5	11	25.0
C/T MTHFR:677, T/T MTHFR:677	40	28	70.0	36	90.0	8	20.0
A/A MTRR:66	17	7	41.2	13	76.5	6	35.3

Table No 3 continuation

Subgroup / Genotype	Number of cases	Hyperhomocysteinemia					
		Measurement 1		Measurement 2		Increase	
		Abs.	%	Abs.	%	Abs.	%
A/G MTRR:66 + G/G MTRR:66	67	41	61.2	54	80.6	13	19.4
A/A MTR:2756 — C/C MTHFR:677	33	16	48.5	25	75.8	9	27.3
A/G MTR:2756 + G/G MTR:2756-C/T MTHFR:677 + T/T MTHFR:677	16	9	56.3	14	87.5	5	31.2
Total group	84	48	57.2	67	79.8	19	22.6

CHANGE IN A BLOOD HOMOCYSTEINE LEVEL IN CHILDREN AFTER FOREST FIRES IN THE CHERNOBYL EXCLUSION ZONE

In view of the fact that there is an association between combustion products and increase in the blood H_{cy} level [24], it is important to identify a change in the blood level of this metabolite in the same children before and after the forest fire in the ChEZ in 2015.

In the course of the study, we used results of laboratory examination of 84 children (39 boys and 45 girls) living in Polessky district bordering the ChEZ [47, 48].

In order to measure blood H_{cy} concentrations and carry out a genetic analysis of the folate cycle (FC), each child had blood drawn from the ulnar vein after fasting in the morning twice on 02/04/2015 and 18/12/2015. The blood samples were analysed at a laboratory certified under quality standards with the agreement of the parents.

The children's age at the time of laboratory examination was 15.5 ± 0.1 years (95 % CI 15.4-15.7 years). Blood H_{cy} concentrations were measured using a chemiluminescent immunoassay (CLIA) method. Analyser and test kit: Architect 1000 (ABBOT Diagnostics (USA)). The blood H_{cy} level of over 10 μmol/L was defined as hyperhomocysteinemia.

The genetic analysis of the FC included the identification of the following allelic variants: C677T and A1298C of the MTHFR gene (methylenetetrahydrofolate reductase), A2756G of the MTR gene (B_{12}-dependent methionine synthase) and A66G of the MTRR gene (methionine synthase reductase). A real-time PCR method was used. Analyser and test kit: DT-96 detecting thermocycler, DNA-Technology (Russia) [46].

Thus, the above-mentioned laboratory examination of children in Polessky district was carried out before and after the forest fire in the ChEZ.

There was a statistically significant increase in the percentage of cases of hyperhomocysteinemia between two measurements in the total group, as well as in the majority of subgroups based on 100 % inheritance of separate FC genotypes (Tables 3, 4). The exceptions were subgroups that included carriers of genotypes with the MTR:2756 polymorphism G allele and the MTHFR:A1298C polymorphism C allele.

Table 4

Results of comparison of proportions of cases of hyperhomocysteinemia in subgroups of children with different genotypes during two measurements

Subgroup / Genotype	t	p
A/A MTR:2756	2.57	0.011955
A/G MTR:2756, G/G MTR:2756	2.03	0.051264
A/A MTHFR:1298	3.63	0.000567
A/C MTHFR:1298,C/C MTHFR:1298	0.98	0.333133
C/C MTHFR:677	2.45	0.017846
C/T MTHFR:677, T/T MTHFR:677	2.30	0.024669
A/A MTRR:66	2.24	0.038520
A/G MTRR:66 + G/G MTRR:66	2.52	0.013288
A/A MTR:2756 — C/C MTHFR:677	2.37	0.023113
A/G MTR:2756+G/G MTR:2756 - C/T MTHFR:677+ T/T MTHFR:677	2.09	0.049505
Total group	3.26	0.001481

The blood concentration of H_{cy} in the children from the total group and all determined genetic subgroups was significantly higher during the second measurement than during the first one (Tables 5, 6).

Table 5

Statistical characteristics of H_{cy} level values in the blood of children with different genotypes before and after the forest fires in the ChEZ

Subgroup/Genotype	**Number of children**	**$^{1}H_{cy}$, µmol/L (02/04/2015)**		**$^{2}H_{cy}$, µmol/L (18/12/2015)**	
		Me	**IQR**	**Me**	**IQR**
A/A MTR:2756	**57**	**10.7**	**9.0 – 14.1**	**12.8**	**11.2 – 15.8**
A/G MTR:2756, G/G MTR:2756	27	9.6	7.9 – 11.0	10.9	9.9 – 13.0
A/A MTHFR:1298	47	10.3	8.0 – 13.3	12.6	10.9 – 14.5
A/C MTHFR:1298, C/C MTHFR:1298	37	10.4	8.3 – 12.9	11.7	9.8 – 14.4
C/C MTHFR:677	44	9.7	7.7 – 11.1	11.4	9.7 – 14.1
C/T MTHFR:677, T/T MTHFR:677	40	11.4	9.4 – 14.4	12.8	11.0 – 15.2
A/A MTRR:66	17	9.3	7.2 – 13.0	11.5	9.8 – 13.0
A/G MTRR:66, G/G MTRR:66	67	10.7	9.0 – 13.1	12.5	10.6 – 14.8
A/A MTR:2756 - C/C MTHFR:677	33	9.7	7.5 – 12.2	12.5	10.0 – 14.9
A/G MTR:2756, G/G MTR:2756 - C/T MTHFR:677, T/T MTHFR:677	16	10.2	8.2 – 11.7	12.2	10.3 – 13.4
Total group	84	10.3	8.0 – 13.1	12.3	10.4 – 14.5

Note. [1] — H_{cy} measurement 1, [2] — H_{cy} measurement 2.

The proportion of cases of an individual increase in the blood level of H_{cy} in the total group of children and all analyzed genetic subgroups was reported at a level of over 70.0 %, including in the presence of homozygous carriership of both neutral alleles and risk alleles, polymorphisms affecting the functioning of the FC (Table 7).

Table 6

Results of non-parametric comparative analysis (Wilcoxon T-test) of two samples of homocysteine ($^1H_{cy}$ and $^2H_{cy}$).

Subgroup/Genotype	Standardized Wilcoxon T-test value, Z	Asymptotic significance (2-tailed), p
A/A MTR:2756	- 4.660	p = 0.0001
A/G MTR:2756, G/G MTR:2756	- 3.039	p = 0.002
A/A MTHFR:1298	- 4.318	p = 0.0001
A/C MTHFR:1298, C/C MTHFR:1298	- 3.432	p = 0.001
C/C MTHFR:677	- 4.773	p = 0.0001
C/T MTHFR:677, T/T MTHFR:677	- 3.118	p = 0.002
A/AMTRR:66	- 2.391	p = 0.017
A/G MTRR:66, G/G MTRR:66	- 5.125	p = 0.0001
A/A MTR:2756 – C/C MTHFR:677	- 4.440	p = 0.0001
A/G MTR:2756, G/G MTR:2756 - C/T MTHFR:677, T/T MTHFR:677	- 2.585	p = 0.010
Total group	- 5.566	p = 0.0001

Thus, we can state that there was an increase in the blood H_{cy} concentrations in the same children living in districts bordering the ChEZ between 02/04/2015 and 18/12/2015. This process was not significantly influenced by the FC genome. In most children, the H_{cy} level in the blood increased.

As an example, we should mention the Subgroup 9, in which, as the main genotype, the cases of simultaneous carriership of neutral homozygotes of the MTR:2756 and MTHFR:677 polymorphisms regulating the H_{cy} methylation processes were included.

The findings show that the increase in the level of H_{cy} in the blood and number of cases of hyperhomocysteinemia is associated with an external environmental effect on the body of children from Polessky district.

Table 7

Proportion of cases of an individual increase in the blood level of H_{cy} in children from subgroups with different genotypes

Subgroup/Genotype	Number of cases	Cases of an increase in the blood homocysteine level	
		Abs. number	%
A/A MTR:2756	57	44	77.2
A/G MTR:2756, G/G MTR:2756	27	23	85.2
A/A MTHFR:1298	47	40	85.1
A/C MTHFR:1298, C/C MTHFR:1298	37	27	73.0
C/C MTHFR:677	44	38	86.4
C/T MTHFR:677, T/T MTHFR:677	40	29	72.5
A/A MTRR:66	17	13	76.5
A/G MTRR:66, G/G MTRR:66	67	54	80.6
A/A MTR:2756 – C/C MTHFR:677	33	29	87.9
A/G MTR:2756 + G/G MTR:2756 – C/T MTHFR:677 + T/T MTHFR:677	16	14	87.5
Total group	84	67	79.8

The results of studies of the change in the level of H_{cy} in the blood of the same children are consistent with the results of the comparative analysis of H_{cy} in the blood of children from two districts before and after the fires in the ChEZ [49].

Since the main centers of the fire were located several kilometers from the populated localities of Polessky district (Fig. 1), it can be stated that they were the cause of the increase in the blood H_{cy} concentration in the examined children.

The aerosol/gas mixture formed during the burning of trees, included radioactive elements and black carbon. It easily penetrated the respiratory tract, reaching the bronchioles and alveoli [21].

A positive correlation was established between blood plasma H_{cy} and the concentration of particles in the air, including black carbon and organic carbon. However, the effects of these pollutants were more pronounced in those with low plasma concentrations of folate and vitamin B_{12} [50].

Our studies showed persuasively that the level of vitamin B_9 in the body of children depends on the genetic system of the FC [51, 52].

The highest vitamin deficiency occurs in the presence of homozygous carriership of the T allele of the MTHFR:677 genetic polymorphism which controls the synthesis of methylenetetrahydrofolate reductase (Fig. 5) [51, 52].

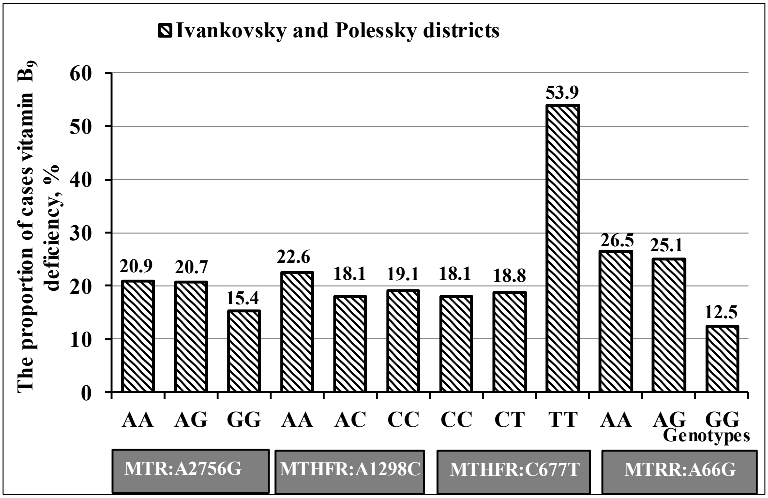

Fig 5. Distribution of cases of vitamin B_9 deficiency in groups of children with different genotypes from the Ivankovsky and Polessky districts.

Note. MTR:A2756G: «1» — AA; «2» — AG; «3» — GG; MTHFR:A1298C: «1» — AA; «2» — AC; «3» — CC; MTHFR:C677T: «1» — CC; «2» — CT; «3» — TT; MTRR:A66G: «1» — AA; «2» — AG; «3» — GG.

In the light of the above-mentioned findings, after exposure to combustion products, the elevation in the blood level of H_{cy}, increase in the proportion of cases of hyperhomocysteinemia and an individual raise in the level of H_{cy} in the blood should be more pronounced in the subgroup of children with low levels of vitamin B_9 associated with the T allele of the genetic polymorphism MTHFR:677 in comparison with the subgroup of children who do not have this allele.

However, this did not happen. A more pronounced reaction to the forest fire was reported in the children with the opposite C/C MTHFR:677 genotype.

Thus, we cannot state that the rise in the level of H_{cy} in the blood of children can be caused only by the products of wood combustion.

In our opinion, the most probable reason for the increase in the concentration of H_{cy} in the blood of children from the districts adjacent to the ChEZ is radioactive elements that are distributed with air currents during the burning of forest trees. In 2015, the maximum density of contamination of the territory in the areas of ground forest fire in sectors No. 306-308 of the Lubyansky forestry division, located on the territory of the ChEZ near the villages of Polessky district, was 1040 kBq/sq.m for ^{137}Cs; 368 kBq/sq.m for ^{90}Sr; 11.4 kBq/sq.m for $^{238-240}Pu$, 14.4 kBq/sq.m for ^{241}Am [17].

This conclusion is confirmed by the results of experiments in which oats grown in the territory affected by the accident at the ChNPP and containing radionuclides ^{137}Cs at a concentration of 445.7 Bq/kg and ^{90}Sr at a concentration of 15.5 Bq/kg was used as food for experimental animals. The oats fed to the animals of the control group contained ^{137}Cs at a concentration of 44.2 Bq/kg, ^{90}Sr — 1.7 Bq/kg. The experiment lasted 28 days.

An increase in the ^{137}Cs levels as compared with the control was found in the body of experimental animals, while there was a decrease in methionine concentrations in the tissue of the liver and skeletal muscles [53], organs intensively incorporating ^{137}Cs radionuclides (Fig. 6) [54], which may indicate that there is a disturbance in its resynthesis from H_{cy}.

Thus, the radiation effect on the body of children results in abnormalities of H_{cy} methylation processes with methionine formation. ^{137}Cs radionuclides dramatically reduce the energy potential of cells by invading mitochondria, and therefore contribute to a decrease in the level of anabolic processes [55, 56].

The effect of ^{90}Sr on metabolic processes is less studied compared to ^{137}Cs. However, this long-lived isotope is a β-emitter, and therefore, it is very dangerous for the child's body [57].

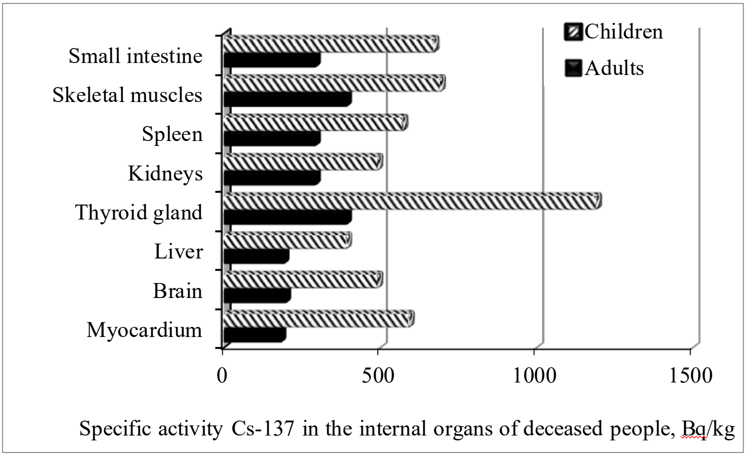

Fig. 6. Accumulation of ^{137}Cs radionuclides (Bq/kg) in internal organs of adults and children — residents of the Gomel region of the Republic of Belarus, who died in 1997 (54).

In the grain of oats grown in the vicinity of the Kukhari settlement of the Ivankovsky district in 2011, the concentration of ^{90}Sr was 17.2 Bq/kg, while that of ^{137}Cs was 49.8 Bq/kg [58]. In addition, it contained increased amounts of Ba and Mn in comparison with the control. Feeding pregnant female Syrian hamsters with this grain led to the occurrence of congenital malformations in their offspring (Fig. 7).

In the course of the studies conducted, a direct association between H_{cy} and pituitary thyroid-stimulating hormone (TSH) was found [59, 60].

At the same time, the genetic factor associated with FC enzymes — methylenetetrahydrofolate reductase and B_{12}-methionine synthase — plays a great role. There was no association between H_{cy} and TSH values in groups of children with no risk alleles of genetic polymorphisms that control these enzymes (A/A MTR:2756 and C/C MTHFR:677) (Fig. 8, 9, 10) [59].

The greatest strength of the association between these metabolites was reported in the group composed in 100 % of cases of carriers of the T risk allele of the MTHFR:C677T polymorphism (Fig. 11) [60], or in the group including the combined carriership of the risk alleles of the MTR:A2756G and MTHFR:C677T polymorphisms (Fig. 12) [59].

Fig. 7. Congenital malformations in the embryos of Syrian hamsters (double-sided cleft of the upper lip), as a result of feeding during pregnancy with oats grown in Ivankovsky district of Kyiv region in 2011 (58).

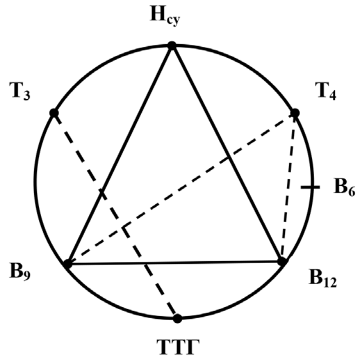

Fig. 8. Associations between metabolic variables in the group of children — carriers of the A/A genotype MTR:2756.

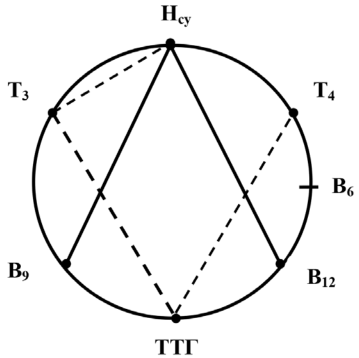

Fig. 9. Associations between metabolic variables in the group of children — carriers of the C/C MTHFR:677 genotype.

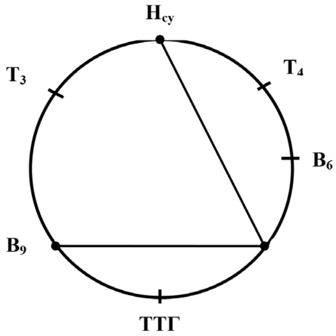

Fig. 10. Associations between metabolic variables in the group of children — carriers of the combination of genotypes A/A MTR:2756 and C/C MTHFR:677.

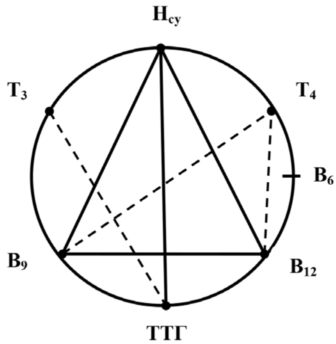

Fig. 11. Associations between metabolic variables in the group of children — carriers of the T risk allele of the MTHFR:677 genetic polymorphism.

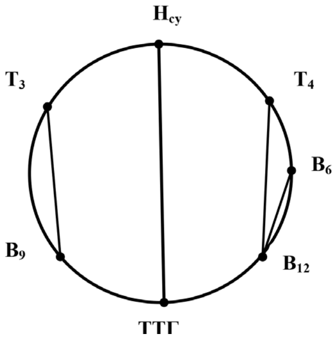

Fig. 12. Associations between metabolic variables in the group of combined carriage of the risk allele G of the genetic polymorphism MTR:2756 and the risk allele T of the genetic polymorphism MTHFR:677.

The inverse association between H_{cy} and vitamins B_9 and B_{12} [59], which, in the present study, was also detected in individual genetic subgroups (Table 8), indicates the dependence of methionine resynthesis on the functioning of FC enzymes. At the same time, the associations of these vitamins with hormones of the pituitary-thyroid axis were determined (Fig. 8-12) [59].

Table 8

Results of correlation analysis between the values of H_{cy} and vitamins B_6, B_9 and B_{12} in groups of children with different genetic polymorphisms

Subgroup/ Genotype	Parameter	Correlation coefficient	Parameter		
			B_6, μg/L	B_9, ng/ml	B_{12}, pg/ml
A/A MTR:2756	H_{cy} μmol/L	Spearman's	-0.035	-0.383**	-0.458**
		p	0.799	0.003	0.0001
		N	57	57	57
A/G MTR:2756, G/G MTR:2756	H_{cy} μmol/L	Spearman's	0.176	-0.334	-0.293
		p	0.381	0.089	0.138
		N	27	27	27
A/A MTHFR:1298	H_{cy} μmol/L	Spearman's	0.048	-0.531**	-0.334*
		p	0.749	0.0001	0.022
		N	47	47	47
A/C MTHFR:1298, C/CMTHFR:1298	H_{cy} μmol/L	Spearman's	0.057	-0.257	-0.439**
		p	0.740	0.124	0.007
		N	37	37	37
C/C MTHFR:677	H_{cy} μmol/L	Spearman's	-0.020	-0.289	-0.513**
		p	0.898	0.057	0.0001
		N	44	44	44
C/TMTHFR:677, T/T MTHFR:677	H_{cy} μmol/L	Spearman's	0.076	-0.486**	-0.199
		p	0.642	0.001	0.218
		N	40	40	40
A/AMTRR:66	H_{cy} μmol/L	Spearman's	0.074	-0.569*	-0.554*
		p	0.779	0.017	0.021
		N	17	17	17
A/G MTRR:66, G/G MTRR:66	H_{cy} μmol/L	Spearman's	0.025	-0.379**	-0.364**
		p	0.841	0.002	0.002
		N	67	67	67
A/AMTR:2756 — C/CMTHFR:677	H_{cy} μmol/L	Spearman's	-0.005	-0.380*	-0.650**
		p	0.029	0.029	0.0001
		N	33	33	33
A/G MTR:2756 + G/G MTR:2756- C/TMTHFR:677 +T/ TMTHFR:677	H_{cy} μmol/L	Spearman's	0.288	-0.588*	-0.344
		p	0.279	0.017	0.192
		N	16	16	16

Table No 8 continuation

Subgroup/ Genotype	Parameter	Correlation coefficient	Parameter		
			B_6, µg/L	B_9, ng/ml	B_{12}, pg/ml
Total group	H_{cy} µmol/L	Spearman's	0.035	-0.406**	-0.405**
		p	0.754	0.0001	0.0001
		N	84	84	84

Note. * — correlation is significant at the 0.05 level (2-tailed), ** — correlation is significant at the 0.01 level (2-tailed).

The proportion of cases of increased blood T_3 levels is significantly higher in the group of children-carriers of the G risk allele of the MTR:A2756G genetic polymorphism associated with the B_{12}-dependent methionine synthase enzyme than in the group of children without this allele (A/A MTR : 2756 genotype) [61].

Thus, the genetic block of the conversion of H_{cy} to methionine at the level of the B_{12}-dependent methionine synthase enzyme in the form of the G 2756 MTR mutation activates the process of the conversion of H_{cy} to cysteine and selenocysteine, and an increased production of T_3. This process involves vitamin B_6 as a cofactor of the cystathionine-β-synthase enzyme. A strong direct association between H_{cy} and vitamin B_6 was found [62]. A strong inverse association between vitamins B_6 and B_{12} confirms the interaction between the FC and transsulfuration reactions [63].

The findings are of great importance for understanding the mechanisms of the formation of pathological processes in the thyroid gland. The identification of the roles of the FC and H_{cy} in the regulatory relations between the pituitary and the thyroid gland will allow to outline the ways of effective prevention of thyroid pathology starting from childhood.

In the course of the studies, a direct association related to the carriership of the MTHFR:677 genetic polymorphism T risk allele is found between H_{cy} and ionized calcium in the blood (Ca^{2+}). At the same time, there was no association between Ca^{2+} and the hormone of the parathyroid glands, Ca^{2+} and phosphorus (P) [64, 65, 66, 67].

The results obtained allow us to state that there are initial stages of development of destructive processes in bone tissue in children with the increased level of H_{cy} in the blood. In contrast to Ca^{2+}, P had closer associations with hormones that regulate mineral metabolism, including the hormone of the parathyroid glands. However, no associations of P with hormones that regulate mineral metabolism were found in groups with homozygous carriership of the MTHFR:C677T and MTR:A2756G genetic polymorphism risk alleles.

Thus, the pathological processes reported in children living in the territory contaminated with radioactive elements of Chernobyl origin are formed with the participation of the genetic system.

PROTECTION OF HEALTH OF CHILDREN PERMANENTLY LIVING IN CONDITIONS OF ENVIRONMENTAL RISK ASSOCIATED WITH FOREST FIRES IN THE CHERNOBYL EXCLUSION ZONE

The results of the conducted studies indicate that the increase in the level of the sulfur-containing amino acid H_{cy} in the blood of children occurred regardless of the state of the genetic system of the FC. Taking into account the proximity of the location of the main initial forest fires in the ChEZ to the settlements of in Polessky district, it can be stated that it was the burning of forest trees that caused the abnormal transformation of H_{cy} into methionine in the child's body. An aerosol mixture containing combustion products and Chernobyl radionuclides was kept for a long time in the places where children lived and easily penetrated their respiratory tract. In addition, combustion products and radioactive elements fell on cattle pastures, and then, with milk, entered the body of children. In this situation, it is difficult to separate the effect of radiation agents from that of combustion products.

Particular attention should be paid to ^{90}Sr, the amount of which has increased dramatically in the last decade, both in wood used by the population for domestic needs and in foodstuff. If in 1992 the ratio between ^{137}Cs and ^{90}Sr in oat grain obtained in the territory affected by the accident at the ChNPP was 10 or more / 1, then in 20 years — 2-3 / 1 [53, 58]. Transuranic elements are present in the ChEZ; in recent years, the level of ^{241}Am, which is a decay product of ^{241}Pu, has increased in the environment.

Thus, forest fires in the ChEZ pose a great danger to the health of children living in border areas, primarily due to exposure to smoke containing radioactive aerosol.

At the same time, an increase in the H_{cy} levels in the blood of children indicates a disturbance in methylation — one of the main metabolic processes in the body. The basis for the development of this process is a decrease in the energy capacity of cells due to a decrease in the production of ATP (mitochondrial level) and its use.

An increased level of H_{cy} in the blood in adults is associated with a blood clotting disorder and the occurrence of heart attacks of internal organs, strokes, diseases of the central nervous system and reproductive organs, pathology of pregnancy and fetus, and cancers.

Studies carried out during the European project (2013-2017) have found an association of H_{cy} with the dysfunction of the pituitary thyroid system in a group of children from districts adjacent to the ChEZ, and showed the role of this amino acid in the disturbance in calcium metabolism. At the same time, the role of a genetic factor that controls the activity of enzymes of the FC has been established.

It can be concluded that hyperhomocysteinemia reflects an imbalance of metabolic processes in a child's body, which is the basis for the formation of severe pathological processes that manifest themselves in specific diseases in the adult age. First of all, this relates to cardiovascular and cancer diseases.

Thus, prevention measures for severe pathological processes which are the main cause of death and disability in the adult population in the territory affected by the accident at the ChNPP should begin in the childhood.

At the same time, it is necessary to regularly monitor the level of H_{cy} in the blood of children contacting with radioactive elements. In the event of large-scale fires in the ChEZ, children should be evacuated to clean areas and stay there until the fires are completely extinguished. At the same time, children should receive increased doses of B vitamins: B_9, B_{12}, B_6 and antioxidants C, A, E.

To prevent them from poisoning by combustion products, antidotes are used, of which the most famous are acisole, sodium thiosulfate, cobalt preparations, acetylcysteine, ascorbic acid, pyridoxine hydrochloride, glucose, methylene blue solution, unitiol. Oxygen therapy is indicated [68].

It is mandatory to assess the state of the FC genetic system, with the identification of individuals at risk (carriers of the T allele of the genetic polymorphism MTHFR:677, as well as the G allele of the MTRR:2756 polymorphism). Children from the risk groups should, first of all, receive B vitamins (B_9, B_{12}, B_6).

In the presence of hyperhomocysteinemia (for adolescents the level of H_{cy} is more than 10 μmol/l), it is recommended to determine the level of TSH, T_3, T_4 and Ca, aspartate aminotransferase in the blood, as well as to assess the state of the cardiovascular system using the method of electrocardiography.

CONCLUSION

Based on the results obtained, we can reasonably state that forest fires in the Chernobyl exclusion zone have negative impact on homocysteine metabolism as well as that of methionine in the body of children living in nearby settlements. This results in the development of serious diseases leading to disability and mortality of the population.

WARNING

The studies carried out show the enormous danger posed to human health by the area around the Chernobyl nuclear power plant, designated as the exclusion zone. For more than 30 years after the accident at the 4th nuclear reactor, the forest trees growing here have accumulated huge amounts of radionuclides and are sources of radiation, one might say mini-reactors. In this regard, it is unacceptable to use these trees for domestic needs (heating houses and cooking, making furniture and building houses).

Due to the high levels of contamination of the territory with radionuclides, and as a result, the danger to human health, the Chernobyl exclusion zone cannot be used for tourist and entertainment events.

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