MINISTRY OF EDUCATION AND SCIENCE OF UKRAINENATIONALAVIATIONUNIVERSITY
FACULTY OF ENVIRONMENTAL SAFETY, ENGINEERING AND TECHNOLOGIES
DEPARTMENT OF ENVIRONMENTAL SCIENCE

APPROVED TO DEFENCE
Head of the Graduate Department
______________T. V. Dudar
«_____»_____________2021

MASTER THESIS

(EXPLANATORY NOTE)

SPECIALTY 101 “ECOLOGY”,
EDUCATIONAL AND PROFESSIONAL PROGRAM:
“ECOLOGY AND ENVIRONMENT PROTECTION”

Theme: «**Assessment of the wildfires impact on the ecosystems of the Chornobyl Exclusion Zone»**

Done by: student of the EK-211Ma group, Oksana A. Zhuravel
(student,group,surname,name,patronymic)

Supervisor: Dr. Eng. Sc., Professor of Environmental Studies Department Tamara V. Dudar
(academic degree, academic rank, surname, name, patronymic)

Consultant to the chapter “Labor Precaution”: ____________ Kateryna I. Kazhan
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Standards Inspector: ____________ Andrian A. Iavniuk
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KYIV 2021

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ
ФАКУЛЬТЕТ ЕКОЛОГІЧНОЇ БЕПЕКИ,
ІНЖЕНЕРІЇ ТАТЕХНОЛОГІЙ
КАФЕДРА ЕКОЛОГІЇ

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач випускової кафедри
_____________Т.В.Дудар
«_____»_____________2021р.

ДИПЛОМНА РОБОТА

(ПОЯСНЮВАЛЬНА ЗАПИСКА)

ВИПУСКНИКА ОСВІТНЬОГО СТУПЕНЯМАГІСТРА

ЗА СПЕЦІАЛЬНІСТЮ 101 «ЕКОЛОГІЯ»,
ОСВІТНЬО-ПРОФЕСІЙНОЮ ПРОГРАМОЮ
«ЕКОЛОГІЯ ТА ОХОРОНА НАВКОЛИШНЬОГО СЕРЕДОВИЩА»

Тема: «Оцінка впливу лісових пожеж на екосистеми Чорнобильської зони відчуження»

Виконавець: студентка групи ЕК-211Ма, Журавель Оксана Анатоліївна
(студент,група,прізвище,ім'я,побатькові)

Керівник: доктор технічних наук, профессор кафедри екології Дудар Тамара Вікторівна
(науковий ступінь, вчене звання, прізвище, ім'я, по батькові)

Консультант розділу «Охорона праці»: _______________ Кажан К. І.
(підпис) (П.І.Б.)

Нормоконтролер: _______________ Явнюк А. А.
(підпис) (П.І.Б.)

КИЇВ 2021

NATIONAL AVIATION UNIVERSITY

Faculty of Environmental Safety, Engineering and Technologies

Department of Environmental Science

Specialty, Educational and Professional Program: specialty 101 “Ecology”, Educational And Professional Program: “Ecology and Environment Protection”

(code,name)

APPROVED
Head ofthe Department
____________Dudar T.V.
«____»__________2021

MASTER THESIS ASSIGNMENT

Oksana A. Zhuravel

1. Theme: «Assessment of the wildfires impact on the ecosystems of the Chornobyl Exclusion Zone» approved by the Rector on September 15, 2021, № 1872/ст.

2. Duration of work: from 15.09.2021 to 29.12.2021

3. Output work (project): dataset on wildfire in the Chornobyl Exclusion Zone, analytical diagrams, literary and scientific sources, legislative documents, statistical database, reports from the Chornobyl Radiation and Ecological Biosphere Reserve and Administration of the Chornobyl Exclusion Zone.

4. Content of explanatory note: (list of issues): review of the literature on the diploma topic, assessment on the wildfire impact on different components of the environment (air, water, biodiversity etc); calculations on the losses as a result of wildfires.

5. The list of mandatory graphic (illustrated materials): tables, figures, graphs.

6. Schedule of the sisfulfillment

№	Task	Term	Advisor's signature
1	Obtaining topics, tasks, searching for literary sources	20.09.2021-24.10.2021	
2	Drawing up a calendar plan for a master's thesis	22.09.2021	
3	Preparation of the main part (Chapter I)	08.10.2021-19.10.2021	
4	Preparation of the main part (Chapter II)	20.10.2021-08.11.2021	
5	Preparation of the main part (Chapter III)	09.11.2021-29.11.2021	
6	Formulation of conclusions and recommendations of the master's thesis	03.12.2021-12.12.2021	
7	Preparation of the section on labor precaution	01.12.2021 - 13.12.2021	
8	Checking the work of the head	14.12.2021	
9	Consultation with the normocontroller	17.12.2021	
10	Registration of the diploma work according to requirements of the operating standards	19.12.2021	
11	Protection of qualification work	29.12.2021	

7. Consultant(s) of certain chapter(s):

Chapter	Consultant (academic rank, S.N.P)	Date,signature	
		Given by	Accepted by
Labor Precaution	Kazhan Kateryna I. PhD, Associate Professor of the Department of Civil and Industrial Safety		

8. Date of task issue: «15» September 2021

Diploma (project) advisor: ________________ TAMARA Dudar
(advisor'ssignature) (S.N.P.)

Task is taken to perform: ________________ OKSANA Zhuravel
(graduate'ssignature) (S.N.P.)

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Факультет екологічної безпеки, інженерії та технологій

Кафедра екології

Спеціальність, освітньо-професійна програма: спеціальність 101 «Екологія», ОПП «Екологія та охорона навколишнього середовища»

(шифр, найменування)

ЗАТВЕРДЖУЮ
Завідувач кафедри
___________Дудар Т. В.
«____»__________2021р.

ЗАВДАННЯ
на виконання дипломної роботи
Журавель Оксани Анатоліївни

1. Тема роботи «Оцінка впливу лісових пожеж на екосистеми Чорнобильської зони відчуження» затверджена наказом ректора від«15» вересня 2021 р. №1872/ст.

2. Термін виконання роботи: з 15.09.2021 р. по 29.12.2021 р.

3. Вихідні дані роботи: дані про лісові пожежі в Чорнобильській Зоні Відчуження, літературні та наукові джерела, законодавчі документи, аналітичні діаграми, статистична база даних, звіти Чорнобильського Радіаційно-екологічного Біосферного Заповідника та Адміністрації Чорнобильської Зони Відчуження.

4. Зміст пояснювальної записки: огляд літератури з дипломної теми, оцінка впливу лісових пожеж на різні компоненти навколишнього середовища (повітря, вода, біорізноманіття тощо); розрахунки збитків від лісових пожеж.

5. Перелік обов’язкового графічного (ілюстративного) матеріалу: таблиці, рисунки, графіки.

6. Календарний план-графік

№ з/п	Завдання	Термін виконання	Підпис керівника
1	Отримання теми,завдання, пошук літературних джерел	20.09.2021- 24.10.2021	
2	Складання календарного плану магістерської Роботи	22.09.2021	
3	Підготовка основної частини (Розділ I)	08.10.2021- 19.10.2021	
4	Підготовка основної частини (Розділ I I)	20.10.2021- 08.11.2021	
5	Підготовка основної частини (Розділ I I I)	09.11.2021- 29.11.2021	
6	Формулювання висновків та рекомендацій дипломної роботи	03.12.2021- 12.12.2021	
7	Підготовка розділу з охорони праці	01.12.2021 - 13.12.2021	
8	Перевірка дипломної роботи керівником	14.12.2021	
9	Консультація з нормоконтролером	17.12.2021	
10	Оформлення дипломної роботи згідно вимог діючих стандартів	19.12.2021	
11	Захист роботи на кафедрі	29.12.2021	

7. Консультація з окремого(мих) розділу(ів):

Розділ	Консультант (посада,П.І.Б.)	Дата, підпис	
		Завдання видав	Завдання прийняв
Охорона праці	Кажан К.І., к.т.н., доцент кафедри промислової та цивільної безпеки ФЕБІТ НАУ		

8. Дата видачі завдання: «15 » вересня 2021р.

Керівник дипломної роботи (проекту): ____________ Дудар Т.В.
(підпис керівника) (П.І.Б.)

Завдання прийняв до виконання: ____________ Журавель О. А.
(підпис випускника) (П.І.Б.)

ABSTRACT

Explanatory note to thesis « Assessment of the wildfires impact on the ecosystems of the Chornobyl Exclusion Zone »: 109 pages, 14 figures, 12 tables, 71 references.

Object of research – assessment of the wildfire impact on the environment components within and in the vicinity of the Chornobyl Exclusion Zone.

Aim of research – to overview and assess the impact of wildfires on the environment components.

Methods of research: comparison, generalization, descriptive, analytical, and calculation methods.

The thesis investigated the main factors of impact of wildfires on various components of the ecosystem within the Chornobyl Exclusion Zone, as well as financial losses from fires on the example of April 2020.

WILDFIRE, CHORNOBYL EXCLUSION ZONE, IMPACT ON THE ENVIRONMENTAL COMPONENTS, DAMAGE AND LOSSES, BIODIVERSITY, RADIATION AND ECOLOGICAL BIOSPHERE RESERVE, CHORNOBYL DISASTER, CONTAMINATION

CONTENT

LIST OF SYMBOLIC NOTATIONS, ABBREVIATIONS AND NOTIONS

ChEZ - Chornobyl Exclusion Zone;

Chornobyl Reserve - Chornobyl Radiation and Ecological Biosphere Reserve;

Chornobyl NPP - Chornobyl Nuclear Power Plant;

WDPA - World Database on Protected Area;

IUCN - International Union for Conservation of Nature;

UNEP-WCMC - United Nations World Conservation Monitoring Center.

INTRODUCTION

Relevance of the work. Nowadays, the global urgency of the problems related to the accident at the Chernobyl Nuclear Power Plant, its scale of influence emphasizes the need for a comprehensive approach to the analysis and solution of environmental safety of the Chernobyl Exclusion Zone. One of the main reasons for the spread of radiation danger is wildfires. They also have a negative impact on the ecosystem, with fires affecting all its components. Also, the statistics of the number of fires does not have a strong downward trend. Therefore, assessing the impact of wildfires on ecosystems is an important task.

Aim and tasks of the diploma work

Aim of the work – to overview and assess the impact of wildfires on the environment components.

Tasks of the work:

1. To overview and analyze the current ecological conditions within the Chornobyl Exclusion Zone including the Chornobyl Radiation and Ecological Biosphere Reserve and radiation background within and in the vicinity of it.

2. To characterize and evaluate the impact on the atmospheric air, water bodies, and soils as a result of wildfires.

3. To compare the impact of wildfire consequences on the Chornobyl flora and fauna.

4. To calculate the ecosystem losses as a result of wildfire damage.

Object of research is the process of assessment of the wildfire impact on the environment components within and in the vicinity of the Chornobyl Exclusion Zone

Subject of research - ecosystems within the Chornobyl Exclusion Zone and their current conditions.

Methods of research – comparison, generalization, description, analysis and calculation.

Scientific novelty of the obtained results. The wildfire impact on the environmental components are systematized and generalized based on the ecosystem approach.

Practical importance of the obtained results. The diploma results can be practically used when environmental research within the Chornobyl Radiation and Ecological Biosphere Reserve as well as in order to provide quality ecosystem services

Personal contribution of the graduate: the idea, content, and practical realization were made independently in the form of preparation and analysis of theoretical part of the work; analysis of literature and processing of data.

Approbation of results. The diploma results were presented at:

1. Міжнародна науково-практична конференція за участю молодих науковців «ГАЛУЗЕВІ ПРОБЛЕМИ ЕКОЛОГІЧНОЇ БЕЗПЕКИ – 2021» 27 жовтня 2021, Харків.
2. IV Всеукраїнська науково-практична конференція - Сучасні екологічні проблеми урбанізованих територій (10 грудня 2021 року).

Publications*:*

1. Zhuravel O., Dudar T. Overview of forest fires impact within the Chornobyl Exclusion Zone. *Галузеві проблеми екологічної безпеки – 2021 (*Харків, 27 жовтня 2021). Харків. 2021. С. 29-31.
2. Zhuravel O., Dudar T. Fire hazard for the residential areas located in the vicinity of the Chornobyl Excluzion Zone. *Сучасні екологічні проблеми урбанізованих територій* (Житомир, 10 грудня 2021 року). Житомир. 2021.

CHAPTER 1

RADIATION CONDITIONS WITHIN AND IN THE VICINITY OF THE CHORNOBYL EXCLUSION ZONE

1.1. Current state of radiation pollution of the Chornobyl Exclusion Zone

The accident led to an unprecedented release of radioactive substances into the atmosphere and long-term pollution of large parts of Europe and adjacent sea areas. The release of radioactive substances continued with varying intensity for more than 10 days. All its characteristics (intensity, altitude, radionuclide and physicochemical composition) changed over time in a complex manner. In a number of regions, the passage of radioactive clouds coincided with the movement of thunderstorm fronts, which led to a high intensity of wet radioactivity fallout. In many cases, especially in remote regions of Europe, the mountainous terrain has played a decisive role in the formation of pollution. As a result, the nature of the pollution of territories located at a distance of hundreds and thousands of kilometers from the emergency unit turned out to be highly heterogeneous. [1].

Territories that suffered from radioactive contamination as a result of the Chornobyl catastrophe within Ukraine belong to the territories where there is a persistent contamination of the environment with radioactive substances above the pre-emergency level, taking into account the natural, climatic and complex ecological characteristics of specific areas may expose the population to more than 1.0 MSv per year, and which requires measures to protect the population and other special interventions aimed at limiting the additional exposure of the population caused by the Chornobyl disaster and ensuring its normal economic activities [2].

The Chornobyl cloud, before dissolving for centuries in the stratosphere, circled the Earth at least twice, leaving traces mainly in the Northern Hemisphere (Fig. 1.1). An analysis of the features of the fallout of radionuclides several years after the disaster showed that most of the long-lived Chornobyl radionuclides settled on the territory outside Belarus, Ukraine and the European part of Russia [3].

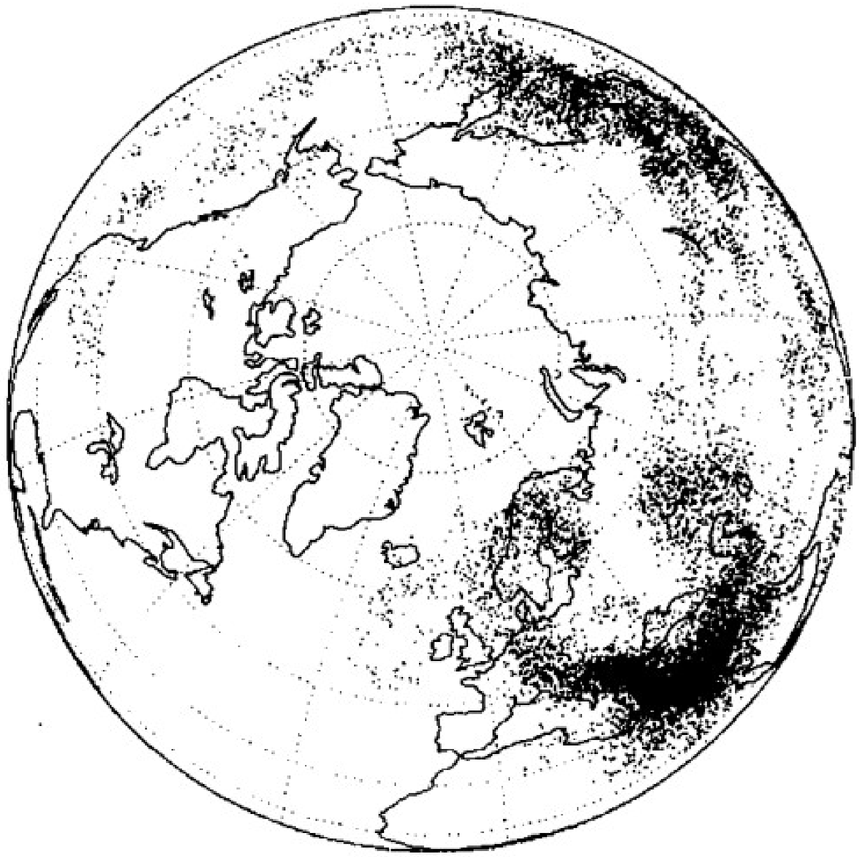

Fig. 1.1. One of the options for modeling the spatial distribution of Chornobyl radionuclides in the Northern Hemisphere 10 days after the Catastrophe

According to the summary data, Europe accounted for 68–89% of the gas-aerosol radionuclides that settled on land from the Chornobyl clouds. They were distributed extremely unevenly. During the active release from the reactor (from April 26 to May 5, 1986), the wind around Chornobyl turned 360°, as a result of which radiation releases (of different radionuclide composition on different days) covered a large area [3].

During this accident, which is the largest in the history of nuclear energy and received the status of a global catastrophe, at an altitude of 7 km, according to official estimates in 1986, more than 1.85×10^{18} Bq of a mixture of radioactive isotopes was released in the form of an aerosol. According to some other estimates, the environment received about 1×10^{17} Bq ^{137}Cs (almost half of its content in the reactor core), about 8×10^{15} Bq 90Sr and more than 1×10^{14} Bq transuranic elements - $^{238-241}Pu$, ^{241}Am, $^{242-244}Cm$. Radionuclide contamination above 37 kBq / m^2 (1 Ki / km^2 - the boundary separating contaminated radioactive cesium and relatively clean areas) was an area of more than 200 thousand km2 at the junction of Ukraine, Belarus and Russia, home to more than 6 million people . Almost 360,000 people were evacuated from the contaminated areas. More than 3,000 km^2 of land were withdrawn from land use.

Radioactive contamination during the Chornobyl accident was caused by three types of precipitation: solid high-level radioactive aerosols of different dispersion, the gas phase of individual radionuclides and radionuclides located in the graphite matrix. The last specific type of radioactive particles was formed during the combustion of graphite blocks, which are used in nuclear reactors as a neutron moderator [4].

The comprehensive system of radiation monitoring and early warning in the ChEZ was developed to expand the functions of the modernized automated radiation control system and improve the processes of continuous control and monitoring of radiation (radioecological) state of the environment in the ChEZ, as well as beyond.

The Integrated Radiation Monitoring and Early Warning System integrates a network of automated monitoring posts that continuously monitor the environment and transmit the data via a radio channel, which is most appropriate for use in the ChEZ, which does not have a developed lead infrastructure.

Software integrated system of radiation monitoring and early warning based on collected data on-line reflects the current radiation situation, and, using the Lagrange model, analyzes data on radioactivity and meteorological parameters, provides forecast calculations of direction and size of radioactive contamination and quantitative and quantitative characteristics at certain intervals.

The complex system of radiation monitoring and early warning has integrated subsystems: automatic radiation monitoring system of the ChEZ; data integration system to control the non-proliferation of radioactive substances and nuclear materials.

The composition of a comprehensive system of radiation monitoring and early warning:

- 69 automated gamma-ray control stations (including automatic radiation monitoring system);
- 4 land and 1 altitude meteorological stations;
- 20 air sampling stations;

- post of automated control of aerosol radioactivity;
- 3 automated water control posts (including groundwater);
- a set of dosimetric equipment for use on site;
- system, presentation software and communication programs;
- central post in Chornobyl;
- remote central post in Kyiv [5].

The State Nuclear Regulatory Inspectorate of Ukraine has issued an Order "On Approval of General Safety Provisions for Radioactive Waste Management before Disposal", where one of the items is radiation and dosimetric control of entities operating in the field of radioactive waste management [6].

There are radiation and nuclear facilities, a system of radiation and environmental control and monitoring, infrastructure facilities that need to be decommissioned, transferred to an environmentally safe state and ensure development in the interests of the state, including the nuclear energy complex.

Today, activities in the ChEZ are carried out in the following areas:

- supporting the barrier function and ensuring the functioning of infrastructure facilities;
- decommissioning of the Chornobyl Nuclear Power Plant (Chornobyl NPP) and transformation of the Shelter facility into an environmentally safe system;
- safe management of radioactive waste, including that generated by the Chornobyl disaster and spent nuclear fuel;
- maintaining the safety of radioactive waste disposal facilities built after the Chornobyl disaster;
- cleaning and decontamination of contaminated territory.

The situation with radioactive waste has become much more complicated since the Chornobyl disaster, which resulted in hundreds of thousands of cubic meters of radioactive waste of various categories and types.

Radioactive waste of Chornobyl origin is currently located at radioactive waste disposal sites, temporary localization of radioactive waste, at the Shelter facility and outside the ChEZ. A large amount of radioactive waste of Chornobyl origin is long-lived.

A significant part of them is stored in conditions that do not fully meet the norms, rules and standards of radiation safety.

Since independence in Ukraine, approaches to ensuring the safety of radioactive waste management have been revised based on the recommendations of the International Atomic Energy Agency and other international organizations, which have accumulated the experience of countries with significant practical experience and developed infrastructure for safe radioactive waste management.

New approaches are reflected in the national laws and regulations of Ukraine. However, there is a need for their further implementation and application in practice [7]

The network of radiation and environmental monitoring of the ChEZ includes about 400 points, sites and observation points for various purposes (personnel production sites, landscape landfills, hydrological sites, ground atmosphere sampling points, tablets of radioactive fallout from the atmosphere, observation wells points, etc.).

Analytical materials prepared for the subjects of the monitoring system on radiation status and changes in the environment of the ChEZ are the basis for the development and adoption of management decisions to implement measures to minimize the consequences of the Chornobyl accident in terms of radionuclide removal the boundaries of the ChEZ [8].

Physical volumes of scheduled work in 2020 amounted to: 4362 samples were taken, 16094 field and 9839 laboratory measurements were performed. These works allowed us to assess the radiation status of the main components of the natural and man-made environment. The frequency of measurements was determined depending on the parameter being monitored and the means of measurement and varied from 1 time per hour to 1 time per year.

In general, the radiation status of the ChEZ in 2020 remained unchanged. It is necessary to note separately the circumstances of natural and man-made nature that affected the radiation situation in the ChEZ, namely: meteorological conditions, fires, biological factors, economic activity in the ChEZ; the fall in the water level in the cooling reservoir has led to an increase in the volumetric activity of radionuclides in certain water bodies [8].

From the general point of view, the ChEZ is the epicenter of the Chornobyl accident. It is here that the radiation impact of the catastrophe on the environment and humans has reached the most dangerous values. There are radiation-hazardous objects on the territory of the ChEZ: storage facilities for radioactive waste in the decommissioning stage, Shelter Object, three storage facilities for radioactive waste disposal sites, more than 800 temporary unequipped disposal sites for temporary localization of radioactive waste. In addition, there is a hydraulic structure - a cooling reservoir of the Chornobyl NPP, which in terms of radionuclides in water, bottom sediments and biological objects is essentially a point of temporary localization of radioactive waste. Huge reserves of radionuclides are located on the territory of the ChEZ (table 1.1) [9].

Monitoring of radionuclide contamination of the surface layer of the atmosphere (at a height of 1 m above the ground) in the ChEZ is carried out according to the following parameters:

- concentration of radionuclides in the surface layer of the atmosphere (performed at 4 observation points in the near zone of the Chornobyl NPP and 9 points in the far zone of the Chornobyl NPP, as well as at two production plants;
- intensity of atmospheric radioactive fallout (performed in 29 observation points);
- the content of "hot" particles in the surface layer of the atmosphere (performed in 9 observation points).

Table 1.1

Stocks of radionuclides in natural and man-made objects of the ChEZ

Object	Activity, Bq			
	total	^{137}Cs	^{90}Sr	Transuranic elements
Exclusion zone area (soils, forests, water bodies, etc.)	$8{,}13\times10^{15}$	$5{,}5\times10^{15}$	$2{,}5\times10^{15}$	$1{,}3\times10^{14}$
Radioactive waste disposal sites	$5{,}5\times10^{15}$	$3{,}6\times10^{15}$	$1{,}8\times10^{15}$	$9{,}0\times10^{13}$
Points of temporary localization of radioactive waste	$2{,}14\times10^{15}$	$1{,}4\times10^{15}$	$7{,}0\times10^{14}$	$4{,}0\times10^{13}$
Cooling reservoir	$2{,}2\times10^{14}$	$1{,}9\times10^{14}$	$3{,}0\times10^{13}$	$2{,}0\times10^{12}$
Total	$\mathbf{1{,}6\times10^{16}}$	$\mathbf{1{,}0\times10^{16}}$	$\mathbf{5{,}0\times10^{15}}$	$\mathbf{2{,}6\times10^{14}}$
Chernobyl Nuclear Power Plant sarcophagus	$3{,}4\times10^{17}$	$1{,}9\times10^{17}$	$1{,}4\times10^{17}$	$4{,}5\times10^{15}$

Regular work on the control of radiation pollution of the surface layer of the atmosphere in the far zone of observation is performed at the control points of Automated Radiation Monitoring System (Fig. 1.2). This also includes the places where the staff of the ChEZ stayed for the longest time - the city of Cheornobyl and the checkpoint «Dityatki". Throughout the monitoring of the ChEZ, there is a steady trend to reduce the concentration of radionuclides of "Chornobyl" origin in the air and, consequently, reduce the total radioactive contamination of the surface atmosphere in the near and far of ChEZ [7].

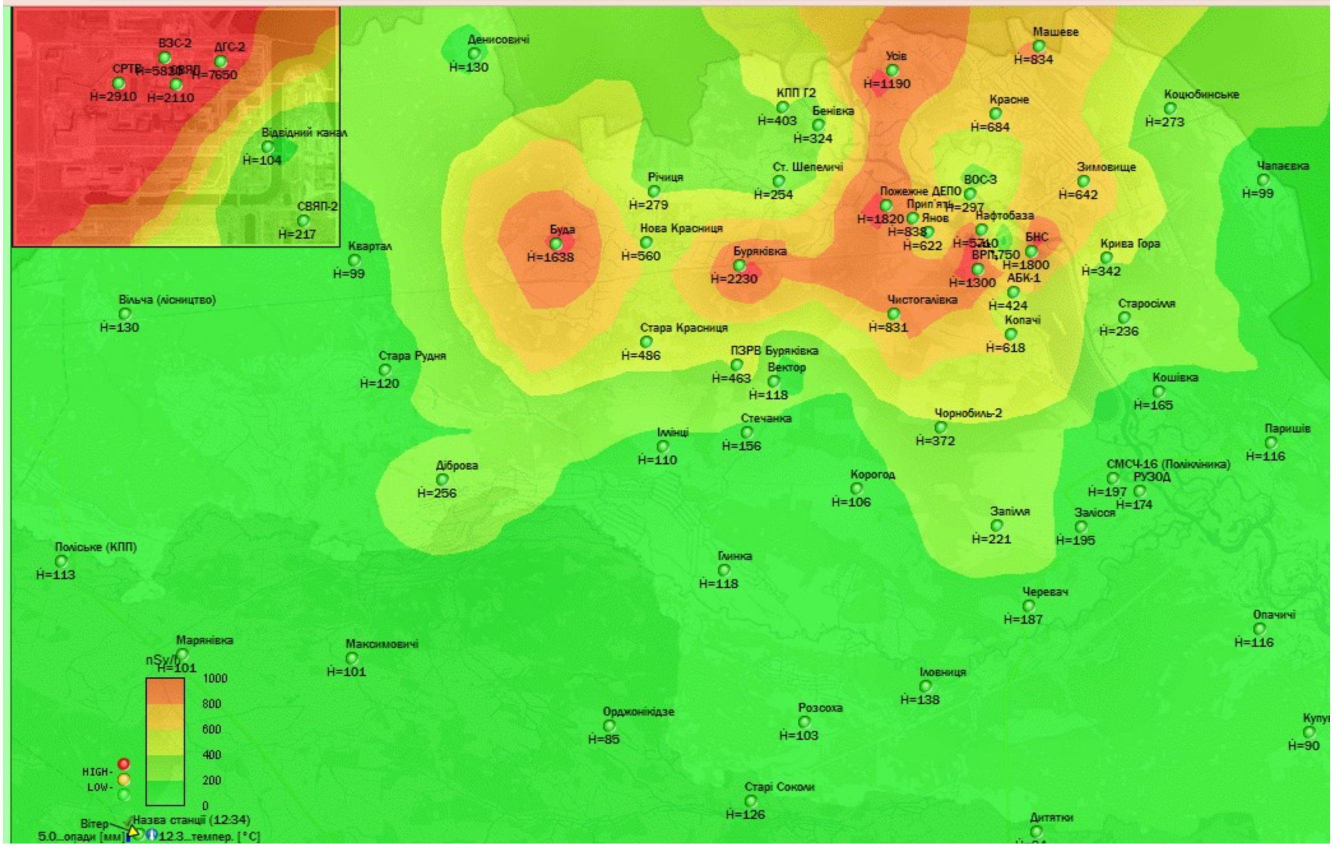

Fig. 1.2. Map of the distribution of radiation dose rates in the ChEZ (November 2021)

At the Chornobyl control point (ChEZ, distance to the Chornobyl NPP 16 km), the average volume activity of cesium-137 in atmospheric aerosols in 2018 was 2.05–10^{-5} Bq / m^3, the volume activity of strontium-90 was 0–0,25*10^{-5} Bq / m^3 (in 2017 2.18*10^{-5} Bq / m^3 and 0.27*10^{-5} Bq / m^3, respectively). The density of cesium-137 was 17.1 Bq / m^2 per year, strontium-90 - 18.9 Bq / m^2 per year (in 2017 17.8 Bq / m^2 per year and 19.9 Bq / m^2 per year, respectively).

According to the State Specialized Enterprise "Ecocenter" of the State Agency of Ukraine for ChEZ Management, the volume activity of strontium-90 in river water during the year ranged from 28 to 260 Bq / m^3 and averaged 91 Bq / m^3 per year (in 2017 - 68 Bq / m^3); the volume activity of cesium-137 was in the range of 12-214 Bq / m^3 with an average value of 54 Bq / m^3 (in 2017 - 35 Bq / m^3).

The removal of strontium-90 by the waters of the Pripyat River in the Chornobyl area in 2018 was 1.15 × 10^{12} Bq, which is 60% more than the removal in 2017. The annual removal of cesium-137 was 0.64 × 10^{12} Bq - 60% more than the previous year. The removal rates of strontium-90 and cesium-137 in 2018 were among the lowest since the accident, but the highest in five years [10].

The ChEZ remains an open planar source of radioactivity with its own distribution structure, the presence of various forms of radioactive elements. The main criterion of radioactively contaminated areas is the density of soil contamination with radionuclides, which reflects the possibility of obtaining an additional dose of radiation of different magnitudes. The main dose-forming radionuclides in the ChEZ are ^{137}Cs, ^{90}Sr and transuranic elements (^{238}Pu, $^{239+240}$Pu and ^{241}Am).

Since the Chornobyl accident, ^{90}Sr and ^{137}Cs pollution levels have decreased by one half-life since the disaster. However, after one half-life of ^{137}Cs, about 91% of the territory remains in the ChEZ with a soil contamination density above 1 Ki / km^2 (37 kBq / m^2), according to preliminary estimates. Throughout the post-accident period, the bioavailability of 90Sr has increased due to its leaching from fuel particles, which has now reached its maximum value. The largest ^{137}Cs air pollution of the ChEZ was registered at the control points of the near zone (5-km around the Chornobyl NPP).

Due to radioactive decay, the activity of alpha-emitting ^{238}Pu decreased by 24%, and the activity of $^{239+240}$Pu did not change. Due to the breakdown of the beta-emitting ^{241}Pu, the alpha-emitting ^{241}Am continues to accumulate, which is added to the 1986 ^{241}Am emissions. Today, the activity of ^{241}Am is higher than the activity of $^{238+239+240}$Pu and it will increase over the next 50 years by 16%, which is the main radiation hazard of the ChEZ until 2070.

The main source of concentration of radioactive elements is the soil cover. The main migration routes of radionuclides are aquatic, to a lesser extent air, biogenic and anthropogenic (man-made). Due to their bioavailability, ^{90}Sr and ^{137}Cs are actively entering phyto- and biomass. Specialized units are taking measures to prevent the removal of radionuclides outside the ChEZ.

Monitoring of the radiation status of surface waters is carried out in 22 points. Particular attention is paid to the Pripyat River, through which radionuclides are transferred from the territory of the Armed Forces to the Kyiv Reservoir. In 2020, the average and maximum values of ^{90}Sr in the water of the Pripyat River in the Chornobyl area were 43 Bq / m^3 and 74 Bq / m^3, respectively, ^{137}Cs - 20 and 129 Bq / m^3, which does not exceed the normative document of the permissible levels of radionuclides for drinking water (2000 Bq / m^3) [8].

1.2. Chornobyl Exclusion Zone today

The territory of the ChEZ belongs to the zone of temperate continental climate with a positive moisture balance. The positive moisture balance indicates that not all the moisture that comes with precipitation is spent on evaporation. This type of climate is characterized by relatively high temperatures and low relative humidity in summer and low temperatures, high humidity and the presence of snow cover in winter. Thus formation of climate occurs under the influence of both sea, and continental air streams. The spring period is characterized by an active rise in temperatures, intense melting of snow cover and rapid drying of the soil. Summer is set in mid-May. The warmest month of the year is July. The summer period is characterized by heavy rains and lower temperatures due to the passage of western cyclones.

The ChEZ is located within the physical-geographical region of Kyiv Polissya - Polissya Lowland - Eastern European Plain [12].

The ChEZ, located in the north of the Kyiv region of Ukraine, was formed as a result of radioactive contamination of the territory after the accident at the 4th power unit of the Chornobyl NPP. Its area is 36,545 thousand hectares. The perimeter of its border reaches 223.5 km, of which 34 km pass along the border with Belarus. There are 76 settlements. In particular, the ChEZ includes the northern territory of the former Ivankiv district of Kyiv region, where the cities of Chornobyl and Pripyat are located, the northern territory of the former Polissya district of Kyiv region (including Poliske and Vilcha), and part of Zhytomyr region to the border with Belarus. More than 90,000 residents of picturesque Polissya have left their homes forever. In recent years, the ChEZ has been the subject of active research by representatives of various fields of knowledge, including foreign researchers.

Rivne, Zhytomyr, Kyiv and Chernihiv oblasts accounted for 82.4% of the total area of radioactively contaminated territories of Ukraine and 66.4% of settlements, as well as 77.8% of the population recognized as residents of radioactively contaminated areas [13].

The State Agency of Ukraine for ChEZ Management is a central executive body whose activities are directed and coordinated by the Cabinet of Ministers of Ukraine through the Minister of Ecology and Natural Resources of Ukraine.

The State Agency of Ukraine for ChEZ Management, as the central executive body, aims to continuously improve the quality of management in overcoming the consequences of the Chornobyl disaster, creating conditions for creative, motivated, transparent and responsible approach in implementing production programs, international technical assistance, and to eradicate corruption, inaction and inefficient use of budget funds.

To date, Acting Chairman of the Agency - Kramarenko Eugene Hryhorovych [14].

The main tasks of the State Agency of Ukraine for ChEZ Management are:

1) implementation of state policy in the field of management of the ChEZ and the Exclusion Zone and Zone of Unconditional (Mandatory) Resettlement, overcoming the consequences of the Chornobyl disaster, decommissioning of the Chornobyl NPP and transformation of the Shelter into an environmentally safe system, as well as public administration in the field of radioactive waste;

2) submission to the Minister of Environmental Protection and Natural Resources of proposals to ensure the formation of state policy in the management of the ChEZ and Exclusion Zone and Zone of Unconditional (Mandatory) Resettlement, overcoming the consequences of the Chornobyl disaster, decommissioning of the Chornobyl NPP and transformation of the Shelter into environmental safe system, radioactive waste management [15].

The ChEZ and the Exclusion Zone and Zone of Unconditional (Mandatory) Resettlement have a special form of management, and its lands are withdrawn from economic circulation and separated from adjacent territories. On the territory of the ChEZ and the Exclusion Zone and Zone of Unconditional (Mandatory) Resettlement there are radiation-nuclear facilities, a system of radiation-environmental control and monitoring, infrastructure facilities that need to be decommissioned and transferred to an environmentally safe state to ensure radiation safety taking into account the interests of the state, in particular the nuclear energy complex [16].

ChEZ and Exclusion Zone and Zone of Unconditional (Mandatory) Resettlement are areas with strictly limited access and movement, which are governed by a block of special laws and regulations. The status of the ChEZ and the Exclusion Zone and Zone of Unconditional (Mandatory) Resettlement is determined by the legislation of Ukraine, in particular, the Law of Ukraine "On the Legal Regime of the Territory Contaminated by Radioactive Contamination as a Result of the Chornobyl Accident". According to the current legislation:

- the ChEZ is the territory from which the population was evacuated in 1986;
- ChEZ and Zone of Unconditional (Mandatory) Resettlement is an area that has been intensively contaminated with long-lived radionuclides, with a density of soil contamination above the pre-emergency level of cesium isotopes of 15.0 Ki / km^2 and above, or strontium of 3.0 Ki / km^2 and above, or plutonium of 0,1 Ki / km^2 and above, where the estimated effective equivalent dose of human exposure, taking into account the migration factors of radionuclides in plants and other factors, may exceed 5.0 mSv (0.5 ber) per year in excess of the dose it received in pre-accident period [18].

Land, water and forest resources of the ChEZ, which act as a natural barrier to the spread of radioactive contamination beyond its borders, require constant monitoring, maintenance and use in compliance with radiation safety requirements.

Areas affected by the Chornobyl disaster include areas in Ukraine that have been persistently contaminated with radioactive substances in excess of the pre-accident level, which, taking into account the natural, climatic and complex ecological characteristics of specific areas, may lead to public exposure. 1.0 mSv per year, and which requires measures to protect the population and other special interventions aimed at limiting the additional exposure of the population caused by the Chornobyl disaster and ensuring its normal economic activity.

Depending on the landscape and geochemical characteristics of soils, the magnitude of exceeding the natural pre-emergency level of accumulation of radionuclides in the environment, the associated degrees of possible adverse effects on public health, radiation protection requirements and other special measures, taking into account general production and social and domestic relations, the territory affected by radioactive contamination as a result of the Chornobyl disaster is divided into zones [16].

The boundaries of the zones are established and reviewed by the Cabinet of Ministers of Ukraine on the basis of expert opinions of the National Academy of Sciences of Ukraine, central executive bodies that ensure the formation of state policy in health care, ChEZ management and catastrophes, environmental protection, safety of nuclear energy use, the central executive body that implements state policy in the field of supervision (control) 4 in the agro-industrial complex, at the request of regional councils and approved by the Verkhovna Rada of Ukraine [17].

Zone I (10-km zone) - the area within a 10-km radius around the Chornobyl NPP, where the main work related to the liquidation of the Chornobyl disaster (radiation-hazardous work) carried out under the programs , agreed with regulatory authorities in accordance with current regulations on radiation safety of Ukraine. If necessary, according to the results of radiation dosimetric control, especially dangerous work is carried out in accordance with special regulations on orders-permits. The territory is divided into two parts, which differ in the density and composition of radionuclide contamination and the nature of activity:

- territory of special danger - the area where work is underway to transform the Shelter into an environmentally safe system, radioactive waste management, decommissioning of the Chornobyl NPP, protection of the Pripyat floodplain from flooding, sanitary and fire safety measures in forests;
- high-risk area - an area where elements of production activities and infrastructure of the ChEZ and the Exclusion Zone and Zone of Unconditional (Mandatory) Resettlement, which provide production activities, are concentrated.

Various regulations on labor protection and radiation protection of personnel are envisaged in these territories.

Zone II (buffer) - the area from the border of the 10-km zone to the outer border of the ChEZ (except for Chornobyl) with a low density of radioactive contamination, promising for return to economic use. This area is characterized by limited activities.

Within its limits, reforestation measures are envisaged, taking into account the prospect of returning this territory to economic use. Some sites can be used as research and other landfills. The buffer zone includes a protected area (at least 10 percent of natural lands). In the territory of the protected zone the regime is observed, which excludes the violation of the natural course of self-restoration of ecosystems by limiting the stay of personnel in accordance with the status of the reserve. Work within this zone is performed in accordance with monthly schedules.

Zone III (location of shift personnel) - connects the part of the territory of Chornobyl, which houses dormitories and administrative buildings together with adjacent areas, catering and trade, socio-cultural, medical and sanitary purposes, access roads to them [18].

The ChEZ and the Zone of Unconditional (Mandatory) Resettlement are located on the territory of the former Ivankiv and Polissya districts of the Kyiv region and the Narodytsky and Ovruch districts of the Zhytomyr region. On July 17, 2020, the Verkhovna Rada of Ukraine adopted the Resolution “On the formation and liquidation of districts” for № 807-IX. This Resolution provides, in particular, the formation of:

- Vyshhorod district of Kyiv region as a part of the territories of Vyshhorod city, Dymersk settlement, Ivankiv settlement, Petriv village, Pirniv village, Polissya settlement, Slavutych city territorial communities;
- Korosten district of Zhytomyr region as a part of the territories of Bilokorovytsia village, Gladkovytsia village, Gorshchykivska village, Irshanska village, Korosten city, Luhyn village, Malyn city, Narodytsia village, Ovruch city, Olevsk city, rural village Choloshovy village.

Assignment of the territory of the ChEZ and the resettled part of the Exclusion Zone and Zone of Unconditional (Mandatory) Resettlement to the territorial communities contradicts the law and violates the legal regime of the territory that was radioactively contaminated as a result of the Chornobyl disaster [16].

As for the territory of the Chornobyl Radiation and Ecological Biosphere Reserve (Chornobyl Reserve), it includes the lands of the former forest complex "Northern Forest", in particular, fully included the former Denisovitskoe, Parishivske, Kotovske, Dityatkivske and Opachytske forests, partially - Lubyanskoe and Korogodskoe. The organizational structure of the Chornobyl Reserve on 01.01.2020 is presented in the diagram (Fig. 1.3) [19].

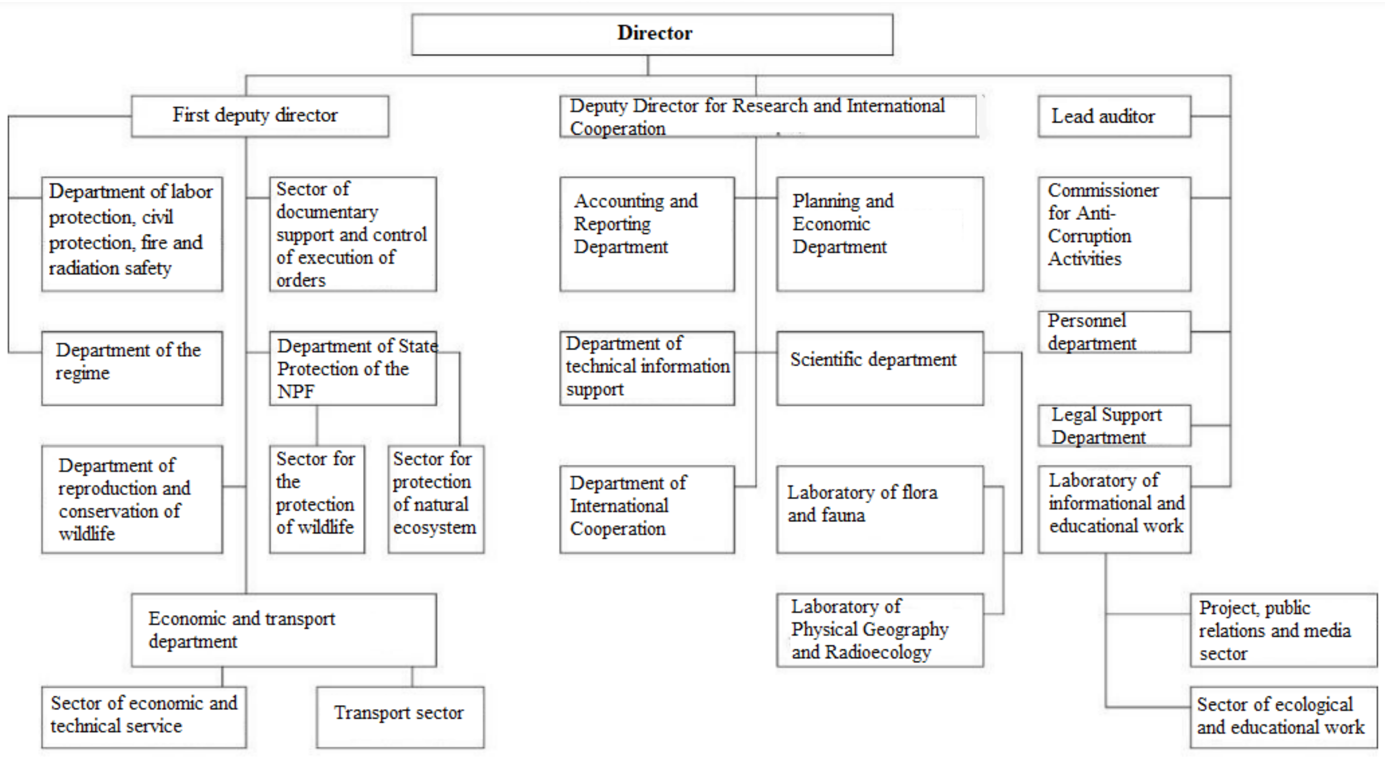

Fig. 1.3. Scheme of the organizational structure of the Chornobyl Reserve

Also one of the main facilities located within the ChEZ is the Shelter facility, which was created to barrier the spread of radioactivity remaining in the destroyed block and to protect personnel, the population and the surrounding area from impact. ionizing radiation and radioactive substances. A localization structure ("sarcophagus") with separate systems was built over the remnants of the 4th Chornobyl NPP unit within six months [20].

On November 30, 1986, the Shelter facility was put into operation. The All-Union Research and Design Institute of Energy Technologies headed the work on burial and decontamination of the territory around the Chornobyl NPP. He also acted as the general designer of the Shelter facility [21].

The peculiarity and complexity of the conservation work of the emergency unit was the lack of experience in overcoming the consequences of such a large-scale accident in both domestic and international practice, as well as the lack of special regulations for the development of design solutions (18 project options were developed).

Thus, the Shelter's building structures are a combination of "old" structures of the destroyed Unit 4 and "new" structures built after the accident. Thanks to this combination, a unique structure was created, the building structures of which perform an extremely important function of a physical barrier to the release of radioactive substances and ionizing radiation into the environment.

In order to carry out construction and installation works on the conservation of the emergency power unit and the construction of the Shelter facility in the system of the Ministry of Medium Engineering of the USSR, the Construction Department № 605 was specially created.

Building structures at that time did not meet the requirements of regulatory and technical documents on safety in terms of structural integrity and had an indefinite service life. Therefore, the facility requires constant monitoring of the condition of structures important for the safety of the Shelter facility, and intervention in the event of a threat of dangerous deviation from their stable condition. Therefore, immediately after the construction of the Shelter facility was completed, research into the condition of its buildings began and continues [22].

1.3. Chornobyl Radiation and Ecological Biosphere Reserve

A few years after the Chornobyl accident, researchers noted the gradual reproduction of fauna and flora: favorable conditions for this were the evacuation of the population and the cessation of economic activity here. Scientists have recorded an increase in the number of typical and rare species of flora and fauna. The forecast for the future was favorable - a slow transformation of anthropogenic landscapes into Polissya natural complexes was expected.

15-20 years after the Chornobyl accident, it became clear that nature is much more powerful even than such a terrible anthropogenic factor as the Chornobyl disaster. The area of several hundred thousand hectares in itself has become a protected area: there have found shelter and comfortable conditions for breeding hundreds of species not only typical but also rare Red Book animals [23].

In 2007, the Chornobyl Special Zoological Reserve of National Importance was established in the Ivankiv district of the Kyiv region by the Decree of the President of Ukraine [24].

The issue of creating a protected area in the ChEZ by scientists and the public has been relevant for a long time. In order to create the reserve from 2013 to 2016, a number of meetings were held with the participation of the National Ecological Center of Ukraine, the Ministry of Ecology and Natural Resources of Ukraine, the State Agency of Ukraine for ChEZ Management, the National Academy of Sciences of Ukraine and other organizations [25].

The Chornobyl Reserve was established by the Decree of the President of Ukraine of April 26, 2016 No. 174 "On the Establishment of the Chornobyl Radiation and Ecological Biosphere Reserve".

The Chornobyl Reserve is located in Ivankiv and Polissya districts of Kyiv region within the ChEZ and the Exclusion Zone and Zone of Unconditional (Mandatory) Resettlement of the territory that was radioactively contaminated as a result of the Chornobyl disaster.

The area of the Chornobyl Reserve is 226964.7 hectares.

The Chornobyl Reserve is a budget, non-profit conservation, research institution of national importance and was created to preserve the natural state of the most typical natural complexes of the biosphere, background environmental monitoring, study of the environment, its changes under the influence of anthropogenic factors.

The Chornobyl Reserve was established to preserve the most typical natural complexes of Polissya, ensure support and increase the barrier function of the ChEZ and the Exclusion Zone and Zone of Unconditional (Mandatory) Resettlement, stabilize the hydrological regime and rehabilitation of areas contaminated with radionuclides, promote the organization and conduct of international scientific research taking into account the Law of Ukraine "On the legal regime of the territory affected by radioactive contamination as a result of the Chornobyl disaster" [25].

The main tasks of the Chornobyl Reserve are:

- providing support and increasing the barrier function of the ChEZ and the Exclusion Zone and Zone of Unconditional (Mandatory) Resettlement;
- stabilization of the hydrological regime and rehabilitation of areas contaminated with radionuclides;
- promoting the organization and conduct of international research;
- minimization of ecological danger and preservation of natural resources of the ChEZ and the Exclusion Zone and Zone of Unconditional (Mandatory) Resettlement;
- preservation in the natural state of the most typical natural complexes of Polissya;
- implementation of background environmental monitoring and radiation situation;
- reproduction and preservation of natural ecosystems;
- conducting periodic inventories of natural resources;
- study of current natural phenomena and processes occurring in ecosystems;
- conducting research in the field of environmental protection;
- preservation of natural diversity of landscapes, gene pool of fauna and flora, maintenance of the general ecological balance;
- observance of the regime of the territory of the ChEZ and the Exclusion Zone and Zone of Unconditional (Mandatory) Resettlement;
- ensuring the protection of the territory of the Reserve with all natural objects;
- prevention of removal of radionuclides from the territory of zones and radioactive contamination of the environment;
- environmental monitoring and medical and biological monitoring;
- maintenance of the territory in proper sanitary and fire safety condition;
- application of methods of fixing radionuclides in the field;
- organization of fire protection of natural complexes;

- conducting environmental educational work, etc [26].

The flora of the Chornobyl Reserve includes 1256 species of vascular plants, 120 species of lichens and 20 species of mosses. Five species of plants from the European Red List grow here (Corispermum hyssopifolium L., Silene lithuanica Zapal, Tragopogon ucrainicus Artemcz, Chamaecytisus lindemannii, Rumex ucrainicus Fisch. ex Spreng). 46 species of flora listed in the Red Book of Ukraine were identified. Plant cenoses included in the Green Book of Ukraine are growing in the reservoirs of the ChEZ. The plant species included in Annex 1 to the Convention on the Conservation of Wildlife and Natural Areas in Europe (Bern, 1979) include: Aldrovanda vesiculosa L., Dracocephalum ruyschiana L., Ostericum palustre (Bess.) and some more [23].

The fauna of the Chornobyl Reserve corresponds, in general, to the composition of the fauna of the Polissya region. More than 300 species of vertebrates (410 in total in the region) have been recorded here, of which 75 species (out of 97 possible) are listed in the Red Book of Ukraine. 14 species of fauna are included in the Red List of the International Union for Conservation of Nature (Nyctalus leisleri, Lutra lutra, Mustela lutreola, Castor fiber, Gapella media, Triturus cristatus, Hyla arborea, Coenonympha oedipus, Formica rufa, Hirudo medicinalis and some more). 16 species from the European Red List have been identified. A significant number of bird species are protected by the Convention on the Conservation of Migratory Species of Wild Animals. Annex 1 of the Berne Convention lists 179 species of fauna.

The main focus of scientists is on the study of rare and typical species of fauna - large predators (brown bear, lynx, wolf) and ungulates (elk, deer, roe deer), whose population has grown significantly in recent years. The unique free population of Przewalski's horses, created in the 1990s, is of great interest to both scientists and visitors to the ChEZ.

Today the species composition of animals in this area corresponds to the natural fauna of this geographical region – Polissya [23].

In accordance with the environmental legislation, the following functional zones are distinguished on the territory of the Chornobyl Reserve (Fig. 1.4).

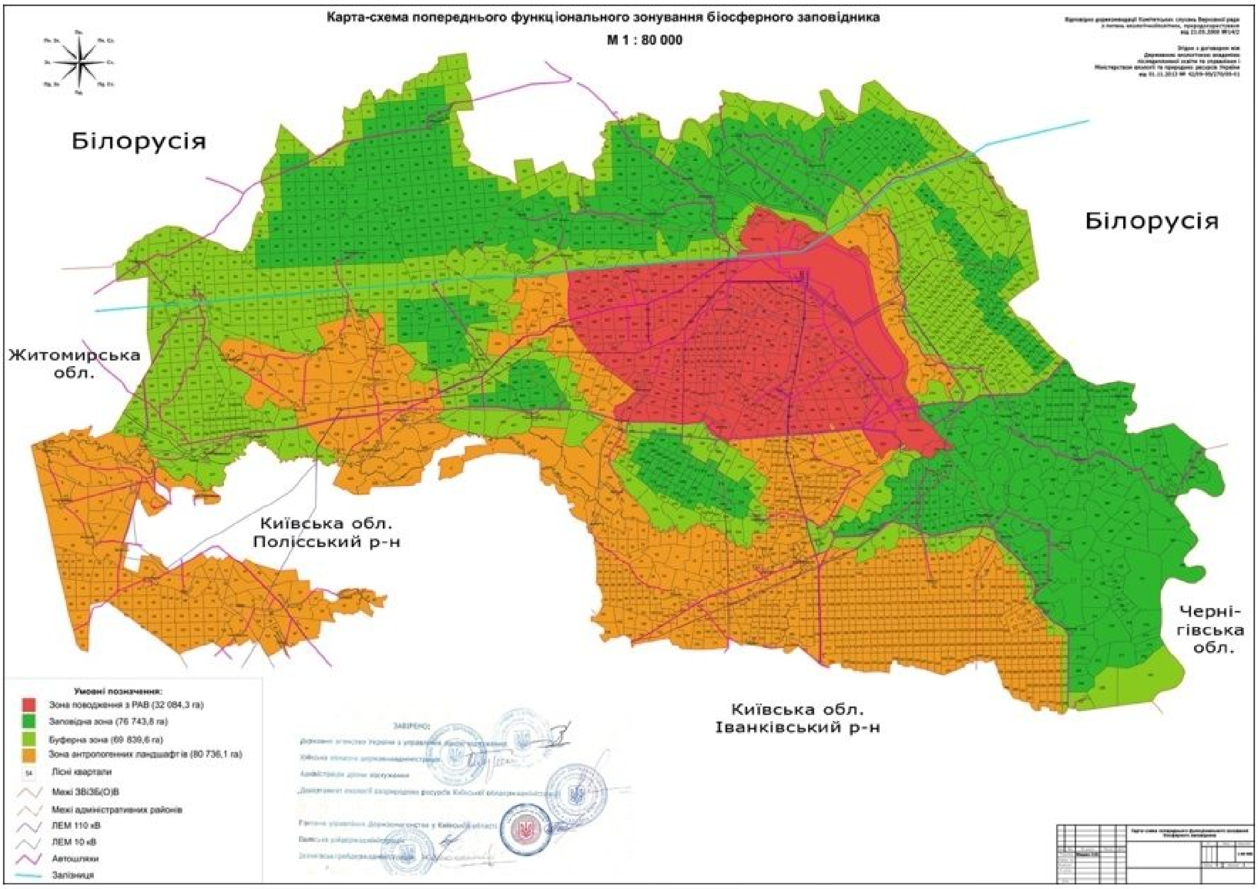

Fig. 1.4. Functional zones on the territory of the Chornobyl Reserve

1. Protected area - the area includes areas designed to preserve and restore the most valuable natural and minimally disturbed by anthropogenic factors of natural complexes, the gene pool of flora and fauna. Any economic and other activities that are contrary to its intended purpose, disrupt the natural development of processes and phenomena or pose a threat of harmful effects on its natural complexes and objects are prohibited on its territory.

2. Buffer - the zone includes the territories allocated for the purpose of prevention of negative influence on a protected zone of economic activity in adjoining territories. This zone includes land adjacent to the protected area and periodically exposed to anthropogenic impact from the surrounding areas. The width of the buffer zone is determined by the depth of penetration of anthropogenic influences. In this area in the prescribed manner are environmental, fire, water, regulatory and other measures aimed at conservation, rehabilitation, reproduction and rational use of natural complexes.

3. Regulated protected regime - includes natural and minimally disturbed areas by anthropogenic factors. Consists of:

- Chornobyl Special Zoological Reserve of national importance with a total area of 48870 hectares;
- Ilyinsky hydrological Reserve of national importance with a total area of 2000 ha;
- Pukhivsky Forest Reserve of local significance with a total area of 13.9 hectares;
- botanical natural monument of local significance “Vykovy oak plantations” with a total area of 11 hectares;
- botanical natural monument of local significance “Alder plantations prof. Tovstolis D. ” with a total area of 4.8 hectares;
- botanical natural monument of local significance “Ordinary pine plots” with a total area of 5.8 hectares;
- complex natural monument of local significance “Horodyshche” with a total area of 5 hectares;
- Botanical natural monument of local significance "Oak" with a total area of 0.02 hectares
- botanical natural monument of local significance "Chornovilkhovy plantations over the river Pripyat" with a total area of 10 hectares;
- botanical natural monument of local significance "Chornovilkhovy plantations over the river Pripyat" with a total area of 16 hectares;
- botanical natural monument of local significance “Pedunculate oak plantation” with a total area of 15 ha;
- protected tract “Age oak plantations” with a total area of 17.5 hectares;
- Zagirya Nature Reserve with a total area of 119 hectares.

4. Anthropogenic landscapes - includes areas of traditional land use, forestry, water use, settlements of personnel, recreation and other economic activities, it prohibits hunting. Ecologically harmful productions are not allowed in this zone, it serves as a testing ground for anthropogenic impact monitoring.

Economic activity within the Chornobyl Reserve is carried out taking into account the peculiarities of land use regime defined by the Law of Ukraine "On the legal regime of the territory affected by the Chornobyl disaster", in compliance with radiation safety, radiation and dosimetric control of personnel in accordance with law.

Scientific research, background ecological monitoring and determination of radiation situation in the Chornobyl Reserve are carried out in order to study natural processes, minimize environmental hazards and preserve natural resources of the ChEZ and the Exclusion Zone and Zone of Unconditional (Mandatory) Resettlement, ensuring constant monitoring of ecosystem changes, scientific bases of protection, reproduction and use of natural resources and especially valuable objects of the Chornobyl Reserve to ensure conservation, protection and reproduction of natural complexes and objects, especially rare and endangered species of fauna and flora listed in the Red books of Ukraine and international Red Lists, research and preservation of historical and cultural values in accordance with a number of laws of Ukraine.

Funding for activities related to the operation of the Chornobyl Reserve is carried out in accordance with the law from the general and special funds of the state budget of Ukraine. Funds from local budgets, charitable foundations, enterprises, institutions, organizations, citizens and other sources of funding not prohibited by law may also be used for this purpose.

The Chornobyl Reserve participates in international cooperation in the field of protection and conservation of natural diversity of landscapes, gene pool of flora and fauna, maintaining the overall ecological balance and ensuring background monitoring of the environment and radiation, minimizing environmental hazards [26].

The ten-kilometer zone around the Chornobyl NPP (radioactive waste management zone or industrial zone) does not belong to the territory of the Chornobyl Reserve [14].

In December 2020, the Chornobyl Reserve was added to the World Database on Protected Area (WDPA) [27].

The Chornobyl Reserve is the most complete global database protected areas. And is a joint project between the United Nations Environment Program and the International

Union for Conservation of Nature (IUCN), run by the United Nations World Conservation Monitoring Center (UNEP-WCMC) in collaboration with governments and scientists [28].

The Chornobyl Reserve together with the Drevlyansky Nature Reserve (Zhytomyr Region) and the Polissya State Radiation and Ecological Reserve (Republic of Belarus) will become unique and one of the largest protected areas in Europe [29].

The Chornobyl Reserve is also part of the Emerald Network – UA0000046(Fig.1.5).

The Emerald Network is a network of protected areas of European importance, created in compliance with the provisions of the Bern Convention on the Conservation of European Wildlife and Natural Habitats. Ukraine ratified the convention in 1996, committing to an Emerald Network. The network aims to preserve species and ecosystems that have been recognized as rare throughout Europe. A list of them is available in Resolutions 4 and 6 of the Berne Convention.

Today, the Emerald network operates in most European countries. However, in the EU member states the network is called Natura 2000, and in non-EU countries - the Emerald network. The Natura 2000 network is identical to the Emerald network in everything except the aspect of membership in the European Union [30].

The Emerald Network of Europe has been created to preserve the natural fauna, flora and types of natural habitats. The Ukrainian part of the Emerald Network of Europe has been under development since 2009. The territory of the planned activity is located outside the Ukrainian part of the Emerald Network of Europe.

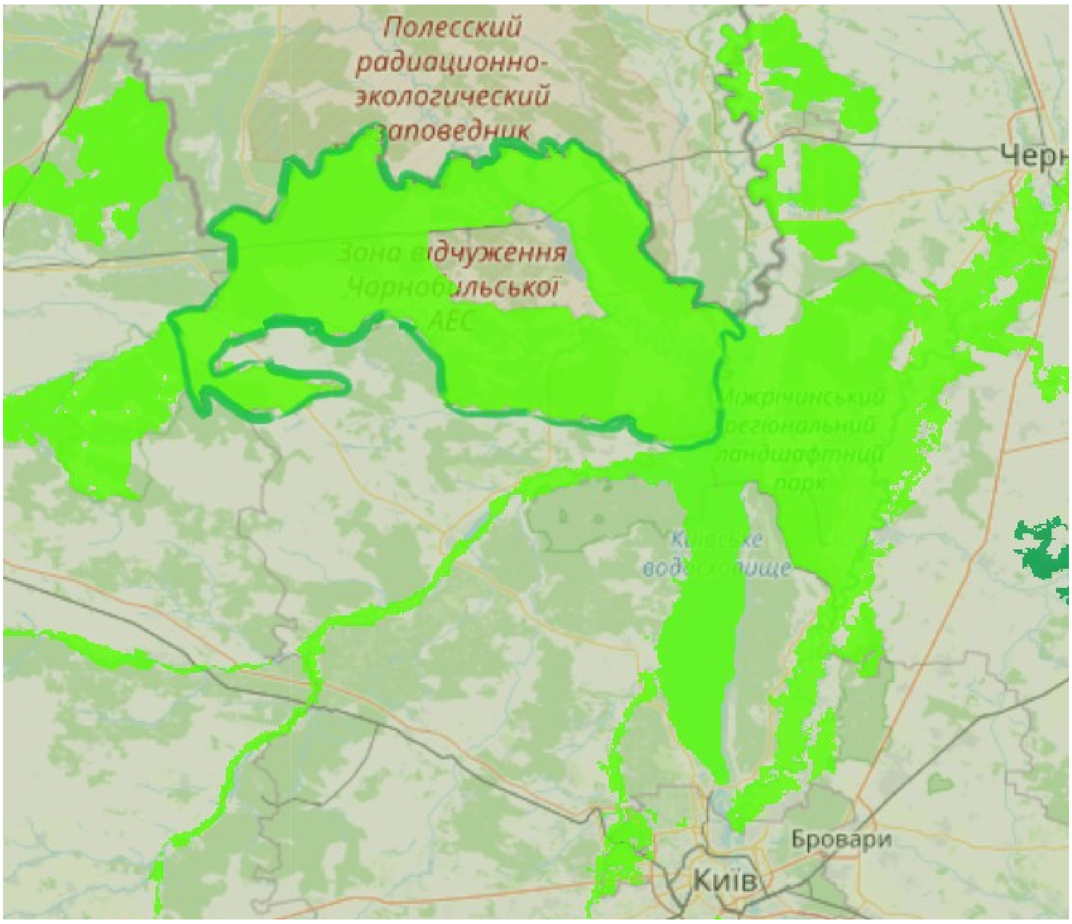

Fig. 1.5. Territory of the Emerald Network of Europe "Chornobyl Biosphere Reserve"

As an object of the Emerald Network, the Chornobyl Reserve is characterized by the following indicators:

- Area, ha: 227381
- Number of bird species: 33
- Number of other species: 32
- Number of types of natural habitats: 25 [31].

1.4. Wildfire as a factor of influencing the radiation condition of the territory

In Ukraine, an average of more than 3000 wildfires are recorded annually, of which almost 90% are caused by human error. The forest area where fires took place during the year averages more than 4000 hectares. The vast majority of fires occur in Kyiv, Chernihiv, Rivne, Zhytomyr and Volyn regions.

Accurate statistics of fires in the ChEZ have been conducted since 1993 after the emergence of the special forestry enterprise "Chornobyllis". In fact, the reason for its creation was the great fire of 1992, which led to the realization that the forest ecosystems of the ChEZ need special management. But the archives also contain data for previous years. (Fig. 1.6) [32].

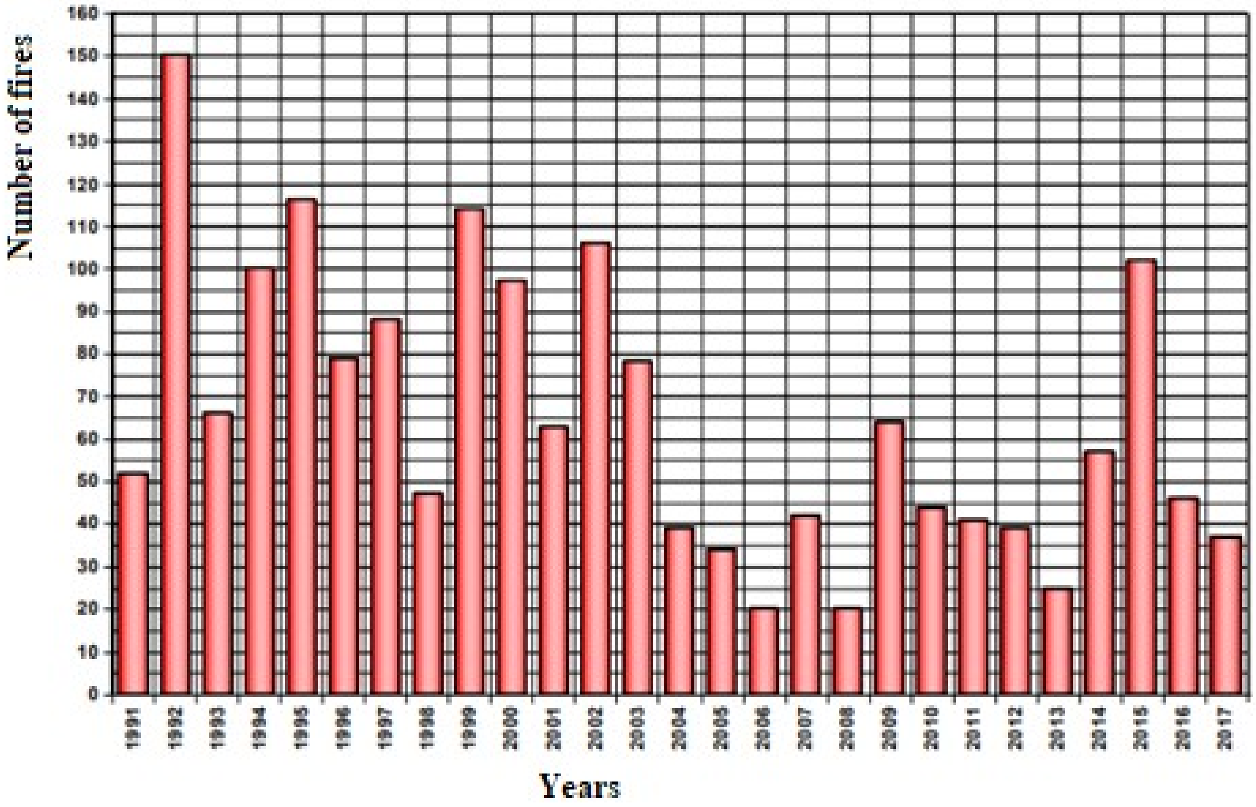

Fig. 1.6. Dynamics of the number of wildfires in the Chornobyl Reserve

During the period from 1993 to 2020, 1702 fires broke out in the ChEZ, which affected 88424.71 hectares of radionuclide-contaminated areas (Table 8.1). The analysis of the data shows clearly visible fire maxima in 1995, 1999, 2002, 2009, 2015 and 2020 - when the number and area of fires was higher than in the previous and next years. In 2020, 71 fires were recorded on an area of 67523.09 hectares. The average area of one fire is 951.03 ha.

The most common types of landscapes where fires are recorded are: coniferous forests, fallow lands, abandoned settlements and swamps (table 1.2). Statistics show that 56% of fires by number or 16% by area occur on fallows. The number of fires in forests is 35% and their area is 84%. In settlements fires make 7%, on bogs 2%. The average area of wildfires is higher than fires on fallows and in settlements, it is 143.33 hectares, and the average area of fires on fallows - 17.09 hectares. However, if we do not take into account the catastrophic fires of 2015 and 2020, the average area of fires in forests and on fallows is 2.83 and 2.68 hectares, respectively (Appendix A) [33].

Table 1.2

Quantity and area of fires in the ChEZ from 1993 to 2020

Year	Area, ha	Quantity	Average area, ha
1993	564,5	66	8,55
1994	130,9	100	1,31
1995	756,7	116	6,52
1996	296,3	79	3,75
1997	304,29	88	3,46
1998	23,38	47	0,5
1999	147,28	114	1,29
2000	194,57	97	2,01
2001	49,93	63	0,79
2002	153,3	106	1,45
2003	157,91	78	2,02
2004	52,63	39	1,35
2005	36,07	34	1,06
2006	55,27	20	1,19
2007	107,8	42	2,57
2008	23,84	20	1,19
2009	97,54	63	1,55
2010	24,72	44	0,56
2011	40,27	38	1,06
2012	45,89	18	2,55
2013	24,37	21	1,16
2014	107,38	53	2,03
2015	16849,3	102	165,19
2016	66,11	46	1,44
2017	258,15	37	6,98
2018	167,23	35	4,78
2019	178,37	65	2,74
2020	67523,09	71	951,03
TOTAL	88437,09	1702	951,03

Assessment of the radiation consequences of a fire in the ChEZ primarily pursues the following goals:

1. Determine the degree of threat to the population living in areas remote from the source of the entry of radionuclides into the environment, outside the border of the ChEZ (30 km or more).

2. Determine the degree of threat to the population in the event of a reduction in the size of the ChEZ.

3. Determine the degree of threat to the personnel involved in extinguishing the fire [34].

Due to the wildfire, the radiation smoke rises to a considerable height, and the transfer of radioactive aerosols occurs over long distances. The lifespan of the radiation smoke aerosol cloud in the lower troposphere (up to 1.5 km) is less than a week, in the upper troposphere - about a month, in the stratosphere - 1-3 years. This causes the deposition of radioactive combustion products in clean areas, which causes serious damage to the environment and, consequently, public health.

Forests have played an important role in limiting the spread of radioactive contamination since the Chornobyl disaster. Therefore, control and analysis of the radiation status of areas due to the effects of natural fires is a necessary component of environmental research.

Today, 55% of the ChEZ is covered by forests, and the area of their distribution is growing - due to the overgrowth of former agricultural lands and former settlements. The forest ecosystems of the ChEZ are characterized by the longest periods of effective half-cleaning from man-made radionuclides compared to other landscapes, as a result of which forests remain critical landscapes in terms of radionuclide inflow through trophic chains to humans [14].

However, during fires, the natural barrier breaks down and becomes a source of pollution. With smoke and ash particles, radioactive substances enter the atmosphere, increasing the risk of inhalation of radioactive substances into the human body. However, the widespread perception of radioactive clouds resulting from fires has not been confirmed by real observations. A sharp increase in the concentration of radioactive aerosols was observed directly near the line of fire. At a distance of several kilometers, the indicators of the radiation status were within the seasonal indicators. Therefore, during the fires of 2015 and 2018, the evacuation of Chornobyl personnel and enterprises of the ChEZ was not carried out. Visiting the territory of the ChEZ for educational purposes was limited only. The personnel involved in extinguishing the fire had personal protective equipment.

In the long run, wildfires are a major factor that can significantly intensify migration processes. After the riding fire 60-80% of cesium radiation enters the mineral part of the soil. At that time, under normal conditions, this value is 20-40%. Destruction of the stand and destruction of forest litter leads to the transfer of radioactive substances on dust particles over long distances.

The fire season in the ChEZ begins with the ascent of snow cover and continues until the onset of stable rainy autumn weather or the formation of new snow cover. The largest number of wildfires (65%) occurs in spring, 25% - in autumn and 10% - in summer. Statistics on the causes of wildfires in the ChEZ show that 60% of fires are related to waste incineration, negligence and arson, 15% - to extreme weather conditions (sparks, lightning, spontaneous combustion, power lines, etc.).

The main distribution of areas and reserves of forested areas by groups of forest-forming species in the regions of Ukraine that were exposed to radiation pollution due to the Chornobyl disaster covers 9 regions. The largest areas of forests contaminated with radioactive products of the Chornobyl accident is up to 20% of the total forest area (Table 1.3) [4].

Forest and meadow fires in radionuclide-contaminated areas release radionuclides into the atmosphere in vapor-gas form (primarily 137Cs and less than 90Sr, the melting and boiling point of which is much higher), as well as ash in the form of submicron and micron aerosols. In addition to these radionuclides, they contain β- and α-emitters 241Pu and α-emitters 238Pu, 239Pu, 240Pu, 241Am and some others. This leads to an increase in the volumetric activity of radionuclides in the surface layer of air in the tens, hundreds and even thousands of times, which can pose a danger not only to firefighters but also to the public by inhaling radioactive substances and, consequently, internal radiation.

As a result of fires, the vertical migration of radionuclides in the atmosphere with the current of hot air may increase, and, most importantly, their horizontal migration with the movement of air, which can take them far beyond the fire area [35].

Table1.3

Areas of forests contaminated with radioactive products of the Chornobyl accident

Region	**Forests surveyed, thousand hectares**	**Pollution zones 137 Cs, Ci / km2**			
		up to 1.0	1.0-5.0	5.0-15.0	> 15
Vinnytsia	234	198,6	35,4	-	-
Volyn	353,1	295,7	57,4	-	-
Zhytomyr	974,3	388,3	450	98	38
Kyiv	416,4	198,1	187,6	20,1	10,6
Rivne	728,8	331,5	391	6,3	-
Sumy	121,9	109,4	12,5	-	-
Chernihiv	725,5	609,9	102,2	13	0,4
Cherkasy	241	190	49	2	-
Khmelnytsky	50	46	3	1	-

The radioactive ash formed as a result of fires is actively involved in the geochemical migration of elements in ecosystems, carrying out uncontrolled secondary radioactive contamination of territories. At the same time, burnt wood has a concentration 50-100 times higher than firewood. Burned forest litter and ash contain 600-180000 Bq / kg 90Sr, from 4,100 to 270000 ^{137}Cs, due to fires released ^{137}Cs deposited with wood in 2015 - 130 GBq, in 2020 - 700 GBq [11].

The consequences of fires are also of scientific and environmental value. Thus, the last large-scale fire in 2020 had a significant impact on about 5% of the Chornobyl Reserve. Of these, about 35% - forests, 55% - fallows, 10% - wetlands [36].

On April 4, 2020, a fire from the Zhytomyr region spread to the ChEZ and Exclusion Zone and Zone of Unconditional (Mandatory) Resettlement, which caused large-scale damage to the territory of the Chornobyl Reserve and the ecosystem of the ChEZ in general (Fig. 1.7), (Appendix B).

The area covered by fire for the period from 04.04.2020 to 07.05.2020 amounted to 67.4 thousand hectares, in particular:

- on the territory of the Chornobyl Reserve - 51.8 thousand hectares;
- forest fund and ecosystem of the ChEZ and the unconditional zone;
- (mandatory resettlement) - 15.6 thousand hectares.

Areas affected by the fire in the Chornobyl Reserve:

- 32413.1 ha of forests (23% of the total forest area);
- 10721.8 hectares of fallow lands;
- 530.5 hectares - swamps;
- 5200 ha - other area (coastal strip of rivers, meadows, etc.) [37].

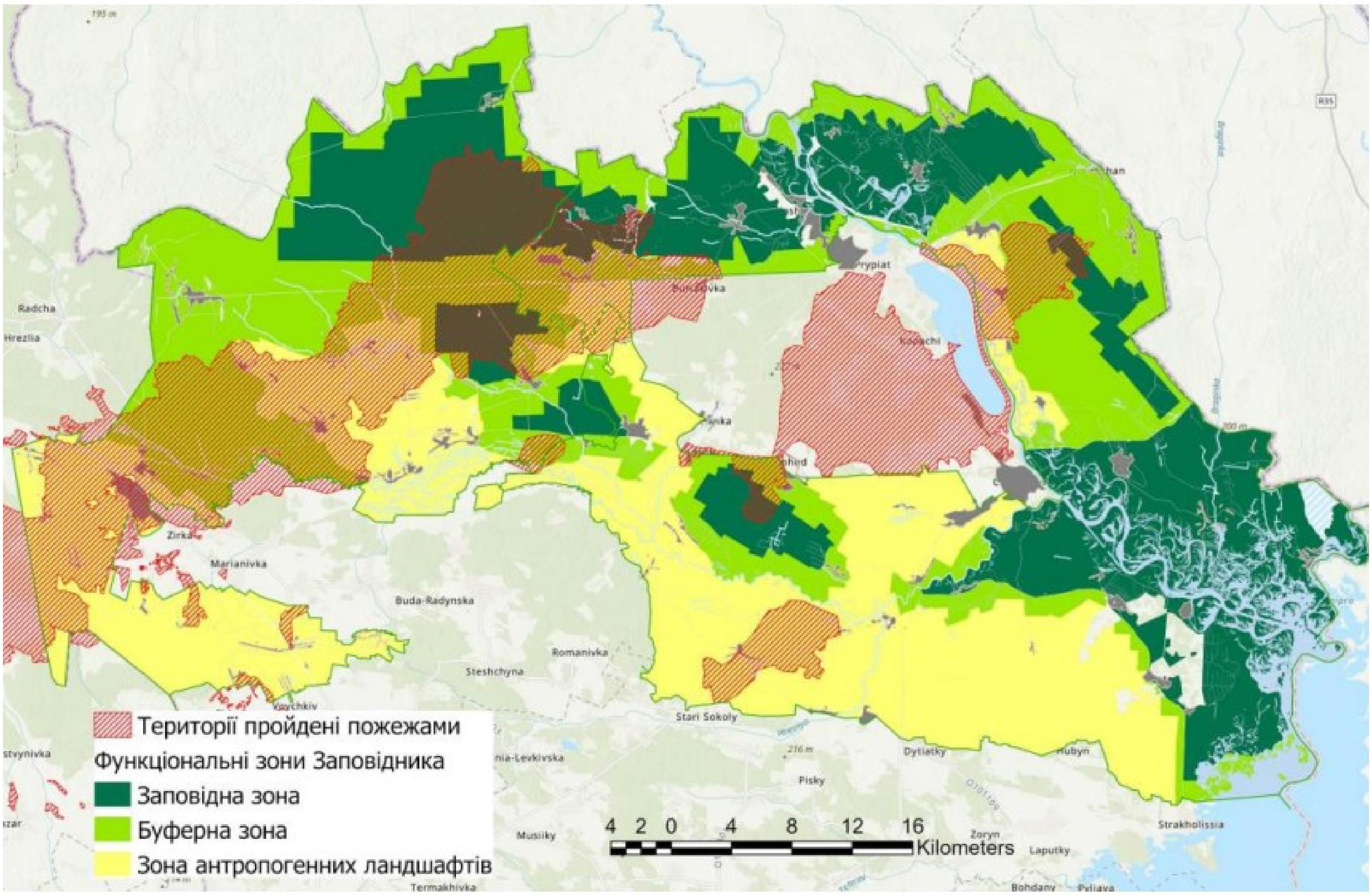

Fig. 1.7. The area of fire in the ChEZ

The results of modeling the emission of radionuclides from wildfires are quite consistent with the data of measurements of the concentration of 137Cs activity in the air of the ChEZ and in Kyiv during April 3-13. For the period after the resumption of intense fires from April 16, the model results were underestimated compared to the data of measurements of radioactive contamination of surface air in the ChEZ. It is shown that the main reason for the differences is the additional contribution of intensive wind uplift of radionuclides from fires in the meadow biocenoses of the ChEZ, which were formed during the previous period, during April 16-17 under the influence of strong winds and dust storms. The wind uplift of radioactively contaminated particles in fires after fires can be a powerful source of air pollution in the area, as well as increase the removal of radionuclides outside it [38].

Large fires pose an increased risk of radiation, so the necessary conditions for effective protection of forests in the ChEZ is the introduction of preventive measures to prevent fires. The main directions should be early detection of fires and effective fire organization of the territory, which would provide for the presence of artificial or natural obstacles to the possible path of such fires in the event of their occurrence.

In the ChEZ, fires not only worsen the radioecological situation, but also increase the risk of spreading fire to large areas, destroying large assets, as well as creating favorable conditions for the reproduction of secondary pests. Thus, keeping the territory in good fire condition, rapid elimination of any fires are the most important components of the overall security of the ChEZ.

1.5. Conclusions to chapter

Today, the ChEZ is an open large source of ionizing radiation with a complex distribution structure, with the presence of various forms of radioactive elements and materials.

In the 35 years since the Chornobyl disaster, due to natural processes and anti-radiation measures, the radiation status of contaminated areas has improved. However, the problem of radioactive contamination remains relevant today and will continue for hundreds of years. Natural cleansing from pollution is quite slow.

Compared to 1986, the radiation background has decreased hundreds of times. The countermeasures taken and the processes of self-cleaning of the natural environment have led to a decrease in the content of radionuclides in the environment, in agricultural products. And this, in turn, led to a reduction in external and internal doses of the population.

There are currently no quantitative current estimates of the radiological status and radioecological damage caused by large-scale fires throughout the ChEZ - periodically there was an uncontrolled redistribution of radioactive contamination, resulting in new habitats exceeding the radiation background compared to its post-accident level in 1986.

A large number of short-lived radionuclides were initially present in the emergency release, and a small proportion of long-lived radionuclides were present. The radioactivity remaining on the earth's surface is now mainly contaminated with cesium-147, strontium-90, plutonium and transuranic elements. Today, the activity of ^{241}Am is higher than the activity of $^{238+239+240}$Pu and it will increase over the next 50 years by 16%, which is the main radiation hazard of ChEZ until 2070.

In order to preserve the unique flora and fauna, stabilize the hydrological regime, rehabilitate radiation-contaminated lands and conduct scientific research, Chornobyl Reserve was established.

Forestry activities will be carried out here to maintain the barrier functions of forest plantations, which can only be performed by healthy, highly productive forests in which fire safety requirements are met. Vegetation is one of the barriers, along with the geological environment and engineering structures, that stabilize the radiation situation inside the ChEZ and reduce the inflow of radionuclides to the surrounding areas.

In almost all living organisms on the territory of the ChEZ there is an adaptive response (increasing resistance of living objects to ionizing radiation in damaging doses after previous action in a small adaptive dose) and its manifestation depends on the adaptive dose, dose rate, type of radiation, time interval between doses and is exacerbated by fires in this area.

Its unique composition includes species listed in the Red Book of Ukraine, the Red List of the International Union for Conservation of Nature, the Convention on the Conservation of Migratory Species of Wild Animals, the Annex to the Bern Convention and the territory is part of the Emerald Network.

Fires in forests that are radioactively contaminated are one of the most dangerous sources of secondary air pollution by radioactive particles. Different scales of wildfires affect the radiation situation in clean areas, where the local population works and lives in the first place. And they also spread from the ChEZ to large areas. Therefore, one of the main tasks is to prevent fires, early detection of causes, minimize their consequences and ensure radiation protection of the population from the negative effects of radioactive clouds.

CHAPTER 2
COMPREHENSIVE ASSESSMENT OF RADIATION HAZARDS OF WILDFIRES AND THEIR ENVIRONMENTAL CONSEQUENCES

2.1. Impact on air condition

The main ways of migration of radionuclides outside the ChEZ are: water (river) runoff (Pripyat River) - about 65%; air (wind) transfer - 10%; in case of fires - 24%; technogenic migration and biogenic removal - 0.5% each [39].

The open combustion of wildfire load is characterized by active combustion with flame and smoldering, as well as high smoke of the flue gases associated with the formation of soot particles - products of inactive combustion. The spread of smoke and soot in the surface layers of the atmosphere promotes the direct entry of radioactive combustion products through the respiratory tract into the human body.

The amount of radioactive contaminants in the ChEZ during the wildfire is determined by 4 groups of factors:

1) power of radioactive release;

2) physicochemical and radiation properties of volatile particles;

3) state of the atmosphere;

4) type of wildfire (bottom, top, transitional) (table 2.1) [40].

Table 2.1

Environmental indicators in a wildfire

Type of wildfire	Temperature	Concentration of "flue gases" in air, mg/m^3				
		CO	CO_2	SO_2	NO_2	C, ash
Crown	1100	800	1200	200	400	40
Surface	1250	1100	2050	450	520	60
Grownd	1380	1600	4300	800	1000	80

One of the main tasks of the Unified State Civil Protection System is to prevent the occurrence and spread of wildfires in fire safety, and in case of their occurrence and spread - to predict the radioactive impact on the environment while ensuring radiation protection of firefighters and the public.

In the process of burning forest vegetation contaminated with radionuclides, radioactive combustion products are released into the environment in the form of smoke, which mixes in the atmosphere with clean air masses and promotes migration, sedimentation and environmental pollution (Fig. 2.1).

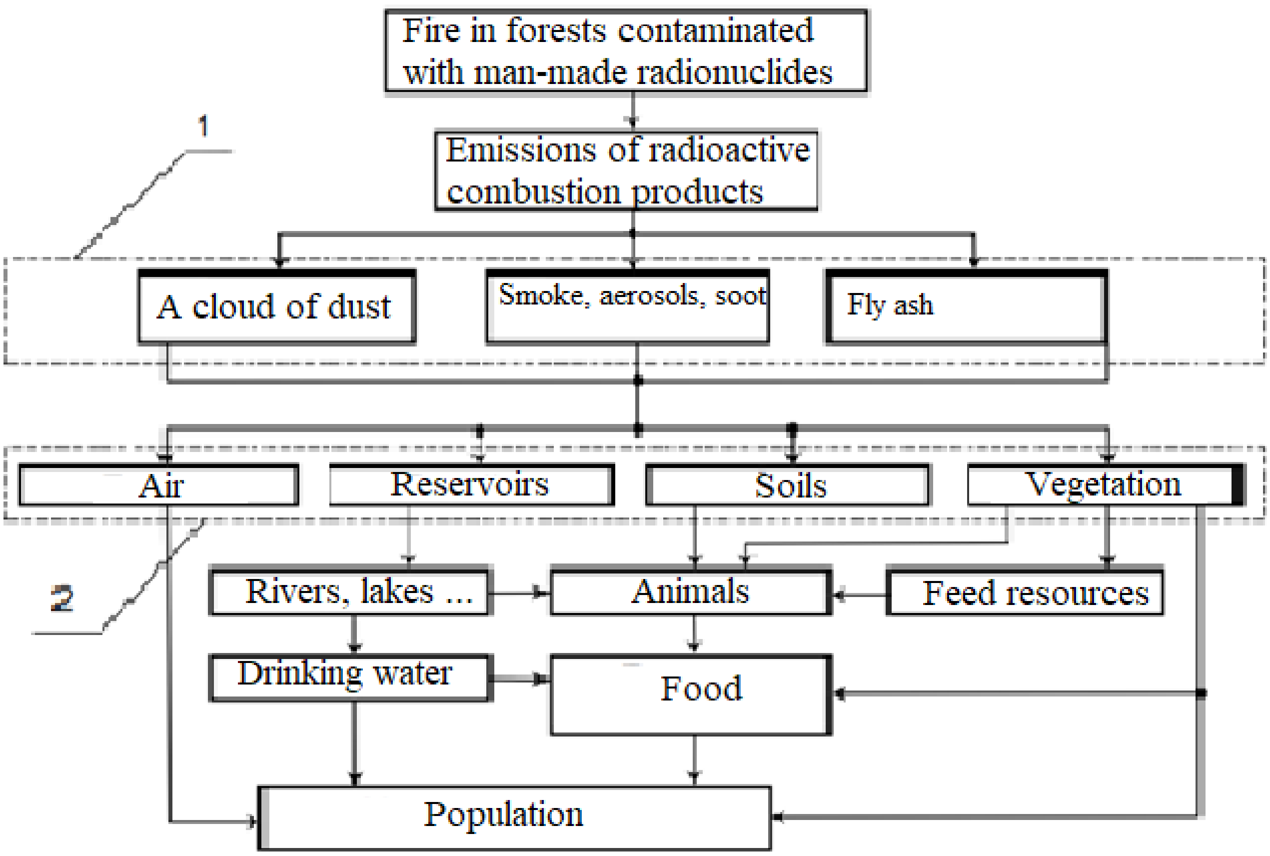

Fig. 2.1. Scheme of sources of radioactive combustion products in the environment:
1 - striking radiation factors; 2 - priority areas of radiation damage

To assess the radiation status during a wildfire, it is necessary to know the place and conditions of wildfire, type of forest plantations and their radioactive contamination, fire hazard class, wildfire load, wildfire type, fire process, presence of radioactive aerosols in combustion products and stage radiation hazard to humans, the process of migration of radioactive combustion products into the environment, the area of radioactive distribution, taking into account wind directions according to meteorological stations, the total time of possible human exposure, the probable nature of the occurrence of malignant diseases and deaths from exposure to radioactive factors, the likelihood of radioecological consequences.

The processes of origin and development of wildfire can be divided into 3 phases: ignition and increase of fire, stationary combustion of fire, extinguishing. The nature and phases of wildfire development can be described by the dependence of the average temperature of combustion products on time. The area where the wildfire originated and developed will be characterized by the presence of areas of combustion, heat and smoke.

To assess the impact of radiation factors during wildfires on the human body used the model of inhalation of radioactive substances (single and chronic), chamber model of the respiratory tract and transport of radioactive substances into the human body, chamber model of radioactive deposition in various human organs and tissues, model excretion of radioactive substances deposited in the respiratory tract: absorption into the blood, into the gastrointestinal tract through the larynx, into the regional lymphatic channels and into the environment (cough and nasal secretions) [39].

As a result of the passage of a radioactive cloud of smoke through settlements, residents will be exposed to the following radiation-hazardous factors:

- external influence of gamma radiation from the plume of smoke;
- external gamma radiation of nuclides that have settled from the plume of smoke on the surface of the environment;
- internal radiation due to inhalation of radioactive particles emanating from the smoke cloud and ash;
- internal radiation due to the entry of radionuclides into the human body with food and water.

The last factor can be practically eliminated by providing the population with clean products. The main factor that determines the next probable radiation exposure in a wildfire is inhalation Cs.

The process of open combustion in forests can be divided into several stages: decay, active flame combustion and attenuation. The ratio or alternation of them depends on weather conditions, quantity, and their flammable characteristics. Open combustion is characterized by high smoke of the air-forming gases, which is associated with the formation of soot particles - products of incomplete combustion, and high-temperature effects on radionuclide particles - the formation of radioactive vapors and aerosols.

The spread of flue gases and aerosols predominates in the surface layers of the atmosphere and promotes the direct entry of radioactive, toxic and carcinogenic substances through the respiratory tract into the body of people involved in firefighting and the population living in the area affected by radioactive combustion products. Currently, there are various mathematical models for analysis and forecasting of air pollution during fire development: deterministic and statistical models, models of local emissions and distribution of polluted air, controlled volume models, finite-difference and stock-discrete distribution modeling impurities, physical modeling of impurity scattering in the atmosphere, regional models of air quality analysis.

Modern statistical models are implemented only for operational forecasting. They are based on past data and often without taking into account the physical characteristics of the air pollution process. The main disadvantage of statistical models is that the conditions of their use may differ from the conditions in which they were built.

Methods of direct modeling of air pollution are based on models that require solving direct and inverse transfer equations. The disadvantage is the difficulty of implementation, the large amount of calculations [40].

Fires in the ChEZ may emit radioactive combustion products with an average total activity of up to 20 Ki / year (^{134}Cs ≈ 15.0 Ki / year, ^{90}Sr ≈ 4.5 Ki / year and transuranic elements ≈ 0.1 Ki / year), which adversely affect Chornobyl personnel and firefighters involved in firefighting, as well as the population of nearby areas and the environment. During a fire, radioactive particles enter the atmosphere, the concentration of which can significantly exceed the maximum allowable values. They are dangerous, first of all, for employees of fire and rescue units who are directly involved in extinguishing fires. Thus, fires in areas contaminated with radionuclides are one of the potentially dangerous sources of dose loads that can affect the health of firefighters in the first place [39].

The problem of modeling the release of radioactive combustion products in the forest consists of a number of independent tasks due to the phased phases of their emergence and spread. There are at least several phases in the development of the migration of radioactive combustion products. In the first phase, the transition of radioactive combustion products into the environment in the form of a smoke cloud. In the second phase, the plume of smoke moves mainly along the earth's surface. In the process of moving away from the source of the fire in the smoke plume becomes less and less smoke particles as a result of their "dry" deposition and scattering. Various dynamic models can be used to describe such a complex process of migration of radioactive combustion products. However, to calculate the transient emissions of radioactive combustion products from several sources of ignition, it is necessary to use calculation methods that are more physically advanced and simple in mathematics.

The risk to human health associated with radiation pollution arises under the following necessary and sufficient conditions: the existence of a source of radiation risk (radioactive substances in the environment or food), the presence of this source of risk in the human body in the form of radiation dose or the concentration of radionuclides, the susceptibility of the human body to respond to said radiation dose or the concentration of radionuclides.

In the event of a local fire during the combustion of 1 ton of combustible materials in the atmosphere can enter: 900 m^3 CO_2, 70 m^3 CO, 240 m^3 water vapor and 2.5 kg of solid particles, 1.5% of which will be fuel particles that may contain transuranic elements, such as: ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Am [40].

The average wind speed is the most important parameter of the dispersion, as it determines the direction of movement and the amount of air that dilutes the radioactivity. Other important factors are precipitation, which washes away radioactivity from the cloud, storms or unstable atmospheric conditions that determine atmospheric diffusion, topography, on which turbulence also depends, and so on.

The nature and phases of wildfire development can be described by the dependence of the average temperature of combustion products on time. The area where the wildfire originated and developed will be characterized by the presence of areas of combustion, heat and smoke. A wildfire begins with a fire, ie the emergence of a fairly powerful source of ignition. In order to start combustion, a sufficiently powerful ignition source must be formed (for example, electrostatic or electric discharge due to lightning, open flames, sparks, incandescent surfaces, arson, etc.). Ignition can occur if there are stocks of dry materials and sufficient temperature and power of the ignition source to initiate thermal pyrolysis of dry combustible substances with the release of combustible gases and vapors, with the formation of "combustible medium" (ie a mixture of gases or vapors with oxygen). At the beginning of the stationary combustion phase it is necessary to form a wildfire zone, shapes, horizontal linear dimensions and spatial location of "stocks" of combustible substances, multi-flame flame in the combustion zone and rising branch of flue gases, flue gas migration zone in the air and a loop of possible radiation population [39].

The phase of extinguishing a wildfire occurs as a result of a sharp deterioration in weather conditions, such as rain, changes in wind direction and speed, and so on. The forest combustion zone is a part of the space where available combustible solids are available for combustion and heating, vaporization, thermal decomposition, release of gaseous fractions, etc. take place. Thermal action zone - a part of the space adjacent to the combustion zone, in which due to the thermal action of radiation, convection, heat transfer there are irreversible changes in the initial state of the forest. Combustible substances are being prepared for flaring in this zone and the necessary conditions for further spread of fire are being created. The smoke zone is the part of the space adjacent to the combustion zone in which the combustion products are distributed in the air.

The process of formation of a "smoke cloud" over the site of a wildfire is markedly different from clouds that develop under normal natural conditions. The physical reason for the formation of a "smoke cloud" is the presence of a powerful heat source, which causes the development of strong convective currents in the local atmosphere and the formation of smoke clouds of considerable vertical length. The power, size and lifetime of the heat source determine the characteristics of the dynamics of smoke clouds and their microstructure. Thus, the speed of upward flow in them can exceed 100 m/s, the current is significantly turbulent, the lower limit is located at an altitude of (1-3) km, the upper limit can reach 5 km and above [39].

The problem of modeling the release of radioactive combustion products during a wildfire consists of a number of independent tasks due to the phased phases of their emergence and spread. There are at least several phases in the development of the migration of radioactive combustion products. In the first phase there is their transition to the environment in the form of a cloud of smoke. In the second phase, the plume of smoke moves mainly along the earth's surface. As you move away from the fire in the smoke plume, fewer and fewer smoke particles remain due to their "dry" deposition and scattering.

Also, the conditions of release of radioactive combustion products into the atmosphere depend on personal factors: the height of the smoke cloud can vary by 2 times, the duration of formation - 1.5 times, the nuclide composition of emissions by 10%, as well as the constant change over time of meteorological data (speed and direction wind, its temperature and humidity, etc.).

Fires in forests contaminated with man-made radionuclides, along with deflationary processes and anthropogenic factors, contribute to the increase of radiation pollution of both the surface layer of air in fire areas and the atmosphere as a whole. In this case, the amount of man-made radionuclides entering the airspace is determined, in addition to the parameters of the type of fire (bottom, top, transitional, underground), the amount of total radiation pollution of the fire, the nature of the landscape, meteorological conditions of radionuclide accumulation (bark of trees and shrubs, pine needles, forest litter, grass).

In 1992, a series of large wildfires took place and bursts of radionuclide concentrations in the surface layer of the air were recorded (measured by the Chornobyl Radioecological Center). The minimum concentration of 137Cs was 1.7 * 10–2 Bq / m^3, which was two orders of magnitude higher than the control level and this contributed to the increase of dose loads on the population. Analysis of available information on the fires of 1992 and the stockpile of radionuclides in biomass revealed that the range of radiation pollution of the atmosphere ^{137}Cs was (30-140) GBq.

The fire lasted for almost three days, as a result of which 30 hectares of forest and 16 hectares of grass cover were destroyed. Significant smoky air was observed in the surface layer of the atmosphere. The analysis of the air sample showed an increase in the ^{137}Cs content to 2.3 * 10–3 Bq / m^3, which exceeded the value of the control level of radioactive contamination in the ChEZ. The fire component 323 of the ^{137}Cs radiation pollution of the air basin was (13.5–70) GBq.

In the summer of 2002, in the territories of the three states of the Russian Federation, Belarus, and Ukraine, there were significant outbreaks of fires in forests and peatlands contaminated with radionuclides during the Chornobyl accident. In the northeast of the Zhytomyr region from 20.08.2000 to 06.09.2002 a large fire was registered, the wind direction is north-north-west. Analysis of air samples taken in the ChEZ at a distance of 10 km from the Chornobyl NPP showed an increase in ^{137}Cs content to 3.2 * 10–4 Bq / m^3. As a result of these fires, radioactive contamination of the air basin with an activity of (0.5–1.6) GBq occurred.

On June 21–22, 2002, an increased concentration of ^{137}Cs was recorded in the surface layer of the atmosphere. Radioactive smoke came from the wildfire zone (north-west, 10 km from Chornobyl), as well as from Ivankiv (6.5 ha) and Vyshhorod (22 ha) districts and Zhytomyr region. In the northwest wind, radioactive smoke from wildfires spread in the direction of Kyiv. Radioactive smoke (soot, ash and moisture), rising up, gradually deposited on the earth's surface depending on the size distribution of combustion products.

According to the State Emergency Service, on April 4, a 20-hectare riding fire was recorded in the ChEZ (Fig. 2.2). Forestry (Kotovske) was burning in the western part of the Zone. Rescuers managed to put out the flames fairly quickly, but the situation was complicated by the emergence of new fires. Already on April 9, the situation for an outside observer began to look critical: the fire reached the village. Chistogalivky in the territory of the forestry close to the Chornobyl NPP (Korogodsky), which meant that the fire was gradually approaching the spent nuclear fuel storage facility and the city of

Pripyat. The social networks also announced the danger for the popular tourist attraction - the town of "Chornobyl-2" and the over-the-horizon radar station "Rainbow" [41].

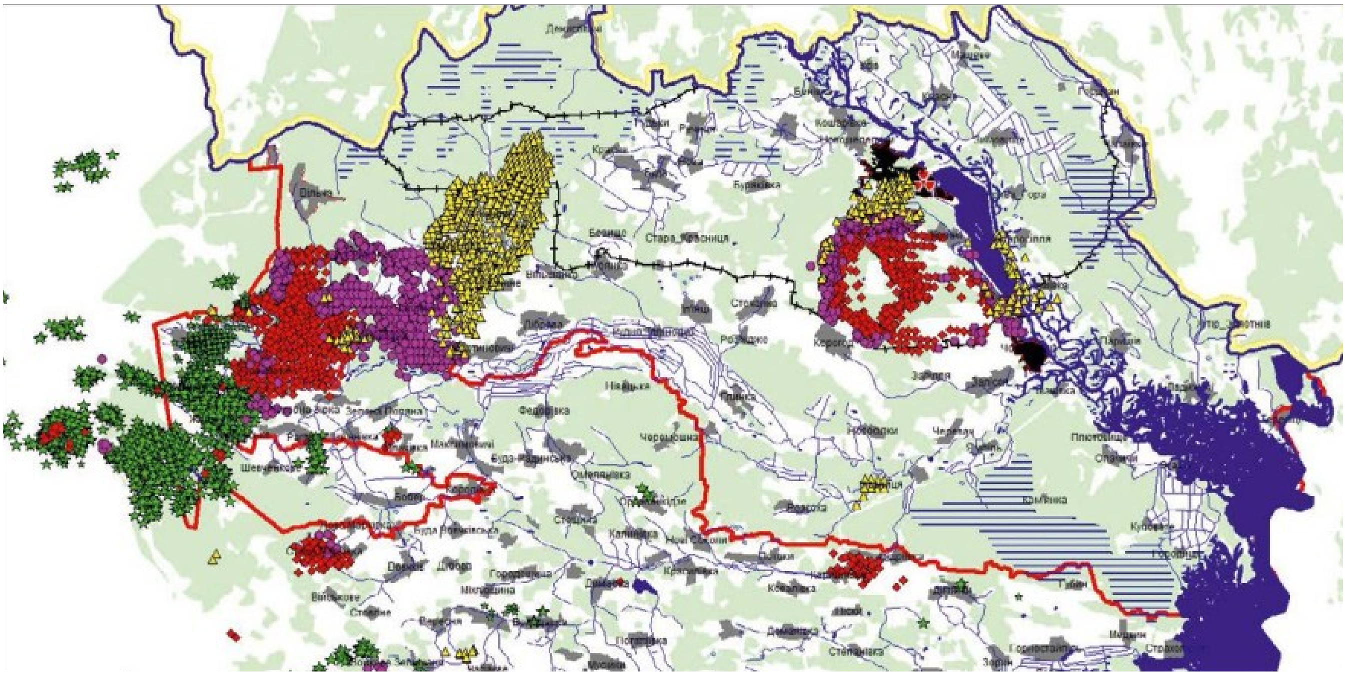

Fig 2.2. Location of individual combustion sources during April 3-13, 2020 according to satellite measurements (* April 3-7, * April 8-9, * April 10-11, * April 12-13)

Calculations of the distribution of ^{137}Cs lifted into the air as a result of wildfires in the SV during April 4–20, 2020 were performed using a set of models of lifting, atmospheric transfer and deposition of radionuclides on the LEDI underlying surface.

The values of the integrated concentration of ^{137}Cs activity in the surface air in Kyiv were obtained in the range of 350 Bqs / m^3 (Prospect Nauki) - 450 Bqs / m^3 (Sviatoshyn), including 250-350 Bqs / m^3, respectively, for 4-13 April and about 100 Bks / m^3 for all districts of Kyiv for April 16-20, 2020.

For the initial period of fires on April 4-7, 2020, the model provides estimates of air pollution, inflated by 4-5 times for Chornobyl and Dityatky, located southeast of the fires in the Polissya region. Between April 7 and 13: their ratios for different measurement posts range from 0.74 to 1.23. The only exception - Dityatky, where model results were inflated 7 times [42].

2.2 Impact on forest litter and soils

Depending on the geological structure, relief, climate, groundwater and surface water, the territory is covered mainly with sod-podzolic (most common), sod and swamp soils.

The properties of sod-podzolic soils largely depend on their mechanical composition, which is due to the mechanical composition of soil-forming rocks. They are mainly sandy, clayey-sandy and sandy, rarely loamy.

Sod-podzolic soils are characterized by an acidic reaction, saturated with bases, poor in humus and gross nutrients. Their humus is very mobile, a significant amount of it is washed away with groundwater.

Turf and meadow soils belong to the soils of the turf process, which occurs under the influence of grassy vegetation. Turf is formed due to the intertwining of soil particles in the upper part of the humus horizon with the roots of grasses, especially meadows.

Sod and meadow soils are common in conditions close to the surface of groundwater. These soils are characterized by a profile of chernozem soil, divided into horizons: humus, transitional, low-humus upper part of the parent rock and parent rock. As a result of frequent excessive moisture in the lower layers of these soils, anaerobic processes prevail, which cause gleying with the formation of oxidative compounds. In gley varieties, only the parent breed is gleyed; in gley gleyed also the transition horizon.

Those soils in which the thickness of the humus horizon together with the transitional one is less than 50 cm are called sod, and more than 50 cm - meadow. Areas with sod and meadow soils in the ChEZ were previously mainly used as natural hayfields and pastures.

Wetlands are most common in floodplains and ancient valleys. These are typical lowland peat bogs with the spread of hypnotic mosses. In the watersheds are often small swamps of the transitional type and occasionally - riding. Wetlands include peat bogs and peatlands. Until 1986, some peatlands were used by local collective farms to extract peat, which fertilized sod-podzolic soils.

The basis of the soil cover in the ChEZ is woody-podzolic soils, in wetlands - peat, characterized by low humus content, high acidity and sandy mechanical composition. The structure of land in the ChEZ is presented below in table 2.2.

Table 2.2

The structure of land in the ChEZ

Land category	%	km ^{2}
Forests covered with forests: Conifers Deciduous	48,5 38,6 9,9	980 780 200
Other forest lands (deforestation, forest roads, etc.)	4,9	99
Total forest land	53,4	1079
Lands of former agricultural use	29,5	569
Not forest lands (sands, swamps)	2,6	53
Water surfaces (rivers, lakes, etc.)	8,5	172
Cities, villages, roads	6	121

At one time, radionuclides that were released into the environment due to natural biochemical and biogeochemical processes migrated into the soil. Since radionuclides accumulate mainly not in plants but in the soil. That is why the soil is the most radioactive element within the ChEZ [24].

Soil-forming rocks are usually fluvioglacial sands, which intersect with lake alluvial and eluvial sands. In many cities, these deposits are covered with moraine loams at relatively shallow depths. In general, the soil cover can be described as relatively homogeneous and depleted.

The intensity of the vertical deepening of the ^{137}Cs stock center varies from 0.1-0.2 to 0.6-0.75 cm / year.

On the territory of the 30-kilometer zone of the Chornobyl NPP in the form of radioactive fallout fell, about $5 \cdot 10^{15}$ Bq, of which $3 \cdot 10^{13}$ Bq accounted for transuranic elements. The highest density of soil pollution for ^{137}Cs reaches more than $8 \cdot 10^{12}$ Bq /

km^2, for ^{90}Sr - 7 · 10^{12} Bq / km^2, plutonium - 3 · 10^{10} Bq / km^2. In fig. 2.3–2.5 shows maps-schemes of ^{137}Cs, ^{90}Sr, $^{239+240}Pu$ pollution density and transuranic elements in the ChEZ.

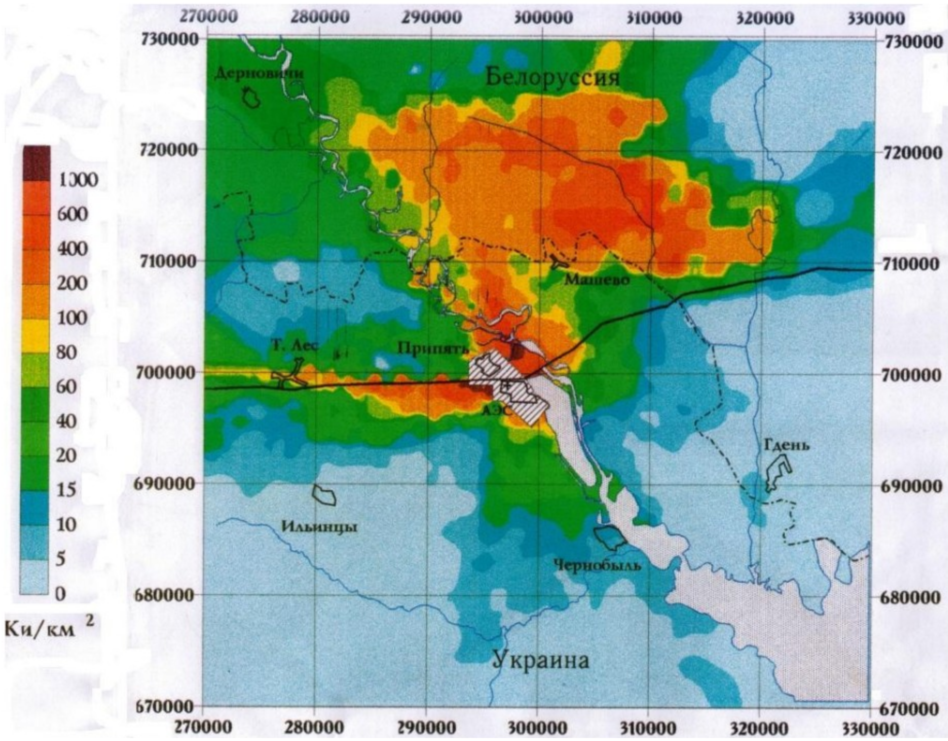

Fig. 2.3. Map-scheme of cesium contamination density (^{137}Cs) in the ChEZ

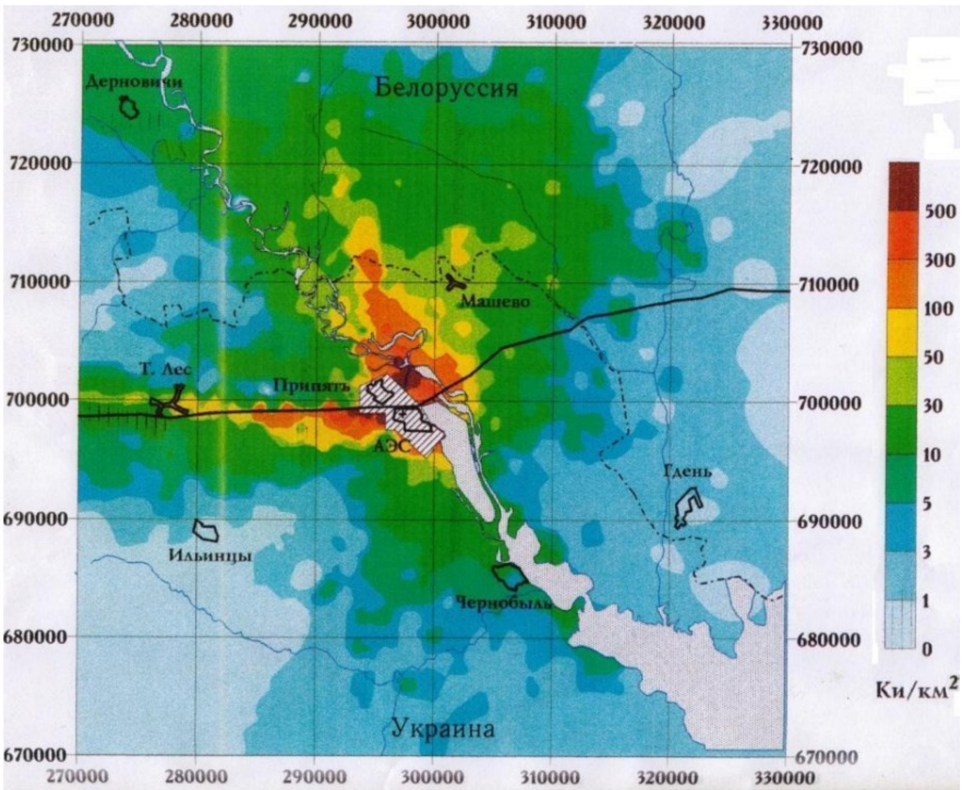

Fig. 2.4. Map-scheme of strontium contamination density (^{90}Sr) in the ChEZ

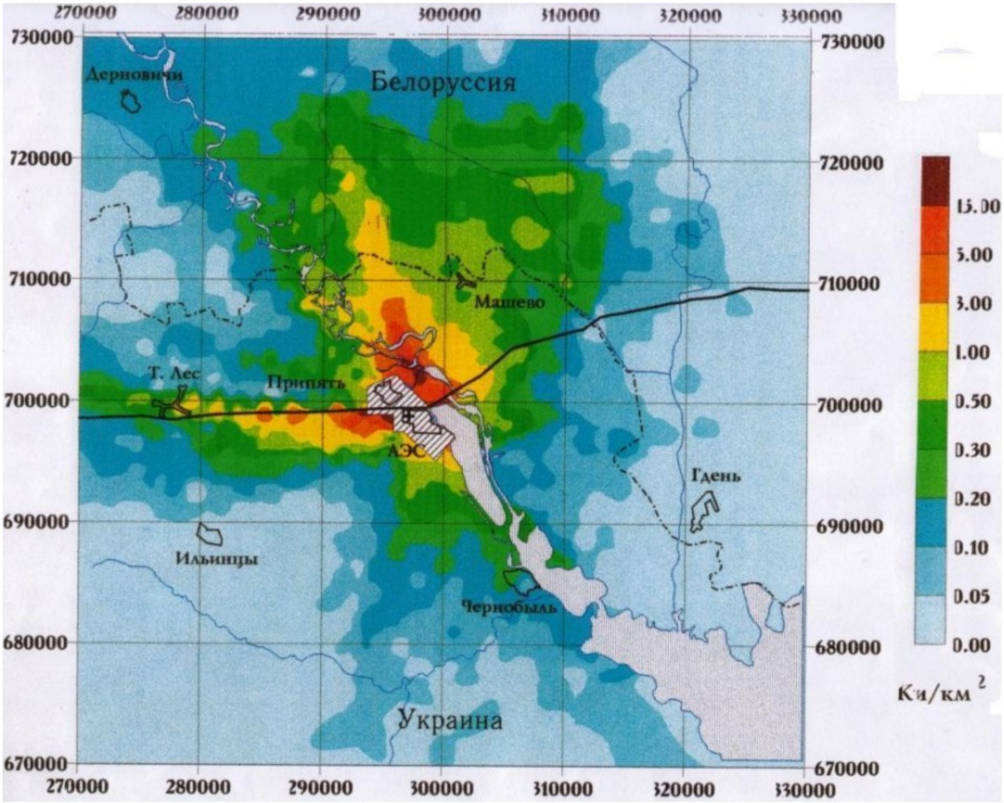

Fig. 2.5. Map-scheme of plutonium contamination density ($^{239+240}Pu$) in the ChEZ

The intensity of radionuclide migration processes in forests is determined by a complex of biocoenotic and biogeochemical factors, such as sorption and desorption, movement with surface and intrasoil composition, biogenic mixing, influence of vegetation composition, as well as diffusion, deflation and convective transfer.

The behavior of radionuclides in the soil and their entry into the wood depends mainly on the properties of the soil (mechanical composition, acidity, humus content, etc.), as well as on the biological characteristics of plant species. Experimental studies show that in forests the main amount of radionuclides (over 98%) is concentrated in the lower part of the forest litter and the upper 10 cm layer of soil.

The nature of the distribution of radionuclides (^{137}Cs, ^{90}Sr and transuranic elements) in pine forest ecosystems is determined by a complex set of radioecological, coenotic, natural factors, as well as the composition and forms of Chornobyl sediments. At the moment, against the background of a decrease in the total density of radioactive contamination, the difference in the distribution of radionuclides in forest soils in different parts of the ChEZ has been equalized. Analysis of the distribution of radionuclides by soil profile in dry and fresh forest conditions showed that their content in the surface horizon of forest litter is insignificant: ^{137}Cs stock is about 1% ^{90}Sr - 0.4, $^{239+240}Pu$ - 0.8 of the total soil composition.

The main part of plutonium isotopes is retained by enzymatic and humus layers of litter. Their presence in the leaf horizon is due to the fall of dead bark, which they adsorbed. In general, the litter of pine stands contains (50-90)% of the total stock of radiocaesium, (40-75)% of radiostrontium and up to 99% of plutonium isotopes, ie the litter remains the main depot of radionuclides [39].

Forest litter is a subsoil formation formed under the forest canopy from the products of precipitation of terrestrial tiers of the forest biogeocenosis. It is somewhat similar to a layer of soil surface, permeated with plant roots. The organic residues that make up the forest floor are at different stages of decomposition. There are several layers in the developed forest litter. The upper layer is formed by fresh precipitation, it is still slightly disturbed by the processes of decomposition and humification; it is easy to distinguish all the plant remains that make it up. The middle layer consists of semi-decomposed residues, some of which have retained the morphological characteristics of plants or their constituent parts, the color of this layer is mainly from brownish-yellow to chocolate. The lower layer is an amorphous humified mass of dark gray, brown or black organic matter. Stock and capacity of litter depend on the species composition of species, forest age, canopy closure, development of living above-ground cover, soil water regime and other factors [43].

Up to 50% of radiocaesium, which is contained in plant material, fallen needles and litter, can enter the environment with dust and soot.

It is important that the main particle size containing radioactive substances is half a micron (0.5, 0.4 μm).

In the areas of fires contaminated with radionuclides, there is an increase in the migration of radionuclides in the soil profile. This is due to:

- changes in physical and chemical forms of radionuclides found in forest litter and mineralized soil;

- elimination of the natural barrier to the migration of radionuclides in the soil profile - forest litter [44].

Due to the lack of care cuttings in the stands of the ChEZ there are negative processes, which are expressed in the accumulation of a significant number of weakened (8-23%) and dry (10-37%) trees, deteriorating coenotic structure of plantations, leading to increased intraspecific competition and stagnant growth trees [45].

An important factor influencing the radiation effects of fire is the structure and humidity of forest litter. In pine plantations of radiation-contaminated forests, 40-50% of the total number of radionuclides in the forest ecosystem are concentrated in the forest litter, which determines its fundamental fire value. The dried surface of the litter begins to smolder from the smallest source of fire, after which the combustion spreads even in its wet layer. The weight of litter varies from 10 to 31 t / ha, with the most fire-hazardous part - precipitation is 0.7-2.0 t / ha. Precipitation burning is the first stage of a fire. Detection of fire at this stage promotes its rapid extinguishing and causes minimal radiological consequences.

Precipitation, which contains an order of magnitude less than ^{137}Cs compared to forest litter, burns during a mobile ground fire (fire hazard factor 300 - 500). At the same time, the enzymatic and humus horizons of the litter, which have higher humidity, are practically not damaged by fire. With an increase in the coefficient of fire danger (700 and more) there are humus-litter fires, in which a low rate of spread of fire causes complete burnout of the horizon. The emission of ^{137}Cs in such a fire is more significant and to ensure radiation safety during extinguishing, it is important to know the total density of soil contamination [46].

The type of fire and its characteristics will be determined by the characteristics of forest combustible materials, part of which is clutter. The intensity of accumulation of forest combustible materials in a certain area of forest is determined by the type of forest, age of plantations and silvicultural care. In areas with a density of more than 555 kBq · m^{-2} (15 Ki · km^{-2}) forestry measures are prohibited by law and were not carried out after the accident, which causes overcrowding and accumulation of forest combustible materials.

Stocks of terrestrial forest fuels materials depend on a number of factors: age of planting, completeness, stock, diameter of planting, number of trees, etc.

In addition to the total stock of terrestrial forest combustible materials, which determines the intensity of combustion during a fire, their fractional structure plays an important role. In the total mass of terrestrial forest combustible materials, the reserves of forest litter in fresh forests and forests are on average 71-73%. In the composition of litter in the forests, the average precipitation is 52%, humus and enzymatic horizons 48%, and in the forests 32% and 68%, respectively. This is due to differences in the rate of decomposition of precipitation and in the phytomass of living above-ground cover, which contributes to the reserve of forest litter during death. Stocks of wood waste, which forms clutter of plantations and affects the vertical distribution of terrestrial forest combustible materials, are 24-27%. Stocks of large branches and trunks of trees average 8%, in some plantations reaching 20%. Twigs d = 2.54–7.62 cm are about 10%, stocks of small twigs.

It is in the forest floor that radionuclides accumulate and solidify (and other anthropogenic pollutants) in the forest ecosystem - in crown fires almost the entire thickness of forest litter burns out and radioactive substances can relatively easily and quickly penetrate into the lower, water-saturated, soil horizons (there may be a problem of groundwater contamination by radionuclides).

The development of fires, their intensity, the possibility of transition from low to high fires are influenced by stocks of combustible forest materials and the sanitary condition of plantations, the possibility of fires and their spatial location - the structure of the forest fund. These two factors determine the natural fire hazard of forests [45].

The main danger of fires is the burning of the main battery of radioactivity - forest litter. At surface fires the sheet layer of a bedding and partially enzymatic suffers. At the top type of fires there is a complete burnout of forest litter and the upper, mineral layer of soil partially suffers from thermal influence. As a result, up to 80% of the radionuclides left after the fire in this ecosystem get into the mineral part of the soil.

The total area of fires in the ChEZ of the Chornobyl NPP can be seen in figure 2.6 [44].

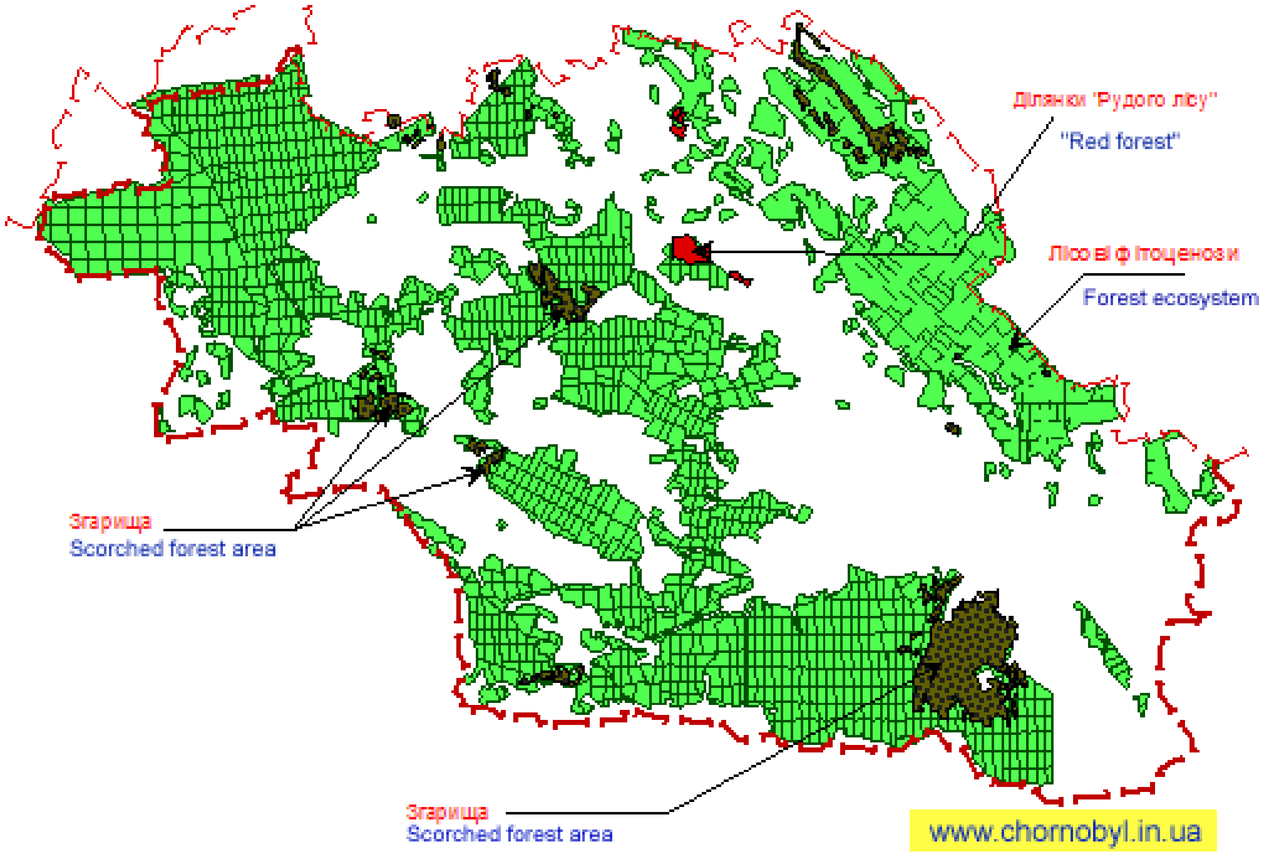

Fig. 2.6. Total area of fires in the ChEZ

During the development of wildfires mineralization of forest litter and organic matter in the upper part of the soil cover to a depth of 5 cm, which poses a risk of wind erosion, intensification of leaching and infiltration of radioactive ash in natural landscapes.

For example, measurements in 2002 show that the density of contaminated litter was (70–900) kBq / m^2 and was covered with radioactive ash particles of 10–20 μm with a specific activity of ^{137}Cs (0.6–1.5) kBq/kg, which can become a secondary source of radiation pollution due to deflation [39].

In 2015, 130 gigabecquerels of radionuclides were released from wood and forest litter, in 2020 already 700 GBq. This is already serious, because according to Ukraine's radiation safety standards, only 800 millibecquerels can reach large cities such as Kyiv [47].

In addition to the direct effects of fires on the environment, which are manifested immediately, there are also secondary effects, the effects of which manifest themselves over time. Thus, significant secondary effects of natural fires are related to the destruction or destruction of woody and grassy vegetation and forest litter, which play an important role in protecting soils from erosion, especially in mountainous areas. High-intensity fires that damage the ground cover can cause:

- the appearance of water or wind erosion, which contributes to the loss of the fertile soil layer;

- loss of macro- and microelements in the upper layer of the soil, which significantly reduces its fertility;

- landslides, villages and landslides that threaten buildings and infrastructure (including roads) and human life (in mountainous conditions);

- development of rapid floods (sudden floods), which are the most dangerous for the lives of citizens of entire settlements.

Wintering insects also burn in dry forest litter. Fires lead to the destruction of soil cover, because plant residues burn directly, soil-forming microorganisms die. In addition, they die from heavy metals formed during combustion. As a result of the fire, ash is deposited, which is a very poor fertilizer and thus leads to increasing depletion of the soil. Destruction of natural deciduous litter leads to a 2-4-fold increase in soil freezing [48].

Fires will increase the pH of soils. This is due to the fact that ash water-soluble compounds, penetrating deep, saturate the absorbing complex with alkaline earth elements and cause a shift in the reaction of the solution to the neutral range.

Under the influence of wildfires, forest litter burns, which affects the organogenic characteristics of soils, especially their upper horizons [49].

The negative consequences of wildfires include the impact on the physicochemical and morphological characteristics of soils. The concentration of heavy metals in the surface horizons of the soil increases several times and exceeds the background values due to the mineralization of forest litter from the burning of grassy vegetation [50].

Heavy metal pollution is a major environmental problem that threatens plants, animals and human health, as well as the quality of the environment. Heavy metals can slowly enter plants, animals and humans through air, water, and the development of the food chain over a period of time. The presence of heavy metals often leads to a decrease in the frequency of soil respiration and there is a negative correlation between microbial soil respiration and heavy metal content. Heavy metals can significantly affect soil ecosystems. Heavy metal contamination negatively affects the activity of soil enzymes, as well as reduces the microbial population of the soil. Heavy metal pollution has a negative effect on nitrification processes, which in turn affects mineralization. With increasing concentration of heavy metals, nitrification processes decrease [51].

The soil after the fire is depleted, the humus content is reduced. The humus horizons of soils respond to the impact of grassroots fire by the loss of nitrogen as a result of partial combustion of its organic compounds.

One of the main sources of organic matter of isolating elements in soils is forest litter. Under the influence of surface wildfires there is a partial or complete combustion of litter, which further affects the properties of soils, especially their upper horizons [50].

Nature also has the ability to self-clean. The values of the effective half-life of 5-cm horizons of natural meadow soils formed on automorphic mineral soils from ^{137}Cs are 20-25 years; for meadows formed on hydromorphic organogenic soils - 8-12 years. The value of the effective periods of semi-cleaning of the upper 5-cm horizons of natural meadows, formed on automorphic mineral soils of light mechanical composition (sandy), from ^{90}Sr is 6-8 years, heavier mechanical composition (loamy) - 10-15 years; formed on organogenic soils - 22-24 years. Effective periods of half-cleaning of horizons of plowed agricultural lands from ^{90}Sr are: for organogenic soils - 22-25 years, for mineral soils of medium and heavy mechanical composition - 12-25 years, light mechanical composition - 2-12 years. Effective periods of half-cleaning of plowed horizons of soils of agricultural lands from ^{137}Cs are: for organogenic soils - 15-20 years, for mineral soils - 20-25 years.

Studies of the rate of dissolution of fuel particles and the transition of radionuclides to mobile forms allow us to conclude that 10 years after the accident is projected maximum contamination of agricultural products with strontium in areas adjacent to the south to 30 km km (Strakholissya, Gubin, p. Gornostaypil, etc.), and for 20 years on a narrow western trail in Kyiv and Zhytomyr regions (direction to the village of Dovgyi Les). In this regard, it is necessary to organize a comprehensive control of contamination of 90Sr agricultural products and food, based on the diet, in potentially dangerous regions to measure its entry into the human body and the correct assessment of dose loads [52].

2.3. Impact on water bodies

Surface waters of the ChEZ are represented by rivers, lakes, ponds, old rivers of the Pripyat and Uzh rivers, the reservoir of the Kyiv HPP, reclamation ditches, water mirrors in front of the filtration dams. Table 2.3 shows the characteristics of water bodies located in the Chornobyl Reserve.

Table 2.3

Characteristics of water bodies in the Chornobyl Reserve

Names of water bodies	Where the river flows	Length within the ChEZ, km	Area of land Reserve	Flow speed, m / sec	Average width, m	Average depth, m
Reservoir of Kyiv HPP		-	10435	-	-	-
Lakes		-	1526,4	-	-	-
Ponds		-	159,6	-	-	-
Channels		-	1314,6	-	-	-
		-	73,3		-	-
Pripyat	Dniper	50	-	0,5	300	5
Uzh	Pripyat	108	-	0,5	50	1,5
Sakhan	Pripyat	11	-	0,3	10	0,5
Illya	Uzh	40	-	0,2	10	0,5
Brahinka		6	-	0,5	25	1
Nesvich	Brahinka	16	-	0,3	10	0,5
Veresnya	Uzh	10	-	0,4	15	1
Greslya	Uzh	9	-	0,4	15	1
Berezhest	Greslya	17	-	0,2	5	0,5
Luboizha	Illya	12	-	0,2	5	0,5

The main source of food for the rivers of the ChEZ is snow cover. The share of meltwater runoff is about 60% per annum; the rest of the runoff is divided, depending on the individual river basins, into soil and rain food. This nature of nutrition leaves its mark on the level of the level throughout the year. The share of underground supply is significant and is equal to 20-33% of the total runoff. Rainwater mainly affects the formation of runoff of small rivers.

Some rivers (Sakhan, Ilya, Braginka and several other minor streams) have been blocked since 1986 in one or more places by special filtration dams to reduce radionuclide removal in the Pripyat River, and several old and backwater reservoirs have been blocked. On the rivers in front of the dams, water mirrors of different sizes were formed in some places.

The creation of a dam on the Braginka River led to a change in the hydrological regime (flooding) on a large area of Parishivsky forestry [23].

The hydrological regime of the Chornobyl Reserve's water bodies during 2020 was determined primarily by the hydrometeorological features of the current year and the preconditions of the previous period.

As in the previous year, 2020 was abnormally warm - according to observations at the Chornobyl meteorological station of the Ukrainian Hydrometeorological Center, the average annual temperature (9.9 ° C) exceeded the norm by 2.7 ° C. All months of the year, except May, were warmer than normal. The annual rainfall was 618 mm (2% more than normal). The distribution of precipitation during the year was extremely uneven (Fig.2.7). Most precipitation fell in May - 144 mm or 267% of normal. The driest months were March (19.8 mm of precipitation, or 64% of the norm for the month) and April (23.2 mm, 54% of the norm) [33].

The main part of the ChEZ is located between the rivers Pripyat and Vuzh. These rivers are characterized by the presence of wide (up to 7 kilometers) floodplain depressions with well-defined floodplain terraces. In addition, the entire territory of the ChEZ is saturated with a network of small rivers and streams, such as the Sakhan, Braginka, Ilya, Grezlya, etc. In the south-east, the ChEZ borders the Kyiv Reservoir. In the central part of the ChEZ there is a large artificial lake - the cooling reservoir of the Chornobyl NPP. The total area of the lake is 22.9 square kilometers. The lake is at the stage of decommissioning (drainage) with a return to the state of a small floodplain. In addition, in the ChEZ there are many other small bodies of glacial origin and several lakes of artificial origin (former peatlands). The nature of the terrain and the high level of groundwater in the past caused waterlogging of large areas of land. Due to the developed network of reclamation canals, some of which were built in the XIX century, swamps occupy no more than 2-3% of the total area, but in the last 30 years as a result of the cessation of reclamation there is a gradual restoration of wetlands.

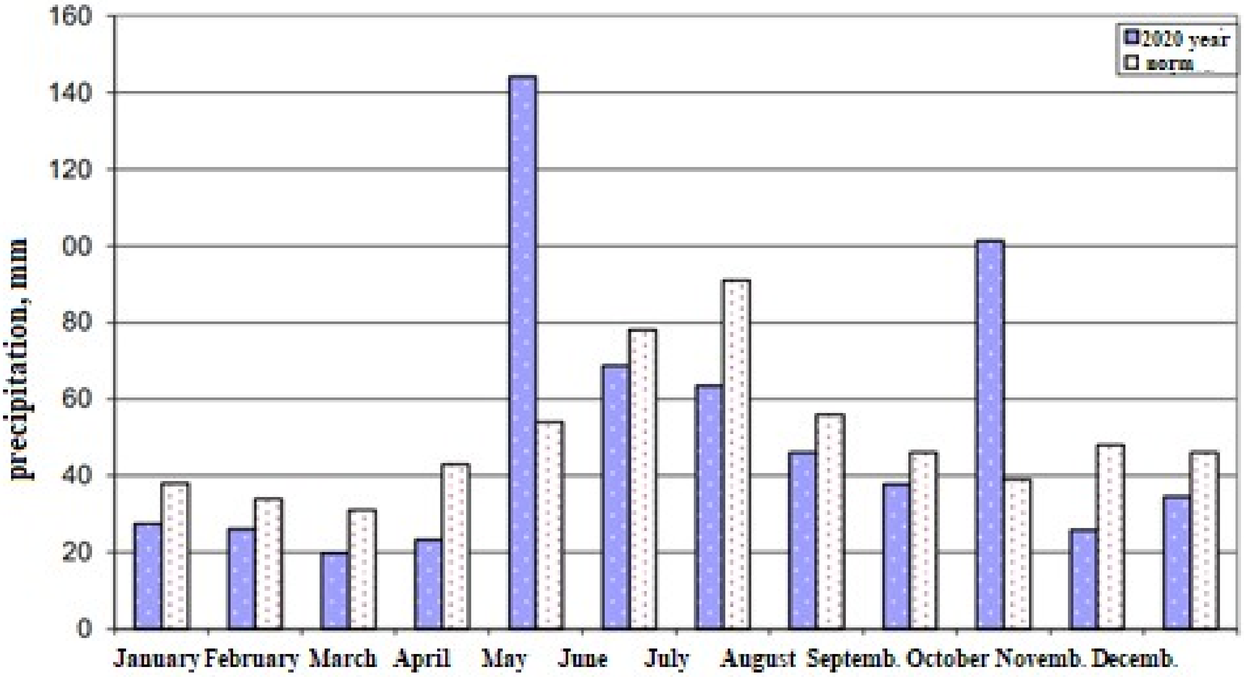

Fig. 2.7. The amount of precipitation per month according to the Chornobyl meteorological station in 2020

The Vuzh River is a flat river that flows from west to east in the southern part of the ChEZ. Near the city of Chornobyl, the Vuzh River flows into the Pripyat River. The swampiness of the river is 7%, and the forest cover of the floodplain is 19%. The catchment area of the river near the village of Cherevach is 7980 km^2 [14].

Flood dams have previously been built in some parts of the Pripyat and Uzh floodplains. They are not being monitored now, the necessary repairs are not being carried out.

At the beginning of the year, even in the presence of ice cover, the water level in the Pripyat River rises slightly and decreases slightly before the beginning of the spring ice drift. Simultaneously with the spring ice drift, there is an increase in the level, which ends in April and May with a spring maximum. The decline in spring levels is much slower compared to the rise and ends in June-July. During August-October, most of them set a threshold level, and at the same time there is a minimum level for the year. Summer rains have little or no effect on water levels. At the same time, autumn rains cause an increase in the level, which lasts until the autumn cooling. The decrease in air and water temperature contributes to the formation of ice phenomena in November (lard, ice drift), there is a temporary decrease in the level. After the formation of the ice cover, the water level rises again and in this state passes to the next year.

Similar changes in water levels during the year are observed mainly in small rivers. However, the rise of the water level in the spring and its decline in small rivers is smaller, and the maximum is observed in the spring in March - April, but it is possible at other times of the year. Accordingly, the duration of the summer limit is greater. In addition, the calm course of the daily water level in small rivers during the low tide may be disrupted by summer rains.

Standing of spring maximum water levels lasts no more than 1-2 days, and on small rivers less than a day.

The average amplitude of fluctuations in water levels on the Pripyat River is 300-500 cm, on the Uzh River - 25-400 cm.

The first signs of ice formation on the Pripyat River appear in the form of lard mainly in the last days of November, on the river in 75 cases out of 100 may not be observed at all. An ice drift appears 2-3 days after the formation of fat, and an ice age appears 10-15 days later.

The average dates of the beginning of the spring ice drift belong mainly to the second - third decade of March. The duration of the ice drift on the Pripyat River is on average 8 days (3-13 days).

The average dates of the beginning of the spring ice drift belong mainly to the second - third decade of March. The duration of the ice drift on the Pripyat River is on average 8 days (3-13 days).

The average ice-free period on the Pripyat River is 240 days on average, and on small rivers it is 259 days or more. But in some years, these figures can vary significantly depending on weather conditions [23].

The Pripyat River is one of the largest water bodies in the ChEZ. The river crosses the ChEZ from north to southwest and the Kyiv Reservoir flows into the border of the 30-kilometer zone. With a total length of the river of 78011 km, within the ChEZ, the length of the river Pripyat is about 50 kilometers. This is the distance from the village of Dovlyady to the place of its confluence with the Kyiv Reservoir. Flowing through radiation-contaminated areas, the Pripyat River plays an exceptional role in the transfer (migration) of radionuclides outside the ChEZ. Scientists have proved that the removal of radionuclides from the water of the Pripyat River is the largest in comparison with other ways (air, man-made, biogenic, etc.). The removal of radionuclides by the river increases during floods and significant flooding of radioactively contaminated areas, floodplains of the Pripyat River. For example, the highest values of radiostrontium removal outside the ChEZ, about 10 TBq, were recorded during the 1999 spill. These values were the highest in the last decade. The main radionuclides contained in the water of the Pripyat River are strontium (^{90}Sr) and cesium (^{137}Cs). The specific activity of these radionuclides in the water of the Pripyat River is in the range of 70 - 100 Bq/m^3 of water at ^{137}Cs and 170 - 400 Bq/m^3 at ^{90}Sr. Permissible concentrations of ^{90}Sr in river water, according to current regulations, are 10000 Bq / m^3. About 80% of all cesium-137, which is carried by the Pripyat River to the Kyiv Reservoir, enters the river not in the ChEZ, but outside it. Radionuclides enter the river from the watersheds of Belarus, which were also exposed to heavy radionuclide contamination after the 1986 Chornobyl accident. Data on radionuclide contamination of fish living in the Pripyat River were obtained during fishing near the city of Chornobyl. It was found that the levels of contamination of fish with radionuclides vary depending on the species of fish. Thus, the content of 137Cs in red pepper was about 150 Bq / kg, in pike - 120 Bq/kg, in bream -105 Bq/kg, in roach – 100 Bq/kg, in chub – 86 Bq/kg, perch - 68 Bq / kg kg and podust - 65Bq/kg [14].

Monitoring of the radiation status of surface waters is carried out in 22 points. Particular attention is paid to the Pripyat River, through which radionuclides are transferred from the territory of the Armed Forces to the Kyiv Reservoir. In 2020, the average and maximum values of ^{90}Sr in the water of the Pripyat River in the Chornobyl area were 43 Bq / m^3 and 74 Bq/m^3, respectively, ^{137}Cs - 20 and 129 Bq/m^3, which does not exceed the permissible normative document levels of radionuclides for drinking water (2000 Bq / m^3). According to preliminary calculations, the removal of 90Sr from the water of the Pripyat River in the Chornobyl area in 2020 amounted to 0.25 TBq (last year - 0.36 TBq, in 1999 - 10.2 TBq). This relatively small value of ^{90}Sr removal is due to the low water content of the Pripyat River this year and the lack of removal of volumetric activity by small rivers, tributaries of the Pripyat River [8].

The cooling reservoir of the Chornobyl NPP was built on the section of the right-bank floodplain of the Pripyat River. From the west, the shores of the reservoir are formed by a floodplain terrace, and from the eastern part - a fencing dam. The length of the dam is about 25 kilometers. Height about 6 meters and width from 70 to 100 meters. The length of the cooling reservoir is 11.4 km, the average width is about 2 km. Depths of the reservoir range from 6 to 20 meters [14].

Monitoring of radionuclide content in groundwater was carried out at three aquifers - Quaternary (145 wells), Eocene (Chornobyl water intake, Pripyat) and Cenomanian Lower Cretaceous (Chornobyl water intake and city water supply). The content of ^{137}Cs and ^{90}Sr in the water of the Chornobyl and Chornobyl water intakes did not exceed 14 Bq / m3 (permissible level for drinking water - 2000 Bq / m^3). Outside the areas of radioactive waste disposal, the vast majority of 90Sr content values are in the range of 100-400 Bq / m^3, 137Cs - 20-40 Bq / m^3. The radiation status of groundwater within the Buryakivka, Pidlisny, and the 3rd stage of the Chornobyl NPP is marked by a certain stability without pronounced tendencies of increasing ^{90}Sr content as the main pollutant. In the measured samples, the ^{90}Sr content varied from 14 to 1800 Bq/m^3 [8].

^{137}Cs concentrations in lysimetric and groundwater were determined. The activity of lysimetric waters on ^{137}Cs depends on the activity of the soil and is 0.0145 - 0.118% (Diggers), and 0.066% (Forests) of the content in the 0-7 cm layer. The concentration in ^{137}Cs groundwater is 2.5-6 times lower than in lysimetric ones. The intensity of horizontal migration in 1996 was insignificant, which is primarily due to the insignificant flow of meltwater and the complete absence of stormwater runoff. On slopes with a steepness of 3.5-6 degrees spring runoff was 2-4.5 mm. The removal of ^{137}Cs is 0.9-1.4 Bq / l, or 0.01-02% of its content in the upper soil layer. Solid runoff due to the formation of dense turf over a ten-year period in the resettled area was virtually absent. The wind transfer of radionuclides was also insignificant and amounted to thousands of percent of the content in the soil [52].

The content of ^{90}Sr in the water of the Pripyat River in the inlet (village of Usiv) during 2020 was recorded in the range from 0.01 to 0.04 kBq / m^3; in the Chornobyl area - 0.02 -0.07kBq/m^3. The volumetric activity of ^{137}Cs (total on suspension and in solution) in the water of the Pripyat River was mainly 0.01-0.04 kBq / m^3 for both the inlet and the Chornobyl. In the water of the river Uzh near the village. Abdominal values of ^{90}Sr volume activity were in the range of 0.04-0.07 kBq / m3; ^{137}Cs - 0.03-0.05 kBq / m^3. Content of radionuclides in the water of the Sakhan River (Novoshepelychi village): ^{90}Sr - from 0.76 to 1.2 kBq / m^3, ^{137}Cs - from 0.10 to 0.4 kBq / m^3. The volumetric activity of 90Sr in the water of the Braginka River was recorded at the level of 0.7-2.3 kBq / m^3. The content of ^{137}Cs is 0.6-0.8 kBq / m^3. The content of radiostrontium in the water of the lake. Deep reaches 83 kBq / m^3, cesium - 3.6 kBq / m^3 [33].

Wildfires in the ChEZ are the cause of declining water regulation, soil protection, sanitation, climate, environmental and anti-erosion role of forests in natural ecosystems. Destruction of coastal forests by fires leads to shallowing of rivers and rapid erosion of their shores. Surface runoff from forests causes a large amount of pollutants to enter surface water bodies after a fire. Forests regulate water flow, the intensity of snowmelt; equalize the temperature regime, reduce the amplitude of oscillations, purify water and air from mechanical and other impurities.

It should be noted that the periods of fire maximum and fire peak often coincide with the summer period. This is especially dangerous for small rivers, as it can reduce their runoff and even lead to death. Due to the small area of the basin, the degree of resilience of small river ecosystems to anthropogenic pressure is much lower compared to medium and large rivers [53].

During a fire, heavy metals get into groundwater, which is very dangerous to use for drinking purposes. With surface runoff, heavy metals enter water bodies, leading to the degradation of aquatic ecosystems.

In the formation of river runoff, the forest has the following functions:

- forests intercept precipitation, using moisture partly to support their livelihoods (transpiration, nutrition of root systems, etc.), and partly replenish groundwater, and at the same time reduce surface runoff;

- forests evaporate much more moisture than the grassy surface. Since there is almost no surface runoff in the forest, rain and stagnant water are absorbed by forest litter, infiltrate the soil and replenish groundwater, which is eroded in river valleys, providing them with underground food;

- rivers whose catchments are covered with forest have a more uniform runoff and a larger share of underground runoff than forestless ones (located in the same zone) [54].

2.4. Impact on biodiversity

The impact of wildfires on ecosystems is complex. The effects of climate change on species and their habitats vary greatly depending on the species, their interaction with other species and where they are located. Fire can be a major factor in changing plant communities in the context of climate change. These features of the impact of fires on the habitat of species must be taken into account in the organization of fire safety and the development of environmental measures to avoid negative consequences [55].

The results of field surveys of fires indicate an ambiguous impact on the fauna of the Chornobyl Reserve. Large and medium-sized birds and mammals have moved from fires in 2020. Importantly, most birds and mammals lacked eggs or young at the time of the fire. Thus, the loss of generation this year was avoided. There may be a direct death of a number of species of animals, especially newborn young, in fires. However, during the inspection of the fires, experts did not find the remains of large and medium-sized animals that died during the fire. It is obvious that some births in wild ungulates can take place in a stressful situation and females can leave newborns to their own devices. It is obvious that such a scenario took place in Przewalski's newborn horse found without the presence of an adult mare.

For ungulates and other herbivores, the necessary forage at the local level was limited or even short-term. However, they made short-term migrations to the unburned territory. Thus, the migration of three herds of Przewalski's horse to the west and south of the fire in the central part of the ChEZ was recorded.

There is also an increase in the density of ungulates - deer and roe deer - in an area of about 5 km along the fire. The fire in the second half of April led to the restoration of a layer of grassy vegetation for a month, especially in open areas.

Local populations of reptiles, small mammals and insects were lost during the fires. These are the groups that could not quickly leave the scene of the fire. In the gray hare in the fires, apparently, the first brood was destroyed by fire.

Anthills were destroyed in places of intense grassroots fires. However, as observations show, in conventional surface fires, the anthill recovers.

Crown fires and intense ground fires led to the destruction of nests of large birds:

- Great grey owl– 1 pc.
- Owl - 2 pcs.
- White-tailed Eagle - 1 pc.
- Lesser spotted eagle- 4 pcs.
- Large spotted eagle - 3 pcs.
- Buzzard - 4 pcs.
- Black storks - 2 pcs.

Long-term effects on rare species will occur due to changes in the habitats of these animals. Yes, for the first two years after the fires in the forests will not be blueberries and cranberries. In the future, berry regeneration will not take place at the sites of fires with dead stands. In places with surface fires and preserved woody vegetation, the yield of wild berries for 3-7 years will be high. The fires will contribute to the formation of more productive grasslands for Przewalski's horse, European deer and elk [33].

The fire destroyed a large number of insects that spent the winter in dry grass and forest litter. Fires that spread during the day in the southern and eastern directions (wind) had a higher intensity of combustion and greater destructive impact on ecosystems. Fires that occurred at night or spread against the wind in the western and northern directions had a low intensity of combustion and less negative impact. The duration of rainlessness in the post-fire period will also be essential for the survival of rare species, possible starvation for many herbivores. The probability of decline or population of herbivorous mammals from death in fire or from short-term lack of plant food is low. However, the final results can be made after field research [56].

The natural function of forests and forest plantations is due to water protection, stock-regulating and climate-regulating properties. Forests and afforestation provide a uniform water supply throughout the year and reservoirs throughout the year. Deforestation causes sharp shallowing of rivers and even their complete drying up. Afforestations that grow on the slopes protect the soil from erosion and erosion, from the formation of ravines.

In grassroots fires, the litter and part of the humus layer, the ground cover, the undergrowth with a bush tier, fallen trees and stumps burn out. A real disaster for the forest - crown fires, when burning both lower and upper tiers of wood. Ground, or underground, fires are characterized by a slow, very persistent spread of burning in peat deposits of swamps and wetlands, characterized by significant losses of organic matter from the forest ecosystem, although the relative frequency of such fires is low. Ground fires most often occur [57].

The ChEZ geographically belongs to the right-bank part of Ukrainian Polissya. Its natural appearance has typical features of this region: the flat nature of the area, high humidity, the presence of a large number of rivers and swamps, significant forest cover. Undoubtedly, the kingdom of plants that grow and cover all parts of the earth's surface - from dry sand hills to swamps - is represented by various forms of groups - from mixed forests to fallow lands. The species composition includes 1,200 species of higher plants, 200 species of mosses, 120 species of lichens.

Plants perform many functions in the landscape: they capture solar energy and form primary biomass, create an environment to maintain biodiversity, regulate surface runoff and local climate.

Among other things, vegetation in the ChEZ plays a role in the non-proliferation of radionuclides. The latter accumulate in plant biomass, where they are released only after their death and tissue decomposition. Yes, trees fix radionuclides in the trunk for tens and sometimes hundreds of years. Analysis of data from various sources shows that the annual removal of radionuclides outside the ChEZ and their deposition in plant biomass - values of the same order. In other words, the amount of radionuclides recorded annually in biomass is correlated with the annual river removal.

Dense vegetation fixes the surface layer of the soil, thereby preventing the rise of dust and pollution of the surface layer of the atmosphere. The last dust storms in the ChEZ were recorded in the late 80's of XX century. and have not arisen since. Forests also reduce surface runoff into rivers. Thus, vegetation stabilizes the environment and smoothes the effects of extreme natural phenomena.

However, during fires, this barrier breaks down and becomes a source of pollution. With smoke and ash particles, radioactive substances enter the atmosphere, increasing the risk of inhalation of radioactive substances into the human body. However, the widespread perception of radioactive clouds resulting from fires has not been confirmed by real observations. A sharp increase in the concentration of radioactive aerosols was observed directly near the line of fire. At a distance of several kilometers, the indicators of radiation status were within seasonal values. Therefore, during the fires of 2015 and 2018, the evacuation of Chornobyl personnel and enterprises of the ChEZ was not carried out. Visiting the territory of the ChEZ for educational purposes was limited only. The personnel involved in extinguishing the fire had personal protective equipment [32].

According to the results of the initial survey in 2020, the area of combustion is represented by forests (about 63%), fallows (21%), meadows and wetlands (7%), fires of previous years (7%) and other lands (2%) . Valuable oak-hornbeam forests, continental immoral pine-oak forests, oak swamp forests, birch and coniferous swamp forests, coastal willow formations, high-grass meadows, eutrophic and oligotrophic upland bogs are present in these areas.

Among the rare and endangered species of flora and fauna, the following were recorded here: forest lily, green-flowered lyubka, late queen, bent cornflower, shady sedge, annual plaun, Lithuanian daffodil, broadleaf dream, blackening dream, etc.

The Chornobyl Reserve has damaged a number of rare habitats of conservation importance and listed in the settlements of Resolution 4 of the Standing Committee of the Berne Convention:

D2.3 – transitional bogs and floodplains - more than 5 hectares

D5.2 – swamps dominated by large sedges - more than 50 hectares

E 1.9 – open dry acidophilic and neutrophilic grass groups - more than 100 hectares

E2.2 – plain hay meadows - more than 10 hectares

E3.4 – wet and wet eutrophic meadows - more than 10 hectares

E5.4 – wet high-grass meadows and fern edges - more than 1 ha

G1.11 – riparian willow forests - more than 10 hectares

G1.21 – floodplain periodically wet forests dominated by alder (Alnus) or ash (Fraxinus) - more than 50 hectares

G1.22 – floodplain forests dominated by oak (Quercus), elm (Ulmus) and ash (Fraxinus) - more than 10 hectares

G1.51 – sphagnum birch forests - more than 5 hectares

G1.8 – acidophilic oak forests - more than 10 hectares

X04 – complexes of upland bogs - more than 0.5 hectares

X35 – mainland sand dunes - more than 10 hectares [33].

The Regulation on the Red Book of Ukraine provides for a number of measures for the organization and reproduction of plant and animal species: from monitoring the population, creating protected areas, banks of the gene pool of endangered species, to conducting extensive educational work among the population, establishing responsibility for destruction or damage of endangered species animals or plants. It was found that the viability of biological species can be ensured only if all plant communities are preserved. Natural plant communities are a set of certain plant species that grow in areas with the same habitat conditions and are in close interaction with each other and with environmental conditions. Therefore, it is also necessary to protect the landscapes with which the groups are ecologically and phylocoenogenetically related. The task of preserving the plant world must be solved in a single plan for the protection of the gene pool and phytocenosis fund, all genetic and phytocenotic diversity of natural ecosystems [57].

To prevent the Chornobyl fires, the State Agency for Environmental Protection and the Ministry of Environment have developed a plan. The document is currently being approved by the authorities. Adoption of the plan will allow:

- to provide fire protection of the exclusion zone with equipment and personal protective equipment;
- create a unified communication system and early fire detection system;
- to train personnel involved in fire prevention and extinguishing [58].

2.5. Conclusions to chapter

Thus, fires that periodically occur in forests and fallows in the ChEZ have negative environmental and radioecological consequences, radionuclides are absorbed by plants, which during fires worsen the radioecological situation and cause re-transfer of radionuclides.

Wildfires have a negative impact on all components of natural ecosystems: they cause pollution of air, soil, surface and groundwater, lead to loss of biodiversity, destroy fauna and flora, cause soil erosion, change river regimes. Wildfires are one of the most dangerous phenomena in the environment, leading to significant economic losses and negative environmental consequences. In the current trend towards global warming, the risk of fires and loss of large areas of forest is increasing, which poses a threat of negative changes in natural ecosystems.

The main transport of pollutants in fires occurs through the air. This is due to the fact that most of the toxic compounds with combustion products enter the air in the form of directed convective flows. Winds also contribute to the transport of pollutants.

The physicochemical properties of soils after fires, which deteriorate because the amount of nutrients in the soil is significantly reduced: humus burns out, nitrate nitrogen content decreases. Under the influence of fire there are changes in such properties as: pH, content of exchange cations, gross and mobile forms of nitrogen, etc. However, it should be borne in mind that the behavior and content of forest litter is due not only to the fire geochemical situation in the region - the rate of water migration and biological absorption, terrain, in addition, all amplified by the content of radionuclides in them.

The rate of vertical migration of 137Cs in the soil was determined by the type and characteristics of their formation. The processes of natural migration of 137Cs depend on the properties of soils, their characteristics and hydrological regime. Economic activity or fires lead to a relatively uniform distribution of the radionuclide in the soil profile.

Ground cover plants (mosses, lichens), herbaceous and shrub plants are no less significant plant filter on the path of radionuclides. Their retention capacity depends on a number of factors (projective cover, biomass value, structure of assimilating organs). According to the degree of interception of radionuclides, they form the following row: mosses, lichens, herbaceous plants, shrubs. A special role here belongs to mosses, which have a large surface area of the aboveground phytomass per square meter of soil. Therefore, the spread of radionuclides during lowland fires is dangerous.

The action of high temperatures during a fire leads to the death of vegetation, or forces representatives of flora and fauna to seek new habitats, sometimes less favorable, since certain species of flora and fauna are able to exist in a certain temperature regime.

Thus, it is necessary to strengthen the implementation of further radiological control of food products of forest origin in radioactively contaminated areas, which will help ensure the consumption of safe products, as well as further study of trends in pollution of forest ecosystems (provide measures to reduce the conversion of radionuclides from soil to plants used for food and feed. This in turn will reduce the radiation doses of the population living in these areas).

CHAPTER 3
ESTIMATION OF FIRE DAMAGES WITHIN THE CHORNOBYL RADIATION AND ECOLOGICAL BIOSPHERE RESERVE

The assessment of the area of fires was performed jointly with the Regional Eastern European Fire Monitoring Center on the basis of satellite imagery data. In the process of surveying fires, conducting field research, aerial photography using unmanned aerial vehicles and analysis of the obtained high-resolution satellite images, the area of fires and their boundaries were established. The assessment of the area of fires was performed jointly with the Regional Eastern European Fire Monitoring Center on the basis of satellite imagery data. In the process of surveying fires, conducting field research, aerial photography using unmanned aerial vehicles and analysis of the obtained high-resolution satellite images, the area of fires and their boundaries were established.

3.1. Methods of estimating fire damage

Based on the obtained data, losses for ecosystems of the Chornobyl Reserve are calculated, quantitative indicators of destroyed and damaged natural complexes by their types, losses of wood, species of flora and fauna are determined in accordance with the 2002 №175 and the resolution of the Cabinet of Ministers of Ukraine of 24.07.2013 №541 "On approval of fees for calculating the amount of damage caused by violation of the legislation on nature reserves." [59].

Losses in each protected area or facility due to an emergency are determined by identifying typical biogeocenoses, similar in type of plant communities, habitat conditions, age and origin, to lay trial areas. Expert assessment of changes in the state of the biogeocenosis due to the emergency situation in relation to its initial state and biogeocenoses-analogues is carried out on the test sites. The number of destroyed and damaged plants and animals by species composition is calculated. The number of destroyed populations of plants and animals and other organisms is determined. The correspondence of the state of the biogeocenosis type after the emergency to its normal unchanged state is determined.

The method of expert assessment determines economic and social losses from the consequences of emergencies that lead to the disappearance of natural complexes or their individual components, unique natural formations, rare, exotic and typical species of flora and fauna, unique species of flora and fauna, natural monuments and unique landscapes. According to the Methodology of damage assessment, losses in the territories of the nature reserve fund are calculated according to the formula:

$$\textbf{Рпзф=Пз+Рз} \tag{3.1}$$

where Рпзф - general economic costs of the nature reserve fund from the consequences of the emergency situation;

Пз - the amount of costs for the restoration of the natural state of the object of the nature reserve fund;

Рз - unreceived income from recreational, scientific, environmental, tourist and other activities of the nature reserve fund.

The cost of restoring the natural state of the nature reserve fund is calculated by the formula:

$$\textbf{Пз = Ап+Анс+}\sum_{i=1*i}^{k} I \tag{3.2}$$

where Ап - costs of examination of the ecological and landscape structure of the nature reserve fund;

Анс - costs of examination of changes in the state of biogeocenoses of the object of nature reserve fund affected by the emergency situation;

I - the amount of damage caused by the i-th biogeocenosis due to the emergency situation for individual components of damage;

k- number of types of biogeocenoses;

Due to the large scale of the fire in 2020, the following types of biocenoses were identified in accordance with the peculiarities of calculating the amount of damage:

- *eutrophic lowland swamps*. The assessment of losses from the destruction of eutrophic swamps was carried out in accordance with Annex 8 to Resolution №541 "Fee for calculating the amount of damage caused by violations of the law on nature reserves due to damage to karst-speleological, geological and hydrological objects." According to which, the amount of damage from the destruction of plants of trees and grasses of the lowland eutrophic swamp is UAH 52,840. for 0.1 ha. Accordingly, the amount of damage will be [60]:

$$\textbf{Іболіт} = \textbf{П} * \textbf{Pi} * \textbf{10} \qquad (3.3)$$

where Іболіт - the amount of damage from the destruction of wetlands, UAH;

П - area of destroyed swamps, ha;

Pi - the amount of damage for damage to the i-th biocenosis, UAH.

- *wetlands*. Damage to wetlands that have not been surveyed and classified with upland and lowland wetlands has been determined in accordance with Annex 6 to Resolution №541 “Fee for calculating the amount of damage caused by violations of nature reserve legislation due to illegal collection or destruction of wildlife herbaceous plants, forest litter, medicinal plants, wild fruits, nuts, mushrooms, berries, secondary forest materials. According to which, the amount of damage from the burning of dry wetland vegetation depends on the area of land origin and for an area of more than 100.1 hectares is 550 UAH per 1 hectare. Accordingly, the amount of damage will be:

$$\textbf{Івбу} = \textbf{П} * \textbf{Pi} \qquad (3.4)$$

where Івбу - amount of losses from burning of dry wetland vegetation, UAH;

П - area of burnt lands, ha;

Pi - amount of damage for damage to the biocenosis, UAH.

- fallows with the available natural renewal. Damage from damage to natural regeneration to the degree of non-cessation of growth was determined in accordance with Annex 3 of Resolution No. 541 "Fee for calculating the amount of damage caused by violation of legislation on nature reserves due to destruction or damage of forest crops, natural undergrowth, seedlings and seedlings." According to which, the amount of damage due to destruction or damage to natural undergrowth and self-seeding aged 6 to 10 years is 41,250 UAH per 1 ha. Accordingly, the amount of damage will be [60]:

$$\textbf{Іпп=П*Рі} \tag{3.5}$$

where Іпп - the amount of damage from damage to natural regeneration, UAH;

П - area of damage to plots, ha;

Pi - the amount of damage for damage to the i-th biocenosis, UAH.

- *forests.* According to Annex 2 of Resolution №541 "Fee for calculating the amount of damage caused by violation of the law on nature reserves due to damage to trees and plants with woody stems to the extent of non-stop growth" is calculated based on tree diameter. The estimated number of trees was also calculated on the basis of taxonomic descriptions. The amount of damage from forest damage will be [60]:

$$\textbf{Іл}=\sum Ід, \tag{3.6}$$

$$\textbf{Ід = Кд*Рід} \tag{3.7}$$

where Ід - the amount of damage from damage to trees of the first diameter, UAH;

Кд – the number of damaged trees of the i-th average diameter;

Рід – the amount of damage to trees of the i-th diameter, UAH.

As examinations of the landscape structure and losses of the Chornobyl Reserve were not carried out, then

$$\textbf{Пз} = \sum_{i=1*i}^{K} I = Іболіт + Івбу + Іпп + Іл \tag{3.8}$$

Accordingly, unearned income from recreational, scientific, tourist and other activities are absent, therefore

$$\textbf{Рпзф=Пз.} \tag{3.9}$$

3.2. Consequences of fires in different parts of the Chornobyl Reserve:

- in the south-western part of the Chornobyl Reserve

The total area of the fire in this part of the Chornobyl Reserve is 43,480.6 hectares (table 3.1), which began on April 3, 2020.

Area of different categories of lands passed by fire in the south-western part of the Chornobyl Reserve in terms of forestry, ha.

Table 3.1

Total area of the fire in this par south-western part t of the Chornobyl Reserve

Category of lands	Denisovitske	Kotovske	Lubyanske	**Total**
Forests	7455,7	3238,3	16340,8	27034,8
Meadows	3792,1	2744,3	2664,4	9200,8
Swamps	1503,9	169,2	1197,5	2870,6
Lost plantings	3375,3	1,3	86,4	3463
Open forest crops	34,8	9,1	0,0	43,9
Chearing	85,5	23,2	145,8	254,5
Roads	63,8	13,6	56,8	134,2
Fire break	-	-	38,2	38,2
Water objects	116,7	110,7	88,3	315,7
Another lands	60,1	36,7	28,1	124,9
Total	**16487,9**	**6346,4**	**20646,3**	**43480,6**

Among the wetlands, about 30 ha of eutrophic swamps and 2840.6 ha of dry wetland vegetation were destroyed.

Іболіт=30*52,840*10=15852 thousand UAH,

Івбу=2840,6*0,55=1562,33 thousand UAH

The costs of damage to self-seeding on fallows, the area of which is 9200.8 hectares, is:

Іпп=9200,8*41,25=379533 thousand UAH

Also, a calculation was made from losses due to damage to forests in this part of the Chornobyl Reserve (Appendix C).

As the examination of the landscape structure and losses of the Chornobyl Reserve was not conducted, then

Пз=15852+1562,33+379533+5195738,48=5592685,81 thousand UAH

Thus, the estimated amount of losses from fires in the south-western part of the ChEZ is UAH 5,592.686 million.

- *in the southern part of the Chornobyl Reserve*

The fire in this part of the Chornobyl Reserve started on April 13, with an area of 3261.6 hectares.

Among the wetlands, 37 hectares of dry wetland vegetation were destroyed

Івбу=37*550=20,35 thousand UAH

Losses from damage to undergrowth and self-seeding on fallows on an area of about 725.9 hectares is:

Іпп=725,9*41250=29943,375 thousand UAH

Losses from losses due to damage to forests in the southern zone were also calculated (table 3.2).

Table 3.2

Calculation of losses from losses due to forest damage

Avarage diameter	Amount of damage (Рід)	Number of trees	Amount of losses (Іл), thousand UAH
1	2	3	4
8	22	212282	4670,212
10	22	106148	2335,267
12	50	98315	4915,735
14	50	169968	8498,416
16	115	147308	16940,477

Continuation of table 1.3

1	2	3	4
18	115	131193	15087,158
20	248	116668	28933,566
22	248	78601	19493,026
24	423	158062	66860,259
26	423	109810	46449,465
28	616	171165	105437,708

30	616	38290	23586,606
32	836	45890	38364,022
34	836	5570	4656,785
36	1084	41511	44997,486
40	1337	13395	17908,718
42	1337	4028	5384,853
44	1546	7513	11615,261
48	1759	682	1199,331
56	1979	212282	4670,212
Total		**2303470**	**467334,349**

As the examination of the landscape structure and losses of the Chornobyl Reserve was not conducted, then

Пз=20,35+29943,375+467334,349=497298,074 thousand UAH

Thus, the estimated amount of damage from fires in the southern part of the ChEZ is UAH 497.298 million.

- *in the eastern part of the Chornobyl Reserve*

The fire in this part of the Chornobyl Reserve started on April 16, covering an area of 4,109 hectares.

Among wetlands, 28 ha of eutrophic wetlands and 590.7 ha of dry wetland vegetation were destroyed.

Іболіт=28*52,84*10=14795,2 thousand UAH,

Івбу=590,7*0,55=324,885 thousand UAH.

Losses from damage to undergrowth and self-seeding on fallows on an area of about 518 hectares is:

Іпп=518*41,25=21367,5 thousand UAH

Losses from losses due to forest damage in the eastern zone were also calculated (table 3.3).

Table 3.3

Calculation of losses from losses due to forest damage

Avarage diameter	Amount of damage (Рід)	Number of trees	Amount of losses (Іл), thousand UAH
8	22	40135	882,975
10	22	63604	1399,291
12	50	175723	8786,125
14	50	259154	12957,712
16	115	431094	49575,775
18	115	257942	29663,297
20	248	187073	46393,996
22	248	156541	38822,125
24	423	174497	73812,034
26	423	63237	26749,411
28	616	86053	53008,887
30	616	4318	2659,695
32	836	53430	44667,497
36	1084	18259	19792,991
40	1337	1825	2440,036
44	1546	7575	11711,512
52	1869	215	401,296
56	1979	40135	882,975
Total		**2219652**	**423724,656**

As the examination of the landscape structure and losses of the Chornobyl Reserve was not conducted, then

Пз=14795,2+324,885+21367,5+423724,656=460212,241 thousand UAH

Thus, the estimated amount of fire damage in the eastern part of the ChEZ is UAH 460.212 million.

- *in the central part of the Chornobyl Reserve*

The fire in this part of the Chornobyl Reserve started on April 8, covering an area of 955.3 hectares.

Among wetlands, 4.2 hectares of dry wetland vegetation were destroyed

Iвбу=4,2*550=2,31 thousand UAH

Losses from damage to undergrowth and self-seeding on fallows on an area of about 277.1 hectares is:

Іпп=277,1*41250=11430,375 thousand UAH

Losses from losses due to forest damage in the central zone were also calculated (table 3.4).

Table 3.4

Calculation of losses from losses due to forest damage

Avarage diameter	Amount of damage (Рід)	Number of trees	Amount of losses (Іл), thousand UAH
8	22	992753	21840,561
10	22	473579	10418,735
12	50	286957	14347,865
14	50	196130	9806,508
16	115	355528	40885,745
18	115	438290	50403,339
20	248	600010	148802,568
22	248	424001	105152,250
24	423	965114	408243,295
26	423	609165	257676,694
28	616	876924	540185,176
30	616	127814	78733,240
32	836	161100	134679,429
34	836	2234	1867,938
36	1084	83149	90133,603
40	1337	16143	21582,676
44	1546	18254	28220,053
48	1759	7318	12872,478
52	1869	6669	12465,283
56	1979	992753	21840,561
Total		**12479672**	**1988317,437**

As the examination of the landscape structure and losses of the Chornobyl Reserve was not conducted,

then Пз=2,31+11430,375+1988317,437=199975,12 thousand UAH

Thus, the estimated amount of fire damage in the central part of the ChEZ is UAH 199.975 million [61].

3.3. Conclusions to chapter

Fires in April 2020 in the Chornobyl Reserve had a major impact on ecosystems. The total area covered by fires was 51,806.5 hectares (the largest center in the southwestern part). Its extinction was facilitated by abnormal natural conditions, as well as anthropogenic impact.

The damage from the fires to the historical and cultural heritage sites turned out to be significant. In all, 35 years after the Chornobyl accident, many immovable cultural monuments have been destroyed or completely destroyed by fire.

Because for an accurate assessment of ecosystem damage from fires, it is necessary to conduct an expert assessment and a detailed survey, so the estimated losses were calculated using mathematical calculations for forest damage and destruction, natural regeneration on fallow lands and wetlands as types of biogeocinosis. Approximate assessment of fire damage within the Chornobyl Reserve was carried out by the "Methodology for assessing damage from the consequences of emergencies of man-made and natural nature."

They have been averaged and need to be clarified and studied in more detail. For a more specific assessment of damage, it is necessary to determine the degree of damage to each ecosystem separately. Such an assessment requires the involvement of significant labor and material resources, as well as a fairly long period of time.

The total estimated damage from fires on the territory of the Chornobyl Reserve is approximately UAH 6,750.171 million.

CHAPTER 4
LABOR PRECAUTION

Every person, every individual to provide for their vital needs carries out a certain type of work. To minimize such negative phenomena in the process of human activity, the employer is obliged to create working conditions in the workplace in each structural unit in accordance with regulations, as well as to ensure compliance with legislation on workers' rights in the field of labor protection. The problem of protection of working personnel, improvement of methods of organization of labor protection at the workplace of the junior researcher in the Chornobyl Radiation and Ecological Biosphere Reserve is presented in this section. His main job is in the office, although it includes work in the open (reserve) [62].

The main provisions on the organization of labor protection in Ukraine are established and regulated by the Constitution of Ukraine, the Labor Code of Ukraine, the Law "On labor protection", as well as developed on their basis and in accordance with their regulations. Any enterprise is obliged to develop methodological recommendations and measures on labor protection in accordance with the Regulations on the development of methodological recommendations on labor protection, approved by the Order of the Committee on Labor Protection Supervision of the Ministry of Labor and Social Policy of Ukraine from January. № 29, 1998, № 9. Therefore, work on labor protection in the economy is carried out and organized according to plan on the basis of the above legislation [63].

4.1. Organization of the working place of expert at the Chornobyl Radiation and Ecological Biosphere Reserve

The following requirements must be met for office work:

- the area per workplace must be at least 6.0 m^2 and the volume at least 20.0m^3.
- premises for work must be equipped with heating, air conditioning or supply and exhaust ventilation.
- the floor covering should be matte with a reflection coefficient of 0.3-0.5. The floor surface should be smooth, non-slip, with antistatic properties.
- workplaces must be located at a distance of at least 1 m from the wall with a window and 1.4 m from a normal wall.

- the design of the desktop must meet modern requirements for ergonomics and ensure optimal placement on the work surface of the equipment used (display, keyboard, printer) and documents.
- window openings of work premises must be equipped with adjustable devices (blinds, curtains, external visors).
- it is forbidden to use polymeric materials that emit harmful chemicals into the air to decorate the interior of the premises.
- production facilities can be equipped with cabinets for storing documents, magnetic disks, shelves, racks, cabinets, etc., taking into account the requirements for the area of the premises.
- the premises must be equipped with first aid kits.
- wet cleaning should be done daily.
- the premises must be equipped with living quarters for rest during work, a room for psychological relief.
- artificial lighting in workplaces should be carried out by a system of general uniform lighting.
- the general lighting system should be solid or discontinuous lines of luminaires located on the side of the workplace (preferably on the left), parallel to the line of sight of workers.
- to ensure permissible noise levels in the workplace, sound absorption devices should be used, the choice of which should be justified by special engineering and acoustic calculations.
- the values of electrostatic and electromagnetic fields at the workplace, as well as the intensity of infrared and ultraviolet radiation must meet regulatory values [64].

4.2. Analysis of hazard factors at the working place

Labor protection of the working place of expert at the Chornobyl Reserve, taking into account the specifiedfeatures, is insured due to certain requirements: documentation; production; equipment; staff.

Hazardous and harmful factors of the production process are an integral part of the defining working conditions.

A harmful production factor is defined as a factor of the environment and the work process, the effect of which on a worker under certain conditions (intensity, duration, etc.) can cause an occupational disease, a temporary or permanent decrease in working capacity, increase the frequency of somatic and infectious diseases, and lead to health problems.

By the nature of the impact on the body of a working person, harmful and hazardous factors are divided into: physical, chemical, biological and psychophysiological, and all four of these factors can affect workers in the laboratory for quality control of medicines [65].

In accordance with ГОСТ 12.0.003-74, valid until 01.01.2022 in accordance with order State Enterprise “Ukrainian Scientific Research and Training Center for Standardization, Certification and Quality Problems” № 111 dated 04.24.2019, the microclimate is referred to as physiological; high levels of noise, vibration; high dust content in the air; high levels of electromagnetic vibrations, ionizing radiation; insufficient or excessive lighting of workplaces. Biological factors includes: pathogenic microorganisms (bacteria, viruses, spirochetes, fungi, protozoa and their metabolic products. Psychophysiological factors are characterized by physical overload (static, dynamic) and neuropsychic overload (mental, overstrain of analyzers, monotony) [66].

According to Ukrainian legislation, an employee has the right to healthy and safe working conditions. The concept of working conditions necessarily includes the organization of the workplace, on which the quality and efficiency of work depends, as well as the preservation of the health of the employee.

The workplace must meet the following criteria: the accessibility of all samples and instruments necessary for the study; convenience of the shape and size of the workplace, approach and exit from it; seat height; inspection from the workplace and the conditions of visual perception; correct definition of the manipulation zone of the arms and the placement of the legs, etc.

As some parts of the ChEZ have radiation pollution, it is necessary to consider radiation as a harmful factor affecting the worker.

- *Natural and artificial illumination*

In office premises, it is advisable to arrange workplaces, regardless of the type of lighting, so that light from natural light falls on them, usually on the left side.

For general artificial lighting should be used, as a rule, bit light sources, preferring the same power light sources with the highest light output and service life.

The normalized parameter of natural light is the coefficient of natural light. The coefficient of natural light is set depending on the category of visual work performed. Basically, the work of a junior researcher in the Chornobyl Reserve refers to works of medium accuracy (IV category of visual works, the minimum size of the object of distinction is 0.5-1.0 mm), for which when using side lighting, the natural light factor is 1.5%. For artificial lighting, the normalized parameter is the minimum level of illumination, and the pulsation coefficient of light flux, which should not exceed 20%. The minimum illumination is set depending on the category of visual work performed [68].

- *The microclimate and ventilation*

The microclimate of the premises is the meteorological conditions of the internal environment of these premises, which are determined by the combined effect on the human body of temperature, humidity, air velocity and thermal radiation.

Optimal microclimatic conditions (presented in table 4.1) are a combination of quantitative indicators of microclimate, which with long-term and systematic action on humans ensure the preservation of normal thermal state of the body without stressing the mechanisms of thermoregulation. They provide a feeling of thermal comfort and create the conditions for a high level of efficiency.

Table 4.1

Optimal microclimate conditions

Season	**Category of work**	**Air temperature, °C**	**Relative humidity,%**	**Air velocity, m\sec**
Cold Season	Easy (Ia)	22-24	60-40	0,1
	Easy (Ib)	21-23		0,1
	Moderate (IIa)	19-21		0,2
	Moderate (IIb)	17-19		0,2
	Difficult (III)	16-18		0,3
Warm	Easy (Ia)	23-25	60-40	0,1
	Easy (Ib)	22-24		0,2
	Moderate (IIa)	21-23		0,3
	Moderate (IIb)	20-22		0,3
	Difficult (III)	18-20		0,4

Productivity and well-being of workers depend on the state of the environment and, above all, on changes in temperature, air velocity, atmospheric pressure, and thermal radiation.

Work category - the distribution of work according to the severity based on the total energy consumption of the body. There are three categories of work: easy: (category Ia) - work performed while sitting and does not require physical exertion; (Ib) - work performed while sitting, standing, or involving walking and light physical exertion. Moderate work: (IIa) - work associated with walking, moving small objects weighing up to 1 kg, which are performed while standing and sitting, require a certain amount of physical stress; (IIb) - work performed while standing, associated with walking, with the movement of loads weighing up to 10 kg, are accompanied by moderate physical stress. Difficult physical work - covers activities involving constant movement, carrying loads weighing more than 10 kg, requiring significant physical effort [67].

- *Noise pollution*

In the room where the specialist works, there are workstations with a personal computer, each of which is equipped with a monitor, a hard drive in the system unit, fans of the cooling system of the personal computer and a keyboard. In addition, peripheral equipment works nearby. Thus, there are noises of mechanical and aerodynamic origin in the room. The approximate equivalent sound pressure levels of the noise sources acting on the programmer at his workplace are presented in table 4.2. The permissible equivalent noise level for the programmer's workplace is 50 dBA [69].

Table 4.2

Sound pressure levels from different sources

Noise source	Noise level, dBA
Hard drive	45
Ventilator	45
Matrix printer	55
Scanner	50

4.3. Preventive action for hazardous and harmful production factors at the working place

Favorable working conditions are impossible without maintaining a normalized microclimate (appropriate temperature, humidity and air mobility).

Consequently, the parameters of the microclimate in the premises must ensure a comfortable well-being of the body, therefore, there must be a reliable climate control system and ensure the cleanliness of the air in the working area.

To ensure proper lighting conditions, it is necessary to improve the quality characteristics of lighting by introducing modern energy-efficient lamps, a remote control system for them and a system for monitoring the working condition of lamps during their operation. Use combination lighting for even lighting. Equally important is the light color of the ceiling, walls and production equipment to evenly distribute the brightness across the field of view. All technical solutions related to the technical re-equipment of the lighting system include measures to replace existing luminaires with more energy efficient ones with built-in luminous flux control systems and are based on the requirements of current regulatory documents, rules and regulations.

The average noise and vibration levels exceed the maximum permissible noise level for the employee's workplace, so it is necessary to replace noisy equipment with silent ones, carry out preventive measures, alignment and balancing of parts. Provide employees with personal protective equipment, namely ear muffs, helmets, suits.

Also reduce the voltage level from the screen and monitor body, or replace them with more modern ones.

Based on the results of the analysis of the severity and intensity of work, you can reduce the time spent working on the computer, taking breaks, the total time of which should be 50 minutes with an 8-hour shift.

With regard to work directly on the territory of the Chornobyl Reserve, the employees may be affected by the following factors:

- unprotected stay in some parts carries the risk of receiving a dangerous dose of radiation.
- animals that are within their habitats
- weather conditions
- faulty technical or laboratory tools for work in open areas

low-quality professional protective clothing.

4.4. Fire safety

Fire safety in the laboratory is an integral part of the organization of the workspace and processes in accordance with the norms of current legislation.

In particular, this area is regulated by the Fire safety regulations in Ukraine approved by order of the Ministry of Internal Affairs of Ukraine dated 30.12.2014 № 1417.

A fire-fighting regime must be established on the territory of the Chornobyl Reserve, which includes:

- the procedure for maintaining evacuation routes;
- identification of special places for smoking;
- the procedure for using open fire;
- the procedure for using household heating appliances;
- the procedure for conducting temporary fire-hazardous works;
- rules of travel and parking of vehicles;
- places for storage and the allowable amount of raw materials, semi-finished products and finished products that can be both on the premises and on the territory;
- the procedure for disconnecting equipment and ventilation systems from the power supply in case of fire;
- the order of inspection and closing of premises after the end of work;
- the procedure for organizing the operation and maintenance of existing fire protection equipment;
- the procedure for carrying out planned and preventive repairs and inspections of electrical installations, heating, ventilation, technological and other engineering equipment;
- the procedure for gathering members of the fire and rescue unit of voluntary fire protection and officials responsible for fire safety in case of fire, call at night, on weekends and holidays;
- procedure for action in case of fire [70].

Fire alarm systems are designed for early detection of fires and alarms to take the necessary measures (eg: evacuation of people, call fire and rescue units, start against smoke systems, fire extinguishing, control of fire valves, doors, gates and curtains (screens), shutdown or blocking (unlocking) of other engineering systems and equipment at the signal of "fire", etc.).

The requirements of current technical standards must be complied with during maintenance measures [71].

4.5. Conclusions to chapter

Therefore, in chapter 4, hazardous and harmful production factors on workplace of a expert researcher at the Chornobyl Reserve, technical and organizational measures to reduce the level of influence of hazardous and harmful production factors in the laboratory were analyzed.

Among the dangerous and harmful factors an important place is occupied by the microclimate of the room, lighting, noise, vibration and directly the employee's workplace.

To ensure fire safety in the laboratory, it is necessary to comply with fire safety rules for all employees and equip the premises with fire extinguishers, emergency exits and install an automatic fire extinguishing system, where possible

CONCLUSIONS

1. As a result of the Chornobyl accident, during 10 days of intensive emissions, the direction of movement of air masses was repeatedly changed, which was accompanied by synoptic phenomena. This led to uneven contamination of the territory with significant differences in both the density of contamination and the radionuclide composition, which led to the formation of zones of radioactive contamination in different directions.

2. Analyzing the current state of the ChEZ, we can say that about 1 million hectares of forests still remain contaminated with radionuclides of man-made origin. The nuclear fuel released from the emergency reactor contained several hundred different radionuclides. To date, almost all of them have disintegrated. Isotopes that affect the environment today include cesium-137, strontium-90, isotopes of plutonium and americium-241.

3. After the Chernobyl accident, the number of fires and areas of wildfire damage in the ChEZ and guaranteed resettlement increased due to a number of socio-economic and radiation-forest factors, the main of which are the deterioration of fire protection, fire condition of forests, insufficient effectiveness of fire prevention and legal framework.

4. As the existing legislative and regulatory framework for the accounting and control of radioactive materials has shortcomings (inconsistencies, inaccuracies, outdated data and methods of solving problems, prevention of terrorist acts, etc.), it needs to be revised and improved.

5. Forests have played an important role in limiting the spread of radioactive contamination since the Chernobyl disaster, so monitoring and analyzing the radiation status of areas due to the effects of natural fires is a necessary component of environmental research. In Ukraine, 12% of the total forest area is contaminated with radionuclides, which is 1.1 million hectares.

6. As a result of wildfire, all components of the ecosystem are damaged or destroyed: soil, vegetation, undergrowth and wood layer, changes in the structure, composition and properties of forest litter and upper soil layers, as well as the microclimate of the area.

7. In the forest litter, pollution is especially dangerous: radioactive substances rise into the foliage and again fall off with it. In addition, radionuclides are actively absorbed

by natural fungi, berries and other plants. Accordingly, animals also remain contaminated with radionuclides and this situation will remain for several decades. That is why low-lying fires are such a special danger in the ChEZ.

8. Therefore, one of the main tasks is the early detection of wildfires, minimizing their consequences and ensuring radiation protection of the population. This can be done with the help of modern equipment and devices. It is possible to conduct an integrated assessment of radiation risks, predict the occurrence and development of emergencies, promptly develop and implement priority measures to eliminate and mitigate the possible consequences of radiation accidents.

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APPENDICES

Appendix A

Distribution of cases and areas in natural complexes of ChEZ by landscape types from 1993 to 2018

Year	Type of landscapes covered by fires							
	Number of fires, cases				Area of fires, ha			
	fallows	forest	abandoned settlements	swamps	fallows	forest	abandoned settlements	swamps
1993		12				18,23		
1994	90	11	7	1	212,37	14,5	3,02	6
1995	46				475,56			
1996	56	3	17		121,04	3,6	184,4	
1997	61	12	14	7	181,03	79,82	44,2	32,74
1998	29	7	10		17,19	3,84	2,3	
1999	91	19	5		274,93	19,07	0,47	
2000	23	41	18		113,4	57,75	18,24	
2002	36	55	10	4	28,27	65,13	58,92	1,86
2003	22	35		2	29,56	109,46		4,8
2004	25	12			35,38	7,18		
2005	10	23			17,15	16,68		
2006	11	8			21,72	33,55		
2007	22	13	4	2	31,53	76,81	0,15	1
2008	10	9			10,64	14		
2009	26	28	5		36,69	50,07	12,65	
2010	13	23	3		11,28	13,53	0,81	
2011	28	9	1		28,54	8,23	3,5	
2012	11	7			10,74	35,15		
2013	14	6	1		21,05	3,3	0,02	
2014	32	20		1	53,09	49,29		5
2015	44	48	2	3	6419	10424	1,02	5,24
2016	16	23			22,95	33,11		
2017	22	11	2	1	44,27	217,31	1,01	
2018	14	15			17,85	149,38		
2019	32	25			125,8	52,58		
2020	30	38	2		5549,5	61971	0,03	2,2
Total	815	513	101	21	2181,3	85266	330,74	59,11

Appendix B

Summary table of ecosystem damage by fires that lasted during April 2020 in ChEZ, ha

Category of lands	South-western part						Western part	South part	Central part				Total area of fires, ha		
	territory of the Reserve, ha				area in the area of radioactive waste management, ha	together in the ChEZ, ha	territory of the Reserve, ha	territory of the Reserve, ha	territory of the Reserve, ha		area in the area of radioactive waste management, ha	together in the ChEZ, ha	all in the Reserve	area in the area of radioactive waste management, ha	together in the ChEZ, ha
	Denisovytske	Kotovske	Lubyanske	all in the Reserve			Parishivske	Dityatkivske	Korogodske	all in the Reserve					
Forests	7455,7	3238,3	16340,8	27034,8	1450,6	28485,4	2484,7	2270,7	622,9	622,9	8728,6	9351,5	32413,1	10179,2	42592,3
Meadows	3792,1	2744,3	2664,4	9200,8	158	9358,8	518	725,9	277,1	277,1	3400,8	3677,9	10721,8	3558,8	14280,6
Swamps	1503,9	169,2	1197,5	2870,6	7,1	2877,7	618,7	37	4,2	4,2	228,5	232,7	3530,5	235,6	3766,1
Fires, dead planting	3375,3	1,3	86,4	3463	0	3463	0	48,3	2,3	2,3	4,6	6,9	3513,6	4,6	3518,2
Open forest crops	34,8	9,1	0	43,9	0	43,9	0	3,6	17,4	17,4	0	17,4	64,9	0	64,9
Viziers	85,5	23,2	145,8	254,5	8	262,5	8,5	25,5	2,7	2,7	61,2	63,9	291,2	69,2	360,4
Roads	63,8	13,6	56,8	134,2	6,7	140,9	10,5	10,9	2,2	2,2	20,7	22,9	157,8	27,4	185,2
Fire break	0	0	38,2	38,2	0	38,2	0	14,9	6,9	6,9	31,6	38,5	60	31,6	91,6
Water bodies	116,7	110,7	88,3	315,7	0	315,7	379,4	43	0	0	119,8	119,8	738,1	119,8	857,9
Other lands	60,1	36,7	28,1	124,9	3,6	128,5	89,2	81,8	19,6	19,6	186,2	205,8	315,5	189,8	505,3
Total	16487,9	6346,4	20646,3	43480,6	1634	45114,6	4109,0	3261,6	955,3	955,3	12782,0	13737,3	51806,5	14416	66222,5

Appendix C

Calculation in south-western of the Chornobyl Reserve from losses due to damage to forests

Avarage diameter	Amount of damage (Рід)	Number of trees				Amount of losses (Іл), thousand UAH			
		Denisovitke	Kotovske	Lubyanske	Total	Denisovitske	Kotovske	Lubyanske	Total
8	22	540914	423673	874489	1839076	11900,103	9320,813	19238,765	40459,681
10	22	554620	372572	753607	1680799	12201,650	8196,581	16579,351	36977,582
12	50	743372	352185	946487	2042044	37168,613	17609,241	47324,339	102102,193
14	50	528544	155438	1149040	1833023	26427,222	7771,925	57452,020	91651,166
16	115	560125	264175	1067170	1891469	64414,334	30380,108	122724,526	217518,968
18	115	259801	89937	1073068	1422805	29877,097	10342,732	123402,802	163622,632
20	248	372759	55869	1050392	1479020	92444,174	13855,587	260497,160	366796,922
22	248	364303	78106	1015791	1458200	90347,120	19370,231	251916,131	361633,482
24	423	379169	110587	1164025	1653781	160388,555	46778,482	492382,459	699549,497
26	423	266506	163814	1041864	1472185	112732,236	69293,362	440708,521	622734,119
28	616	298800	257085	850181	1406066	184060,848	158364,274	523711,537	866136,658
30	616	134928	69675	330862	535464	83115,377	42919,852	203810,791	329846,019
32	836	165801	85558	473317	724676	138609,653	71526,101	395693,386	605829,140
34	836	1086	4428	168	5682	908,264	3701,417	140,504	4750,185
36	1084	88607	30777	213567	332951	96050,415	33362,265	231506,268	360918,948
38	1084	2121	1384		3505	2299,483	1499,728		3799,211
40	1337	28257	4912	101582	134751	37779,585	6568,006	135814,729	180162,320
42	1337	3123		992	4115	4175,889		1326,466	5502,355
44	1546	8108	1173	38861	48142	12535,029	1813,919	60079,112	74428,060
46	1546			594	594			917,971	917,971
48	1759	10476		10593	21069	18427,512		18633,242	37060,754
50	1759	700	351	761	1812	1231,480	616,900	1338,195	3186,576
52	1869	2114		8122	10236	3950,667		15179,513	19130,179
56	1979	236		282	517	466,677		557,185	1023,862
Total		**7434298**	**6346885**	**15332040**	**29113223**	**1221511,981**	**553291,523**	**3420934,976**	**5195738,480**