National University of Life and Environmental Sciences of Ukraine

Regional Eastern Europe Fire Monitoring Center

Report

“Baseline information and gap analysis of
current status of fire management in ChEZ”

for the GEF – UNEP project
“Conserving, Enhancing and Managing Carbon Stocks and Biodiversity
in the Chornobyl Exclusion Zone"

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Abstract

Over recent decades, a number of nuclear accidents resulting in radioactive contamination of large areas of forest land have occurred in different parts of the world. The growing number of new nuclear power plants implies an increasing risk of similar events in the future. This article analyses wildfire risks and hazards for fire fighters, persons working in the Chernobyl Exclusion Zone (CEZ), and the environment as well as the specificities of current fire management in the best documented case – the CEZ. In the CEZ, insufficient forest and fire management during the past 28 years, along with dead wood due to insects and diseases, has resulted in a high wildfire hazard in the 260,000 hectares of forests and grasslands of the Ukrainian part of the CEZ, an area that is highly contaminated with long-living radionuclides of plutonium (^{238}Pu, $^{239+240}$Pu, ^{241}Pu), ^{241}Am, ^{137}Cs and ^{90}Sr. Up to 9,000 ha of pine forests are completely dead and are in the highest wildfire risk category. In most of the middle-aged pine plantations, 9-20 % of trees have already died, and another 31 % are expected to die during the next decade. Combined with the fact that nuclear radiation leads to a decreased speed of decomposition of dead organic material, this development will increase available fuel and corresponding wildfire hazard. The numerous wildfires, that have already occurred in the CEZ, including the catastrophic fires of 1992 (17,000 ha), have revealed the existence of ignition sources across the whole CEZ, including in the most contaminated areas. Fire prevention and suppression activities pose serious risks for firefighters who may reach their annual radiation dose limit over a relatively small number of days. In addition, the current management infrastructure is inadequate to mitigate existing and future wildfire risks. Recommendations for urgent steps to improve fire management in the CEZ are therefore proposed.

Keywords: Chernobyl Exclusion Zone, radioactive contamination, wildfire, fire management, forest, silviculture.

Content

Introduction

The problem of forest fires in the exclusion zone remains one of the most acute and urgent among the radiation, environmental and social problems of Ukraine. This is primarily due to the potential radiation consequences of catastrophic highland fires in the area that will result in large-scale secondary radiation contamination of surrounding areas, including agricultural land and surface water, as well as exposure of personnel in the exclusion and population areas, this region.

According to the unanimous opinion of Ukrainian and American experts, on the territory of the exclusion zone there were prerequisites for the emergence of a catastrophic forest fire, which cannot be controlled by existing technical means. Such a fire will lead to the migration of a considerable number of radionuclides outside the exclusion zone with the smoke plume that will reach the territories of the neighbouring countries of Ukraine. A striking example of the transboundary atmospheric transport of radionuclides is the Fukushima-1 nuclear accident in March 2011, which has been reported in Europe and the United States.

25 years after the Chernobyl disaster, exclusion zone forests have entered a critical phase of their development, which has significantly increased their fire risk. Due to a set of negative factors, including global climate change, forests lose their natural stability and go into a decay stage, accompanied by the drying up of trees and the accumulation of significant amounts of forest combustible materials. More than 2 million cub. m of dry radiation contaminated wood has already accumulated in the forests of the Exclusion Zone, and the area of forests with continuous drying of trees exceeds several thousand hectares.

Small fires occur regularly in the Exclusion Zone: over the period 1993-2016, more than a thousand fires were recorded in all parts of the area, including the most polluted ones, indicating the continued presence of fire sources in the forests. The high environmental risks of Europe from major radiation fires in the Exclusion Zone have been addressed by a number of reputable national and international institutions, including the National University of Life and Environmental Sciences of Ukraine, Yale University, USA, US Forest Service, UN Global Fire Monitoring Center (UN ISDR) OSCE, Council of Europe.

International research community and national authorities since 2007 made a number of step toward resolving of the problem of fire management in ChEZ, including: international conferences held at the National University of Life and Environmental Sciences of Ukraine in July 2007: 1) "Reducing the risk of emergencies due to catastrophic forest fires in Chernobyl contamination zones", 26-27 July 2007, NULES Ukraine; 2) Interdepartmental international meeting on the topic: “Measures to prevent emergencies (fires) in the forests of exclusion zone and zone of unconditional (compulsory) resettlement”, 6.10.2008, Ministry of Emergencies of Ukraine; 3) Letter of the President of Ukraine dated January 1, 2008 №1-1 / 5, order of the Prime Minister of Ukraine № 811/1/1 / -08 dated January 12, 2008, order of the First Vice Prime Minister No. 811/4 / 1-08 of 13 May 2008, as well as of the Verkhovna Rada of Ukraine Resolution No. 1368 of May 21, 2009.

But for the moment main challenges on a way to making fire management in Chornobyl safer and reliable located mostly on the ground and required more research to understand risks, well trained and well equipped fire personal, interagency communication and set of new regulations and instructions that guarantee putting together all those components toward integrated and safe fire management in the zone.

1. Natural conditions, fires and contamination

1.1. The Chernobyl accident and establishment of the Zone

An explosion in reactor No. 4 of the Chernobyl Nuclear Power Plant in northern Ukraine on 26 April 1986 resulted in the release of up to 12,000 PBq[1] of radioactive material into the environment (IAEA, 1996). Twenty-eight years after the disaster, radioactive contamination continues to be an important environmental issue in Ukraine, Belarus and Russia. Shortly after the explosion, residents were permanently evacuated from the most contaminated 30-km radius zone around the plant, a zone that in 1996 was extended along the western contamination path. This area has been designated the "Chernobyl Exclusion Zone" (CEZ). The radioactive elements 137Cs and 90Sr, with a half-life period of 30 and 29 years respectively, are amongst the most widely spread. Because of their physical-chemical properties, they are the most likely to affect human health. The 10-km zone surrounding the Chernobyl NPP is in addition highly contaminated by plutonium[2], with half-life times ranging from around one hundred to thousands of years. The radioactive decay of 241Pu will generate contamination by another radionuclide of significance to human health, 241Am, which is expected to increase over the next 100 years (IAEA, 2006).

The main reasons for establishing the CEZ in 1986 were to restrict exposure of the population to contaminated areas and to enforce a special protection regime to minimize propagation of radionuclides outside the zone. An automated system (ASKRO) using 39 sensors was established to monitor aerial radioactivity. The system covers the core of the CEZ. An additional environmental monitoring system was established to monitor the level of radioactive contamination of soils, underground and open water, vegetation and wildlife.

Spring floods of the Prypiat River[3] and vegetation fires are the two most important factors that contribute to migration of radionuclides outside the CEZ.

- To prevent the washing out of radionuclides during spring floods, artificial dams were built along the most contaminated locations of the Prypiat River. It has

1 PBq = Peta-Becquerel = 10^{15} Becquerel
2 ^{238}Pu, $^{239+240}$Pu, and ^{241}Pu will be referred to below as "plutonium"
3 The Prypiat river flows passed the Chernobyl NPP and its water has been used for cooling the nuclear reactors.

been observed that radionuclides still migrate with floodwater during spring time. However, this poses a relatively low threat to the population due to a high level of dilution with clean water.

- The significance of wildfires as a threat was fully realized only six years after the accident, when large and numerous wildfires in August 1992 burned up to 17,000 ha of contaminated forests and grasslands. Some of the fires crossed the border into Belarus and spread into the Belarusian part of the CEZ. Following these catastrophic wildfires, the specialized Chernobyl Forestry Enterprise, with a total staff of 400, was established to carry out forest and fire management in the CEZ and prevent the migration of radionuclides out of the zone.

1.2.Natural conditions, forests and land use in the CEZ

Before the Chernobyl NPP accident, land use in the current territory of the CEZ was equally divided between agriculture and forestry. Now all of the CEZ lands outside of the villages, the towns of Chernobyl and Prypiat and the former NPP, have been categorized as “forest lands” and cover a total area of 240,000 ha. Of this, 150,000 ha (57 %) is made up of forest, while some consists of grasslands. However, due to the natural regeneration of forests on former agricultural fields, especially in locations where disturbances of the grass layer have occurred, the forest area is increasing, primarily in areas adjacent to forests. The CEZ is largely characterized by dry sandy soils (glacial outwash) and Scotch pine (Pinus sylvestris) forests therefore prevail, currently representing 89,000 ha, while other forest lands are covered by deciduous softwoods (mostly Betula pendula, Populus tremula and Alnus glutinosa – 50,800 ha) and oak (Quercus robur – 7,500 ha) (Figure1).

In the aftermath of the emergency period, the territory of the exclusion zone was changed several times as a result of the radiation situation. Currently, from the administrative point of view, the exclusion zone (zone I) belongs to the Ivankiv administrative district, and the unconditional (compulsory) resettlement zone (zone II) to the Polissya administrative district. As a result, the alienated territory, which has been allocated by the main feature - radiation contamination, is subordinated to two administrative regions, which does not contribute to its optimal management, reducing the risk of natural fires in order to minimize removal from the alienated radioactive contamination territory.

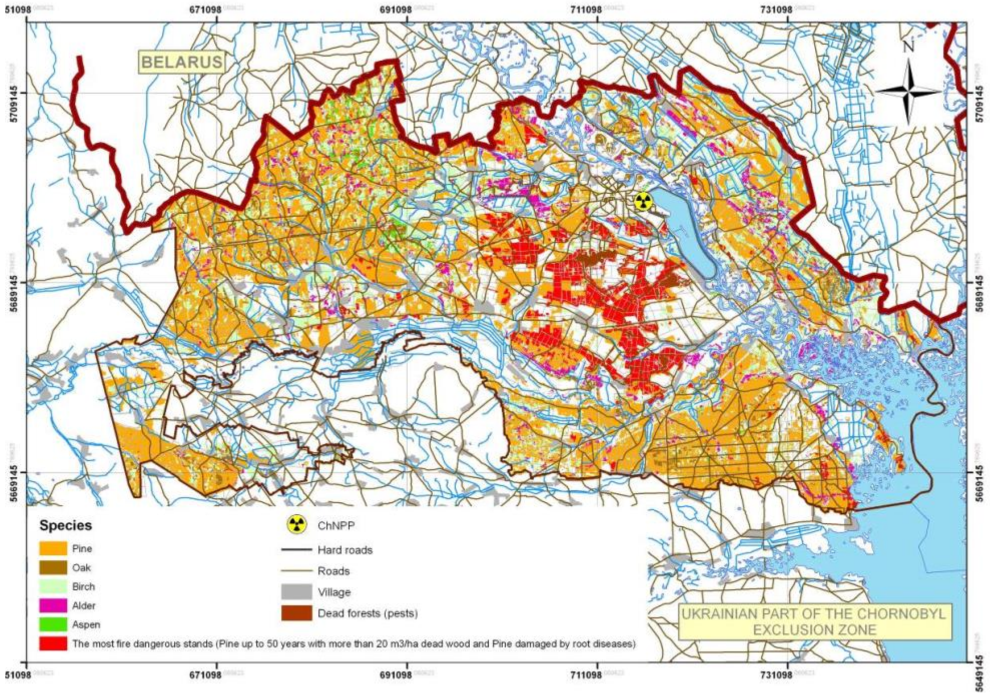

Figure 1. Distribution of main forest species in the CEZ. Note: The red-marked areas are Scotch pine (*Pinus sylvestris*) forests damaged by root rot (*Heterobasidion annosum*). Source: Zibtsev et al. (2012).

The alienation of the 30 km zone was accompanied by the transfer of contaminated land to the Ministry of the Chornobyl Disaster Management. Accordingly, this led to the cessation of the entire complex of forestry activities in the forests of the former Chornobyl, Novoshepelichsky and Polissia forestry enterprises, as there were no specialized forestry enterprises within the newly established ministry.

In 1992, after the catastrophic fires with a total area of up to 17,000 hectares, the State Specialized Production Complex Forest Enterprise "Chornobyllis" was established in the Exclusion Zone (since 2005, the State Forestry and Forestry Company of Chornobyl Forest). Considerable resources of the newly established enterprise have been spent on clearing and reforestation in a continuous combustion area of about 5,000 hectares, which was created after the 1992 fire in the area of Opachichi village. Due to a number of reasons, since the second half of the 1990s, the financing of the enterprise, its technical and human resources declined, which did not allow to cover a large area of forest area with the necessary volumes of measures. In addition, in the most polluted forests in the area of the "western footprint" forestry activities were banned for radiation safety reasons.

According to the results of the last forest inventory of the Exclusion Zone forests, which was carried out in 2006 and its results were updated as of 2011, the total area of the state forestry enterprise “Chornobylska Pushcha” is 240 570 ha, which is divided into seven forestry. The average forest area of district is 34.4 thousand hectares, but this indicator varies considerably in different forests. Thus, the smallest Kotovsky forestry occupies 7,2% of the territory, the largest - Lubyansk - 25,6%. The level of radioactive contamination also differs significantly in different forestry areas: the lowest level is recorded in the Children's and Opachitsky forests, the highest - in the Korogodsky and Kotovsky forests. With such high pollution of the territory, it is advisable to distribute the forest fund so that the most radioactive forests are concentrated in 1-2 forest areas, which would be distinguished by methods of forestry management, more experienced personnel and its enhanced protection. In other units, forest management would be closer to conventional forestry technology.

According to the zoning approved in 1998, 23.4% of the territory belongs to the zone of the protected (protected) regime, another 31.2% is the zone of restricted conducting of ecological and forestry measures, and 45.4% is the zone of moderate conducting of ecological and forestry measures.

The largest share of the area with protected (the most radiation restrictions) regime of forestry is located in Korogodsky (30%), Parishovsky forestry (43,1% of the territory or 20,8 thousand hectares). In the Dyatkovo and Opachitsky forests there is no conservation zone. The moderate activity zone (the most active measures is the form) is typical for Dityatkovsky (76.6% of the area) and Denysovetsky (66.0%) forestry, and if based on absolute indicators - in Lubyansky (23.5 thousand hectares) and to Ditiatky (21.9 thousand hectares).

In general, it should be noted that the forest area in the Exclusion Zone is 5- 15 times more than the forest area ranger districts outside the Exclusion Zone, which together with radiation pollution creates extremely difficult conditions for safe fire management. When organizing the protection of forests from fires, it is necessary to take into account the significant diversity of radiation pollution in each forest and the presence of 2 or 3 zones at a time. There are 2 potential solutions to this problem: 1) For each forestry, the tactics and strategies of forest fires must be different depending on the area of the fire. All quarters are grouped into 3 or 2 groups, and the response forces act in accordance with the radiation threat of fire; 2) it is necessary to define new boundaries, which will include quarters with homogeneous pollution.

1.3. Age structure

An important parameter of forest fire danger is their age. The age structure of the forest fund of the State Forestry and Forestry Company "Chornobyl Forest" is heterogeneous. Medieval plantations predominate, accounting for 61.9% of the area. Young plants make up 17.3%, arriving plantations - 11.9%, mature and overbearing - 8.9%. Artificial origin is mainly found in young and medieval plantations, where their participation ranges from 33% to 49%. The share of forest crops in the incoming age group and older does not, in the aggregate, exceed 4.5%.

1.4. Origin of forests

More than a third, namely 35.1% of the forests of the Chernobyl Pushcha belong to forest crops, 64.9% respectively are stands of natural origin. The conditions of the region are conducive to the further natural regeneration of forests, which is a valuable property in the conditions of forestry associated with radioactively contaminated territory, increased risk of personnel exposure, undeveloped forest road infrastructure.

1.5. Species composition

Species composition is one of the main factors that determines the natural fire hazard along with the site types, the age of the plantation and the category of land. The forests of the Chernobyl Pushcha State Forest Enterprise belong to the Central Polissya of Ukraine and are currently characterized by the typical distribution of forests by this group of rocks: coniferous - 89.9 thousand hectares (59.5%), softwood - 52.9 thousand hectares (35.1%), hardwood - 8.2 thousand hectares (5.4%). The analysis of the ratio of the groups of rocks by the total stock of wood shows that in coniferous plantations 73.3% of wood is concentrated, in softwood - 21.9%, in hardwood stands - 4.8% of wood. This means a higher concentration of aboveground forest combustible materials, which can be used in riding fires, in the coniferous group, which is negative in terms of fire risk.

The most widespread tree species under the conditions of the State Forestry and Forestry Agency are pine, which occupy 89.7 thousand hectares (59.4% of all forests) with a total stock of 24.6 million m3 (73, 2% of total forest stock). Pine is characterized by the highest productivity in comparison with other species in these conditions, both in average stock and in average growth. The second most prevalent tree species in the forest fund is the birch, which is the main species on area of 38.8 thousand hectares (25.7%) with a stock of 4.9 million m3 (14.6%). Birch plantations are characterized by low fire risk if the pine participation in them does not exceed 4-5 %. These two species, which are most typical for Polissia, cover 85.1% of the forest area and contain 87.8% of their total stock. Alder grows on 6.6% and oak on 4.7% as well as maples, ash, linden tree and other wood species cover 3.3% of the area are relatively resistant to fires and can be used as fire barrier elements.

1.6. Thinning

Historically, more than 50 % of the pine forests in the CEZ were monoculture plantations created in the 1950s and 1960s by a very dense scheme of planting (7,000 to 10,000 seedlings per ha). Since 1986, thinning operations have been dramatically reduced or completely abandoned in the majority of pine stands because of the present level of radiation.

Latter has significant consequences for wildfire hazard. The magnitude of a wildfire is depending on the amount of available fuel, which is essentially determined by the intensity of thinning and removal of debris. With reference to the 2006 Forest Management Plan for the CEZ, a significant portion of planned silvicultural measures were not implemented due to a lack of funding and personnel. For example, between 2004 and 2006 only 50 % of planned early thinning in young stands (up to 20 years old) was undertaken, in middle-aged stands only 20 %, and in premature stands 20 %. Timber from the last-mentioned type of thinning is of commercial use, primarily as pillars for coal mining. It needs to be underlined that silvicultural measures are only executed on sites approved by the Radiological Control Service of the CEZ (“Ecocenter”) if the contamination of timber (round wood without bark) is less than the allowable threshold of 1,000 Bq/kg (Ukraine Ministry of Health Protection, 2005). Failure in providing minimum silvicultural intervention in forests increases fuel loads and does negatively impact forest health.

1.7. Forest health, insects and diseases impact

Massive outbreaks of the pine lappet moth (Dendrolimus pini) took place in the CEZ in 1997 and 2006, of the nun moth (Lymantria monacha) in 1995, and of the common pine sawfly (Diprion pini) in 2003. Due to a lack of effective protection measures, up to 8,500 ha in the most contaminated central part of the CEZ was damaged heavily by these insects. Another 12,300 ha were damaged by root rot (Heterobasidion annosum (Fr.) Bref.). Forest inventory data show that 15,300 ha of forests in the CEZ have been damaged by different agents, including 5,300 ha by pests (Anonymous, 2007). As a result, fire hazard in large areas of forest has increased substantially. Remote sensing data have confirmed that 9,000 ha of forest are completely dead due to fires and pests (Zibtsev and Gilitukha, 2012).

2. Fire hazard

The level of fire hazard of forest lands in the CEZ is assessed according to the official “Scale for assessment of natural fire hazard of forest lands" approved by the State Agency of Forest Resources of Ukraine (Rating scale, 2005). The Scale includes 5 classes (Hazard Class I – maximum; Hazard Class V – minimum) and takes radioactive contamination into account. In particular, Class I fire hazards include all conifer forests less than 40 years old, all conifers on dry and sandy soils, sites affected previously by fires, clear-cuts, and grasslands (Figure 2).

Figure 2. Example of a 35-year old Jack Pine (*Pinus banksiana* Lamb.) stand in the CEZ (Korogod forest ranger district) (left) and a 40-year old Scotch Pine (*Pinus sylvestris* L.) plantation (right) documented in August 2014, both classified as Fire Hazard Class I. Photos: S. Zibtsev.

According to official data, 66 % of the forests belong to Fire Hazard Class I, of which 38 % are lands contaminated with levels above 555 kBq/m^2 ^{137}Cs, and 13 % of the forests belong to Class II. Forests with the highest natural fire hazard levels are concentrated in the central and southern parts of the CEZ, including the most contaminated territories west and northeast of the Chernobyl NPP (Figure 3).

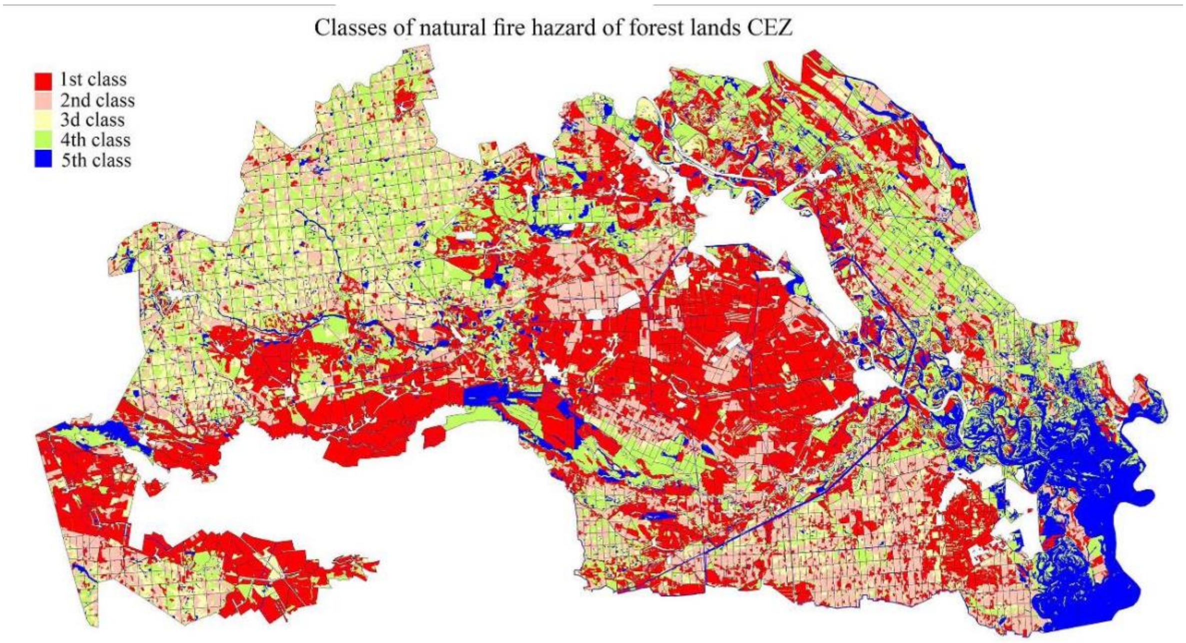

Figure 3. Natural Fire Hazard Classes of forest lands in the Ukrainian part of the Chernobyl Exclusion Zone (Status: January 2013). Source: Zibtsev et al. (2012).

All abovementioned factors taken into account in fire hazard classes, where class 1 is highest fire hazard (pine plantations, cut area) and class 5 - lowest - wet forests. Distribution of the fire hazard classes on the territory of ChEZ is showed on Fig. 4.

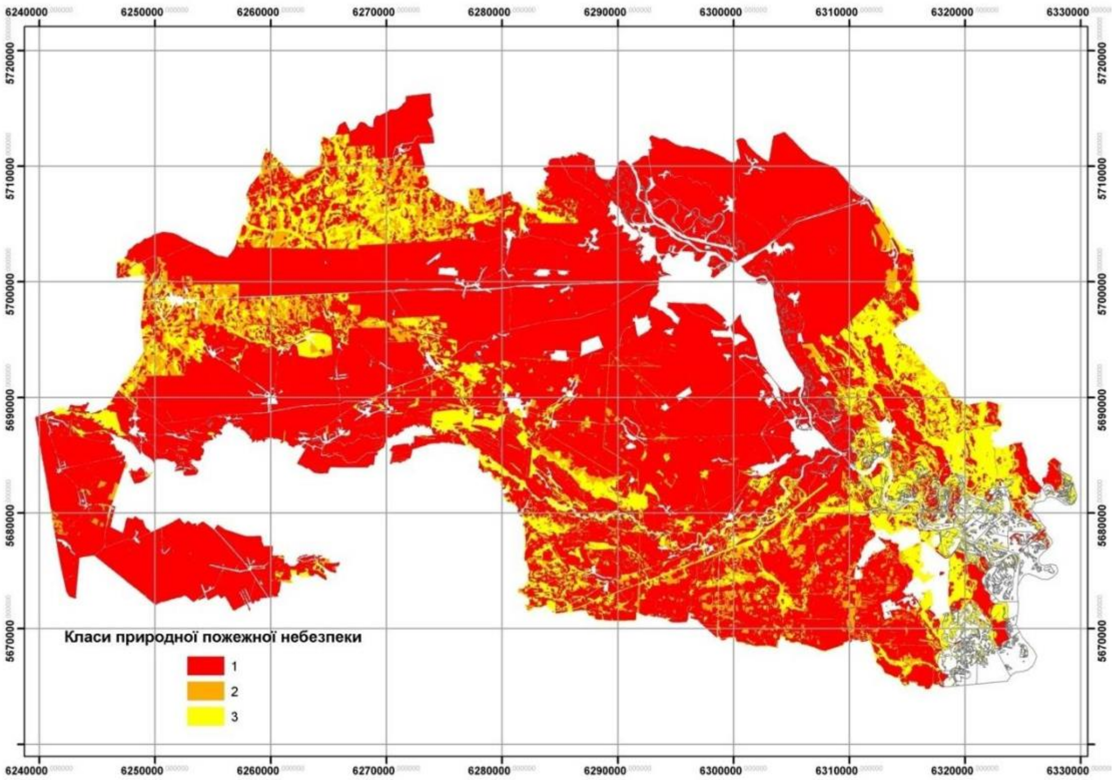

Figure 4. Complex natural and radiological fire hazard classes of the Exclusion Zone

The map above taken into account natural fire hazard and radioactive contamination. All forests higher than 15 Ki-sq. km is attributed to Class1. With this approach 101369.6 ha of lands attributed to Class 1 based on radiological criteria. Another 75187.6 ha attributed to Class 1 based on fire criteria. So, majority of lands in ChEZ could be characterized with highest Class 1 fire hazard.

2.1.Fuel load

Terrestrial combustible materials (LGM) is one of the major drivers of wildfire. Any fire in the forest begins with the burning of forest floor or living ground cover belonging to the group of land-based LGMs. Studying the reserves and composition of the ground-based LGM in the Exclusion Zone will allow to more effectively predict the main forest fires and its effects.

An estimated 1.4 million m^3 of dead, radioactively contaminated wood that could fuel wildfires has accumulated in the CEZ. Forecasts predict that the quantity of contaminated dead wood will increase to 2.4 million m^3 by 2020 (Zibtsev, 2013). Overcrowding of forests is weakening trees and increasing wildfire hazard (cf. section 10). As of 2014, 6–20 % of trees are dead but still standing in middle-aged stands. The dieback of another 8-31 % is expected over the next 5–10 years. Most of the pine plantations are at a stage of minimum increment due to the competition for space, light and nutrition between trees in stands. The amount of downed and standing deadwood in the CEZ is estimated at 9–26 m^3/ha. The total stock of forest combustible materials in pine stands ranges from 110 t/ha in 22-year old stands to 220-280 t/ha in 44–64-year old stands. Of these, 13–16 % is ground fuel and 84–87 % is above ground. Ground fuel is made up of forest litter (89–92 %), woody debris (8–10 %), and living forest vegetation (up to 1 %).

2.2.Surface fuel

The total stock of terrestrial LGMs in fresh subors is 16% higher than in fresh bor condition. However, the difference in stocks varies considerably. At age of 53, the stock of land-based LGMs are 7% higher, 44% higher at 44, and 54% lower at 37 years. The reason for such large fluctuations in terrestrial LGM stocks is the peculiarities of each individual stand. Under the same conditions, the same age differences in terrestrial LGM stocks in the test areas reach up to 45% (Zibtsev, Borsuk, 2015). The greatest impact on differences in terrestrial LGM stocks is attributed to forest litter, which accounts for about 70% of their total stock. On average, forest flooring in bors is 16% less than in subors. The difference in litter stocks ranges from 1 to 50%. In addition to the general stock of ground-based LGMs, which determines the intensity of burning during a fire, differences in their fractional structure should be considered depending on the site type.

Forest litter stock in fresh subors (B2) are higher in bors (A2) and in average reach 73.6% and 71.8%, respectively. As a part of the litter in the bors, the average precipitation is 52%, the fermentative and humus horizons are 48%, and in the subors 32% and 68%, respectively. This is due to differences in the level of decay and in the stockpiles of the grass composition, which, when dying, contributes to forest litter stock. In turn, in fresh bors, compared to suburbs, have larger stocks of wood waste (27.5 and 24.9% respectively). The reserves of small branches (1-hr d <0.6 cm) are the same and average 2.1%. Particles 100-hr (twigs d = 2.54-7.62 cm) more in subors by 0.6%, and particles 10-hr and 1000-hr (twigs d = 0.6-2.54 cm and d> 7,62 cm, respectively) more in bors by 1-2%.

In addition to the types of forest vegetation conditions, the fuel load is influenced by the age of the plantations. With age, land LGM stocks are increasing. This is primarily due to the accumulation of litter with age. The accumulation of litter with age is due to the increase in the productivity of crowns and the slower decomposition of the litter. The decomposition of forest floor in older plantations is slowed down by the change in the reaction of the soil medium, namely its acidification by decay of needles. The acid reaction of the soil leads to a decrease in the activity of soil micro- and mesofauna.

The fractional composition of the forest floor of pines changes with age and with increasing soil richness. In bors (A) at 50-60 years of age decreases the content of fraction 1Hour

Concluding need to be mentioned, that fractional composition of the forest floor determines the intensity and behavior of the fire. The predominance of small fractions (1 hour) promotes the occurrence of mobile fires of low or medium intensity. The large reserves of large (10-100) fractions and the fermentative and humus horizons of the forest floor contribute to the emergence of persistent high intensity fires and in turn determine the damage to the stand and the emission of radionuclides during the fire. The fractional composition, capacity and reserves of the forest floor depend largely on the types of forest stand conditions and the age of the plantations. They increase with increasing soil richness as well as with age, with the fractional composition of combustible materials changing by 1-3%, the content of fractions 10 Hours by 10-14% compared with 30-40 years of plantations, slightly increases the stock of humus and enzymatic horizons from 25-30% at the age of 40 to 40-50% in 60-70 years.

2.3.Aboveground fuel

Stock of aboveground forest combustible materials are increasing with age of stands. The increase of above ground fuel stocks is natural and corresponds to the increase of phytomass reserves, but it does not affect the fire risk. In case of crown fires, only needles take an active part in the burning, and the wood and bark of the trunks and branches are practically not burning. With the increasing age of plantations, height of crowns in trees rise and become inaccessible to the flames of surface fires. The most dangerous are the young stands with lowered crowns, low-complete plantations and plantations with dense undergrowth and undergrowth. Among the test areas, these criteria are only met by planting at the age of 22, which has low crowns lowered in trees.

Within structure of above ground LGMs is dominated by timber, which accounts for 75-85% of their stock. The needle is the least in the crowns of 3.5-7% (5-10 t · ha-1), which is the conductor and supporter of burning in crown fires and the main source of radionuclide emission. Soil richness does not have a significant impact on the fractional structure of aboveground LGMs, the difference in the weight of fractions in their structure at the studied objects is up to 3%.

Coniferous forests, compared to deciduous forests, are much highly flammable. In addition to terrestrial LGMs, which are the main contributors to fires, needles and small shoots in crowns create the possibility of the occurrence and spread of crown fires, which have great economic and environmental damage. Unlike pine needles, leaves in the crown of deciduous plantations delay the progress of fire and may stop the development of crown fires. In the forests of different ages, the fire danger is different, the most dangerous are the young, the least - mature and overmatured plantations.

In the Exclusion Zone, the largest stock of above ground LGMs are concentrated in medieval plantations. Another 10.4% of aboveground LGMs are concentrated in the most dangerous for fire-fighting young stands. It is in these plantations that there is the highest risk of crown fires and involvement in the burning of all LGM groups.

Among territory largest stock of above ground LGMs are concentrated in the Lubyansky Forestry and the smallest in the Kotovsky Forestry. The distribution of aboveground combustible materials is fairly uniform. Significant stock of above-ground LGMs are concentrated in areas with high radioactive contamination (> 5 Ki · km-2) - 30%. Forestry is prohibited in these territories, so LGM is intensively accumulated in the plantations. In plantations where forestry activity is permitted, 29% of crown fuel stock is concentrated. However, the risks posed by forest fires are higher in areas with a high density of radioactive contamination. Fires in these territories carry a high environmental risk, exposure to firefighting personnel.

As expected, the largest above ground LGM stocks are concentrated in the first class of natural fire hazards, where the risk of fires is highest. This is due, first of all, to the consideration of radioactive contamination in its determination. In general, need to be underlined, that distribution of the above ground LGM is consistent with the patterns of forest growth. Its inventories increase with age, with the increase of the completeness of the plantations and depend on the productivity of the plantations in different site class conditions. The data obtained through the simulation is confirmed by the data obtained in the test plots.

3. Fire whether based danger

Weather is the most variable factor during a fire season compared to fire sources and LGMs. Forest burnout depends on weather conditions that directly affect the ability of LGMs to burn, and is the second factor that causes forest fires to occur after the presence of fire sources.

The climate of the Exclusion Zone is moderately continental with relatively warm humid summers and mild winters. The total solar radiation in the region for the year is 95-100 kcal / cm2, and the radiation balance is about 40 kcal / cm2. The duration of sunshine is in the range 1800-1900 hours per year, including the highest - in July (an average of 290 hours), the lowest - in December (25 hours).

The sum of effective air temperatures above 5C is in the range of 2000-2200 and above 10 is in the range of 800-1000. The number of days with an air temperature from 5 to 15C is 90-100, and more than 15 C - 110-120. The duration of the growing season averages 194 days. The average annual temperature ranges from 7.0-9.0 ˚C. Average monthly air temperatures are quite high and in summer months reach 19.6 C. These months are the most fire hazardous. However, the highest rainfall occurs in the summer months, mainly in the form of showers. However, this does not significantly reduce the risk of fire for long periods.

The dependence of rainfall and the number and area of forest fires is traced. During the years with the least amount of rainfall, the greatest number of fires occurs and their total area exceeds 150 ha. These include 1994, 1999, 2002 and 2003 year. The number of fires in these years reached 100-120 cases. In years with significant rainfall (650 mm or more), the number of fires and their area are lower. In addition, fires are inherent in the uneven appearance of the area, they are confined to the appearance of sources of fire. Sources of ignition occur most often along roads and near settlements, i.e. related to the human factor.

During the year, on average 332 days are characterized by little windy weather, the average wind speed of which does not exceed 3 m · s-1. And the average number of days during the year with a wind speed of more than 5 m · s-1 is small (2-3 days). However, at low average wind speeds, wind speeds are high at some hours. So, the number of days with a maximum wind speed of up to 5 m · s-1 is 3-4 on average, the number of days with wind gusts that can cause the passing of grassroots fires in the upper reaches (more than 10 m · s-1) is on average 220. More days with high maximum wind densities occur in the winter months, and the months of the beginning and end of the fire season when the fire hazard is lowest.

For the assessment of weather-based (meteorological) fire danger, a 5-grade scale is used in Ukraine with Fire Danger Class V being the highest. The Fire Danger Class determines the level of preparedness of fire brigades and of the intensity of ground/air patrols for forests. However, a comparative analysis of fire history and official Fire Danger Classes based on a modified Nesterov Index reveals that the current early warning system does not reflect a realistic value of the fire-weather danger. A local fire danger scale based on the methodology by Kurbatsky (1963) was therefore developed for the CEZ (Zibtsev and Gilitukha, 2012) (Table 1). It includes a seasonal variation by introducing indices for a spring-summer and a summer-autumn period.

Table 1. Comparative analysis of scales used in the current early warning system and the local scales proposed for the Chernobyl Exclusion Zone (CEZ).

Fire-weather Danger Class	**Value of Ukrainian fire weather indices** (modified Nesterov Index)		
	Local scale of fire weather danger proposed for the CEZ		**Current early warning system used in Ukraine**
	Spring–summer (10 March–10 June)	**Summer–autumn (11 June–30 October)**	
I	<250	<1400	<400
II	251-1000	1401-3550	401-1000
III	1001-2100	3551-5400	1001-3000
IV	2101-2800	5401-6400	3001-5000
V	>2800	>6400	>5000

As can be seen from Table 1, the early warning system currently used makes a lower assessment of weather-determined fire danger particularly for Fire Danger Classes IV and V (highest risk classes) during the summer-autumn period, where the official scale indicates a fire danger one class lower than that demonstrated by real fire occurrences. The reason is that during the development of the current system in 2011, no data was included from the large forest fires of 1992. Such data, however, will need to be taken into account in developing a new, local early warning system for the CEZ.

4. Radiation contamination of forests and fire hazard

Currently, the territory of the Chernobyl Pushcha State Forestry Company is officially divided into the following zones of ecological and forestry impact:

1) a reserve regime where the density of cesium-137 contamination is more than 3700 kBq · m-2 (100 Ki · km-2) , strontium-90 is more than 370 kBq · m-2 (10 Ki · km-2), plutonium-239 is more than 11,1 kBk · m-2 (0.3 Ki · km-2). The main purpose of carrying out ecological and forestry measures is protection against fires

and pests of the forest, in certain areas specific measures are possible to maintain the viability and fire resistance of the plantations. Forestry works are carried out according to a special regulation, agreed with the bodies of the State Inspectorate;

2) restricted forest management zone in which the density of cesium-137 contamination is 1480-3700 kBq / m2 (40-100 Ki · km-2), strontium-90 - 111-370 kBq · m-2 (3-10 Ki · km-2), plutonium-239 - 3.7-11.1 kBq · m-2 (0.1-0.3 Ki · km-2). The main purpose of carrying out ecological and forestry measures is to improve the sanitary and fire condition of forests, to maintain the viability of plantations and their protective functions. In a more or less distant perspective, this area should gradually be restored to normal forestry;

3) unrestricted forestry zone, where the density of cesium-137 contamination is up to 1480 kBq · m-2 (up to 40 Ki · km-2), strontium-90 - up to 111 kBk · m-2 (up to 3 Ki · km -2), plutonium-239 - up to 3.7 kBq · m-2 (up to 0.1 Ki · km-2). The main purpose of conducting ecological and forestry activities in this area is to bring forests back to normal sanitary condition, to maintain their viability and to gradually return to the traditional forest management regime (Fig. 5).

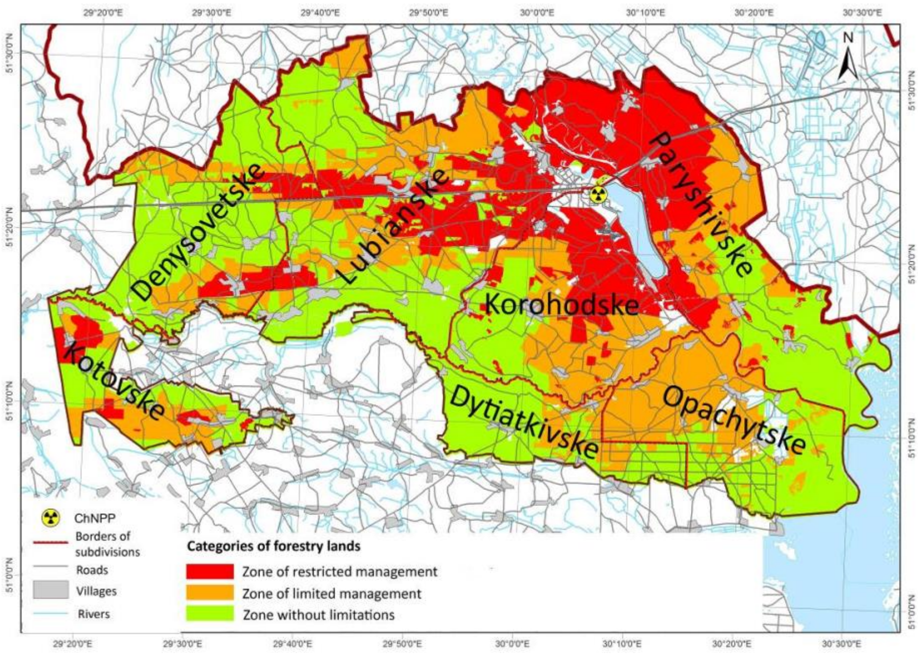

Figure 5. Locations of forest ranger districts in the different CEZ contamination zones. Source: Zibtsev et al. (2012).

The greatest fire danger is the forests of the protected areas and the restricted forest management regime, where the restriction of forest management causes the transition of forests to the natural state and gradual accumulation of depletion. The forest area of these categories is 54%. In the rest of the territory, management can be carried out in accordance with Recommendations without restrictions, including - forest management measures are necessary to maintain the proper condition of forests. Currently, the planning and implementation of ecological and forestry activities is carried out on the basis of the division of forests by the density of radionuclide contamination according to the Chornobyl Radioecological Center.

This zoning is based on an estimate of 137Cs soil density and does not take into account the contamination of strontium and radionuclides by the plutonium group. At the same time, the radiation effects of fires depend significantly on the specific participation of different radionuclides in the total density of soil contamination.

Forest ecosystems are the most complex of all terrestrial ecosystems, characterized by significant biodiversity and complex cenotic structure. It is the multicomponent nature of forest ecosystems, the complexity of their spatial structure and the mosaic of radioactive contamination that create major difficulties in the development of the prognosis for the migration of man-made radionuclides in forests and their rehabilitation. In addition, there is a complex of legislative problems, without which the rehabilitation of the most affected forest areas, for example, in the area of unconditional resettlement and requiring urgent forest management measures, is impossible. The development of a special program of measures for their implementation has long been ripe.

The peculiarities of the exclusion zone and the zone of unconditional (compulsory) resettlement, due to the specific nature of the radioecological status and the special legal status, require a special approach to solving the problem of forest protection against fires. In the forests, most of the radionuclides that have entered the environment from the destroyed reactor are concentrated. The territory is characterized by high diversity of composition and forms of radionuclide deposition, high mosaic density of radioactive contamination. Therefore, the complex specialized forestry technologies used in the forest lands of the exclusion zone should be different from the traditional ones used outside it.

This is due, first of all, to the presence of high levels of radioactive contamination in the crown and bark of trees and in forest floor; secondly, the need to reduce the collective dose of radiation, that is, to minimize the number of workers in the ionizing radiation zone at the minimum necessary time to perform this work; third, some differences in approaches to achieving the goal of preserving and restoring forests in the exclusion zone; and, finally, to prevent the removal of radionuclides outside the exclusion zone.

The analysis shows that the principles of doing business in forests currently implemented in the Zone is not always justified. The experience of recent years proves that the cessation of economic activity in the Zone. B does not lead to the rapid return of contaminated ecosystems to their original state. On the contrary, such developments in many cases lead to secondary negative radioecological and environmental consequences. In particular, such consequences are the deterioration of the sanitary condition of the forests, the increase of fire danger, and, in turn, the danger of secondary pollution of the territories.

When considering radiation-ecological aspects of forest fires in the Chernobyl zone, scientists of the SSNPP "Ecocenter" analyzed the occurrence of large fires in forest areas with varying degrees of contamination. They found that during the mass forest fires, in the summer of 1992, an increase in the total nuclide concentration from 1.7 · 10–2 Bq · m – 3 in Chernobyl to 1.5 Bq · m – 3 was recorded near the fire site. near area. The analysis of the available information on the fires of 1992 and the stocks of radionuclides in biomass has made it possible to establish that the range of integrated radiation pollution of the atmosphere 137Cs during this period was 28-130 TBk. Therefore, the presence of forest areas with a contamination density of about 40 MBq · m-2 creates a potential threat of atmospheric air pollution in case of fires, because even with relatively small combustion centers (up to 1 km2), 137Cs up to 40 TBk (about 1000) is possible. Ki) and spread it over long distances. Radionuclide emission studies were conducted by Yoshchenko, Kashparov. and other researchers. They set out experiments on controlled piles on the drafts and determining the composition of the smoke. The emission of radionuclides from forest fires was studied by Dusha Gudym, however, these studies were conducted in Russia.

Radiation Fire and Fire Hazard Investigations at the ChEZ is almost none, a number of studies were conducted in Ukraine outside the Exclusion Zone, as well as in Russia and Belarus. In Ukraine radiation contaminated forests were investigated by A.S. Malinowski, scientists of the Polissya Branch of UkrNDILGA, Institute of Agricultural Radiology. Most studies did not address forest fire hazards and fire risks. Considerable volumes of work on the study of fire danger of forests in the areas of radiation contamination were conducted in Belarus and Russia.

Summarizing the above information, it should be noted that the available scientific studies indicate that the dynamics of forest plantations in ChEZ is accompanied by an increase in their fire risk. Among the contributing factors are the increase in the area of damaged and decaying forests, forests damaged by pathogens and harmful insects, the lack of forestry measures in most plantations that need them. Radiation pollution is a major factor limiting forestry activities in forests and contributing to increased fire risk.

Scientific studies have shown that fires in radiation-contaminated forests are accompanied by secondary transfer of radionuclides and pose a risk to firefighters, personnel of the exclusion zone, and in the event of a catastrophic fire (similar to the 1992 fires), and to populations outside the area. In the specialized literature there are no results of systematic studies of forest fire danger, there is no analysis of the forest fund in terms of current and future fire risk. The data presented in the literature are characterized by considerable discrepancy; estimates of the state of forests are often made during forest management and forest pathology surveys, i.e. information is based on ex-ante estimates. It does not allow to assess the dangers and risks of catastrophic wildfires and, in accordance with these dangers, to create an adequate system for early detection and rapid extinguishing of wildfires.

5. Fire history

An analysis of the patterns of spatio-temporal distribution of forest fires is an important for successful fire prevention, timely detection and extinguishing of forest fires in the territory. This requires an analysis of forest burning (spatio-temporal distribution of forest fires) by forest departments, land categories and by zone as a whole. Fires are regular events in ChEZ (Fig.6).

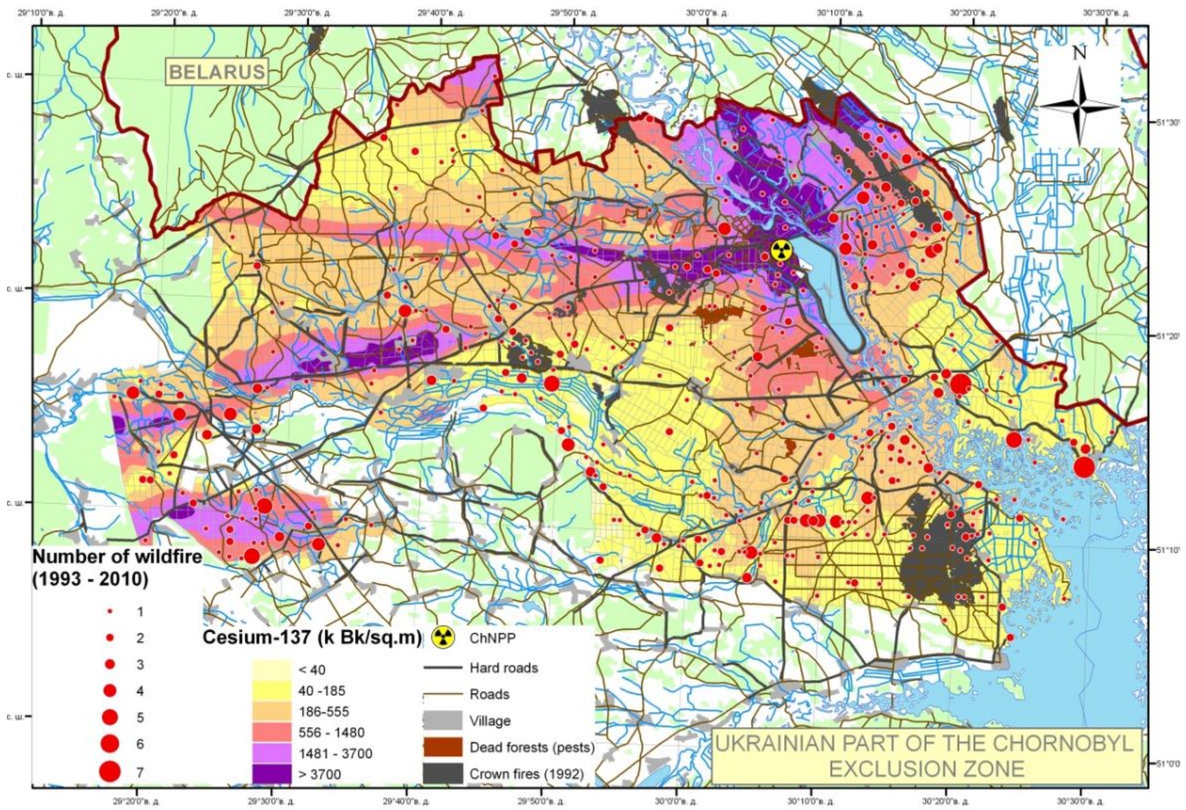

Figure 6. Fire history (dots), forest dieback zones and radioactive contamination

Based on fire statistics and data of Remote Sensing it was found that wildfires during post disaster period occurred all over the Zone including most contaminated core zone and drove massive dieback of forests. Forest and grass fires are regular occurrences in the CEZ despite the special territorial management regime which restricts access and land use. In 1986, the 10-km and 30-km zones around the Chernobyl NPP were fenced off and checkpoints controlled by police were established on the main access roads around the CEZ. Since then, however, fences have collapsed in some places due to deterioration, wildlife or damage caused by people entering the CEZ illegally. According to the current rules, only professional staff of the CEZ (ca. 300 local managers and researchers) and officially guided tourists are allowed to enter the CEZ). An analysis of fire history based on statistics available from the Chernobyl Forest Enterprise shows that over 1,147 forest and grasslands fires occurred in the CEZ between 1993 and 2013.

5.1.Seasonal dynamics

Analysis of the monthly dynamics of the number and area of fires in different categories of land showed that the share of forest fires increased from 25-32% in March May to 45-50% in July. And on the area from 15-20% in March-April to 52-65% in August September. This situation clearly reflects the readiness to burn different types of combustible materials. Thus, the high risk of fire occurs on the fallow lands earlier than the forest, since the dry grass dries faster compared to the forest floor, as well as differences in light and water modes of the forest and open areas.

The most dangerous months are April-May. In these months, 63.6% of all fires occur, and the area of fires is 82.3%. November and winter months are the least flammable. If the fire period is taken into account, the largest average fires are observed in March and May. In the remaining months the average area of fires is lower than the average area of the enterprise.

5.2.Long-term dynamics and fire size distribution

As a base data for the characterization of the long-term course of forest burning, the data from the forest fire cases of the Chornobyl Pushcha State Forest Enterprise for the period 1993-2016 were used. The greatest radiation hazard arises in the case of large fires, so it is advisable to consider them separately. Exclusion zone refers to areas with ground protection, in which the category of large include fires of 25 hectares or more.

Large and very large fires can have catastrophic environmental consequences and can lead to repeated radioactive contamination. Thus, by number - 91.6% of all fires - small fires, with an area of up to 5 ha. The total area of such fires is 39.3% of the area of all fires in the area. The same indicators for large fires are characterized by the inverse ratio: for a small number - 12 fires (1.2%), the total area of large fires - 29.9%. The average area of fire in the exclusion zone is 2.54 ha.

It should be noted that large fires occurred in different parts of the area during all period. During these years, there were several large fires per year, after 1999 there is one large fire in several years. Regarding the type of these fires, it should be noted that all of these fires were grassfires, originated and spread on the fallow lands or settlements, only one in the forest plantation. The main conditions for the prevention of major fires are their timely detection and effective fire organization of the territory, which would presuppose the presence of artificial or natural obstacles in the possible way of such fires in case of their occurrence.

The fires in 1995, 1999, 2002 and 2009 are mainly related to weather conditions. There were no significant changes in the density of the fire sources in the forests and the management regime that could have affected the number of fires during this period. For the development of the fire protection system, information on the combustion features of the main categories of land in the exclusion zone is required. According to the stock data of SSCP "Chornobyl Pushcha", such are fallows, forests and settlements. The analysis of the given data shows that 57% of fires by number or 69% by area occur on grasslands. The number of fires in forest areas is 31%, and their area is 19%, 10% are fires in settlements. These data indicate that the average area of forest fires is lower than the fires in the fallow lands and in settlements, it is 1.8 hectares, and the average area of fires in the fallows is 3.6 hectares.

The analysis of the long-term dynamics of the number and area of forest fires indicates the gradual changes in the share of different categories of lands covered by fires. Data show a gradual increase in the share of forest fires and a decrease in the share of fires in the fallow lands in recent years. So, if the share of forest fires by 1999 did not exceed 20%, then after 2005, their share in area exceeds 50%, and by number - 40%. In turn, the share of fires at the diversions decreased in number from 70-90% to 50-60%, and by area to 20-50%.

The analysis shows that the highest number of fires occurs in the Parishivsky and Lubyansky Forests of 21% and 17% respectively. Their total area of fires is also the highest at 29% and 19% respectively. The smallest number of fires occurs in the

Korogod forest. During the analyzed period, 1.8% of fires were burned 1.0% of the Exclusion Zone territory. The greatest burning in the number of fires is observed in the Kotovsky forestry, where occurred 4.7% of the ignitions. In terms of total forest area, Kotovsky forestry is the most burning - 2.2% of the area. Also, attention should be paid to the Parishivsky Forestry, where the share of fires is higher than the average value of the enterprise. The least burning is inherent in the Korogod forestry - 1.4% of the number of species and 0.5% of the area covered by fires. The level of combustion in various forestry ranges greatly: from 0.5% to 0.6% to 2.2%. According to the number of fires, forestry can be divided into 3 groups: 1. High risk of fire - Parishivske, Lubyansk - 9-12 fires per year (maximum - 26-39); 2. Medium risk - Denysovetskoye, Kotovskoye, Opachytskoye - 7-8 fires per year, maximum - 16-31; 3. Low risk - Dityatkovske, Korogodske - on average 4-5 fires per year, maximum - 12-15.

The time and spatial distribution of the fires shows that they occur more or less regularly over the whole territory of the CEZ, including the most contaminated areas in the 10-km zone with the highest levels of ^{137}Cs, ^{90}Sr, plutonium, and ^{241}Am contamination. It is also clear that in the north and north-eastern parts, fires have regularly crossed the borders between Ukraine and Belarus. Wildfires have been recorded in grasslands (55 %), forests (33 %), former villages and even in swamps during periods of drought. The highest fires occurrence is in spring, between March and May, but risk of catastrophic fires highest in the second part of the fire season (July and August), as in 1992. In that year, crown fires burned up to 5,000 ha of forests, particularly in the south-eastern part of the CEZ in the Opachichi forest ranger district. Fires burning in Russia during the extreme heat wave of summer 2010 are another example of such a situation.

6. Ignition sources

Most of fires occurred due to human impact and during period of human activity. On average, 38.0% of all fires occur in the period from 14 to 16 hours of the day, 17.0% of fires occur from 16 to 18 hours, 7.7% - from 18-20, 14.4% - in the period from 12 to 14 hours. In general, from 10 to 18 - 90.5% of all fires occur, from 12 to 16 - 56.2% of fires, from 12 to 18 hours - 60.7% of all fires. Distribution of fires by hour, close to normal with a maximum of 12 to 16 hours. Thus, the maximum readiness of the fire service should be assured at least 10 to 20 hours. The maximum values of the number of fires in a certain hour of the day, which take place in all time gradations, determine the presence of a round-the-clock probability of fire occurrence of the respective duty regime during the period of fire maximum.

7. Human and technical capacity of fire management

Since the Chernobyl disaster, major mitigation efforts have focused on reducing the risk of radioactive radiation from the fourth reactor, as well as studying the effects of radiation on human health and the surrounding ecosystems. At the same time, there has been increasing concern among forestry staff and scientists that the forests of the ChNPP Exclusion Zone and the Mandatory (Unconditional) Resettlement Zone pose a significant risk to public health and staff health in the event of a catastrophic wildfire. The key to preventing a crisis is the readiness of firefighting forces and facilities, the availability of an early detection system for fires, as well as the willingness of fire departments to deal with large fires, primarily horseback.

Between 1986 and 1992, large forest fires did not occur in the zone, but in 1992, the dry summer caused the occurrence of numerous fires, which damaged some 17,000 hectares of forests, including 5 thousand ha of crown fires. After this event, a specialized state-owned forest enterprise "Chornobyllis" (later renamed "Chornobyl Pushcha") was created, which significantly increased the opportunities for forest protection against fire by forming fire crews, concentrating fire extinguishing equipment (fire trucks, helicopter). One of the priorities of the Chornobyl Pushcha was to extinguish all the fires that occurred. The fire protection of forests has been organized sufficiently effectively. It should be emphasized that the scheme of organization of forest protection from fires in unpolluted territories was used as a basis. Despite the fact that fires have occurred annually in the former agricultural lands and in places of former settlements because of people, no essential efforts toward improvement of fire management were taken.

It should be noted that although the Chornobyl Pushcha achieved some success in extinguishing fires, other areas of forest fire protection were not given sufficient attention, which determined significant negative consequences in 2015. In particular, no special forestry measures aimed at reducing the amount of forest combustible materials were carried out. The main reasons for this are radiation restrictions, insufficient funding and the inability to dispose of contaminated wood. Overseas experience, including the history of wildfire management in the United States over the last decades, shows that the Government's interest in forest fire risk reduction is significantly reduced in the years without major fires, even if the risk of large fires is high or even higher than in years with many and area of fires. Nowadays, in relatively healthy coniferous plantings, the high density and closedness of the canopy causes a decrease in the amount of forest combustible materials under the forest canopy, where dry pine needles and forest litter predominate. This arrangement of forest burning materials causes predominantly grass-roots fires of short flame length. In the vertical structure of the forests, there is no gap for the transition of grassfires to crown. However, in extreme weather conditions, even large-scale fires may occur even in such conditions.

The processes of naturalization of forests in the absence of active forest management activities lead to the death of some trees and an increase in the amount of light beneath the forest canopy, resulting in forest biofuels in the form of undergrowth, undergrowth and shrubs. Such processes are actively developing in the medieval pine plantations created on former agricultural lands. Such succession of forests results in a more uniform vertical (stepped) distribution of forest fuel materials, which, in turn, increases the risk of a grassroots fire going into a crown fire. Numerous foci of pine silkworm are found in the soil, which causes defoliation of up to 60-80%, and in worst cases up to 100% of needles on damaged trees, foci of root sponge (Fomitopsis annosa Karst.), Which are found in most pine forests, including artificial pines, planting an area of 1024 ha near the village of Leliv.

8. Roads

In general, the main paved roads in the CEZ connecting the town of Chernobyl with check points and with the Chernobyl NPP are constantly maintained. These roads are used to transport local and international personnel, and local villagers that live permanently in the CEZ; to deliver construction materials for Confinement II (new sarcophagus); and for overall nuclear infrastructure and territorial management (power lines, pipelines, etc.). Many of the roads to remote, abandoned villages (Cherevach, Rozsoha, Denisovichi and others), however, are gradually deteriorating and may soon be unusable for wildfire suppression purposes. Most of the abandoned forest roads are now blocked by downed trees and natural tree regeneration. Under conditions of absence of regular thinnings and other routine forestry activities, most of forest roads as critically important part of fire infrastructure covered with fallen of growing trees and could not serve more for fast response of fire brigades (Fig. 7).

Figure 7. Examples of fallen trees and regeneration of forest species on forest roads that makes impossible use of forest roads for fast delivering of fire resources

To date, fire danger in forests is increasing rapidly due to the drying up of individual trees, clumps or woodlands. The fall of trees causes the formation of windows in the forest. Increased illumination leads to an increase in spatial diversity and the amount of forest fuel material in the form of undergrowth and shrubs. This mixture of live subfloor vegetation, together with clutter, the remains of trees damaged by fires, previously creates a new hazardous situation with the distribution of forest burning materials in the plantation. Such processes prove that fires will be more intense in the future than those that occurred in the area before. The height of the flames will increase, the combustion time of the forest fossil materials will be longer, accompanied by the emission of more smoke and burnt particles, and therefore radionuclides. Fires of this kind are called catastrophic fires. Such fires will be very difficult to control. Catastrophic fires pose a threat to the safety of both firefighting personnel and other people in the area. Forests that do not have any forest management activities or monitored piles subsequently come to this state naturally.

A clear example of this transformation is the history of forest protection in the United States. The US Forest Service has been actively pursuing a policy of complete firefighting and fire control over the last 50 years, which has been the main cause of many catastrophic, uncontrolled fires in the US West over the past five years. These mega fires, covering thousands of acres, occurred during hot, dry and windy weather and burned every few weeks. Of the more than 69 million acres managed by the US Forest Service, large areas are covered by landscapes similar to Zone - with vastly undergrowth, dry fallen trees and reclaimed secondary species.

An important area of fire prevention in the exclusion zone is the maintenance of a network of fire-fighting roads. At present, the efficiency of firefighting services in the area and the speed of response are significantly reduced by the unsatisfactory condition of the road network. Prior to the accident, the main network consisted of the main roads with hard pavement (Dzyatyky, Paryshiv, Opachichi, Cherevach, Korogod, Novy Shepelichy, Polissye, as well as dirt roads, most of which passed through quarterly clearings. Currently, about 90% of forest roads are not suitable. The main reason for this is the natural restoration of tree species. The best light regime, regular disturbance of the soil by wild animals, fires create favorable conditions for germination of seeds. In some clearings and former forests birch, aspen, pine, oak, and other trees that can reach up to 20-24 cm in diameter at chest height have appeared in large numbers on the roads. there is a need to plan and optimize a complete network of roads, which will ensure the delivery of fire trucks, equipment, forces to the most fire hazardous areas. Field studies show that road infrastructure does not meet the goal of rapid localization and extinguishing a catastrophic fire.

The purpose of protecting forests from fires should be to extinguish the fires in the initial stage and keep the fire near the surface, that is, to prevent them from going to the highland fires to minimize the risk of emergencies. This can best be achieved through the planning and implementation of a comprehensive forest fire protection plan. A key part of this plan should be to reduce the stockpiles of hazardous forest combustible materials and prevent their accumulation, fire prevention and effective firefighting.

Common methods to reduce the threat of fires are to reduce the amount of aboveground forest combustible materials by thinning congested stands, cutting down and removing trees from dry and dry trees. First of all, such forestry activities should be planned in forests with a high concentration of sources of fire - near settlements and production sites, in particular in the Chernobyl NPP, Pripyat, and other industrial sites in the area. Unfortunately, the high level of radioactive contamination of soils and vegetation significantly limits the possibilities of this area to reduce the risk of fires.

9. Fire prevention

The following steps should be considered as a priority fire prevention in the ChNPP Nuclear Power Plant. Analysis and revision of the forest protection plan for the Chornobyl NPP. Such a plan should be a mandatory part of the forest fire protection system and should take into account the specific features of the area. The purpose of a forest fire protection plan is to develop a document that combines vegetation information, a description of areas in danger from a forest fire in the area, a history of forest fires in the region, a plan to reduce the number of LGMs, and more. The implementation of this plan will coordinate efforts to reduce the likelihood of catastrophic fires, by reducing the number of LGM in forests and in fallow lands, reducing the negative impact of pests and forest diseases on forest burning in the most efficient, safe and economically acceptable way. An important part of the fire protection system should be fire safety issues, fire safety measures and the availability of personal protective equipment. At the moment, it should be noted that the existing fire control project is outdated and out of date and does not reduce the risk of catastrophic fire.

There is currently no information available on the stock of forest flammable materials in the forests of the Exclusion Zone, except for the data collected within the framework of this topic. No models of forest combustible materials have been developed. In the following forest management, a prerequisite is the inclusion in the standard list of taxation indicators of the accumulation of forest combustible materials of different types on each section.

Studies have shown that an existing fire protection plan for forests, which should include the full range of tools for preventing, detecting and responding quickly to a fire, does not meet the current state of affairs and the high risks involved. The project was completed after the catastrophic fire of 1992. The main disadvantage of the mentioned project is that its methodological basis is Design Guidelines developed in Soviet times for conditions, mainly taiga forests. Also, the design of fire-fighting measures did not take into account the features of radiation contamination and offered personal protective equipment.

An essential prerequisite for improving the existing forest fire protection system is the creation of a GIS-based fire information system and remote sensing data, which will be the basis for planning preventive measures and making operational decisions on fire fighting. In particular, it is necessary to create a series of maps showing all elements of firefighting: areas with a high level of accumulation of LGMs, fire ponds, swamps, fire breaks and other limiting elements, roads, fires, pests and diseases of the forest, other infrastructure. Much of this data already exists, but it must be organized in one program and digitized.

The next step after the creation of modern information support for fire protection of forests should be to optimize the location of strategic fire gaps. To do this, it is necessary to identify and map areas with a dangerous amount of LGM in the area through ground surveys and modeling. After identifying critical fire hazard areas, fire gaps should be created to ensure that the most dangerous potential catastrophic fires can develop. In order to accomplish this task, the Chornobillis specialized enterprise must use the data of the latest forest management and convert all the information into digital format in order to use the GIS capabilities. Predictions and simulations of forest fires behavior should be developed for the exclusion zone. Currently, measures to eliminate LGM in the Zone are restricted mainly to the areas along the main roads and are being implemented without taking into account the need to reduce the real fire risk.

Due to the fact that most forest fires in the forest are initiated by humans, special planning is needed to reduce the number of fire sources in the forests. At present, the main fire prevention measure undertaken by the Chornobyl Pushcha enterprise in the Chernobyl Nuclear Power Plant is the placement of fire-fighting in strategically important places. A number of additional measures are needed to improve the effectiveness of fire prevention.

It is necessary to analyze the existing preventive measures, train forestry personnel on fire prevention methods and develop a plan of fire prevention measures. It is also necessary to identify the main culprits of the fires caused by the people and to expand training and advocacy among the population and staff by organizing a firefighting campaign. This action should also target schools and locals living around the Zone, as well as people working or living in the DR. It is also important to increase the intensity of fire patrols during critical fire safety periods. It is advisable to introduce mandatory restrictions on fire seasonal highs, such as the banning of fires, smoking, road closures, forest entry closures.

Extinguishing fires. Early detection of a fire in combination with its rapid and effective extinguishing is the basis of any firefighting strategy. Effective response to possible catastrophic fires in HAs to fire highs will be unlikely due to outdated and worn out firefighting and communication equipment. In this regard, existing firefighting equipment, such as radio communications, fire trucks and water pumps, needs to be upgraded to improve the firefighting efficiency. Most of the equipment dates from the 1970s, which will not effectively extinguish any catastrophic fire in the region.

The conducted studies allow us to formulate four main conclusions: a) there is and is constantly increasing the risk of fire in covered and uncovered forest areas in the Chernobyl Exclusion Zone, which can lead to catastrophic fire; b) measures to reduce the amount of forest combustion materials carried out in the Zone are very limited and insufficient; c) the existing information support for the protection of forests from fires does not meet the high level of fire risks; d) firefighting techniques and technologies, as well as personnel readiness, do not take into account the risk of catastrophic fire and radiation risks to personnel.

10.Fire detection

Fire detection on CEZ forest lands before 2009 was based on daily helicopter patrols at midday, detection from fire lookout towers and ground patrols during periods of high fire danger. During the past years, helicopters have no longer been available. Only seven lookout towers (H = 35 m), all established before the failure of the Chernobyl reactor, are now used for fire detection on 260,000 ha of forests lands. However, most of them need repair or replacement. Spatial analysis shows that only 26.8 % of the CEZ is covered by ground fire detection (Figure 8).

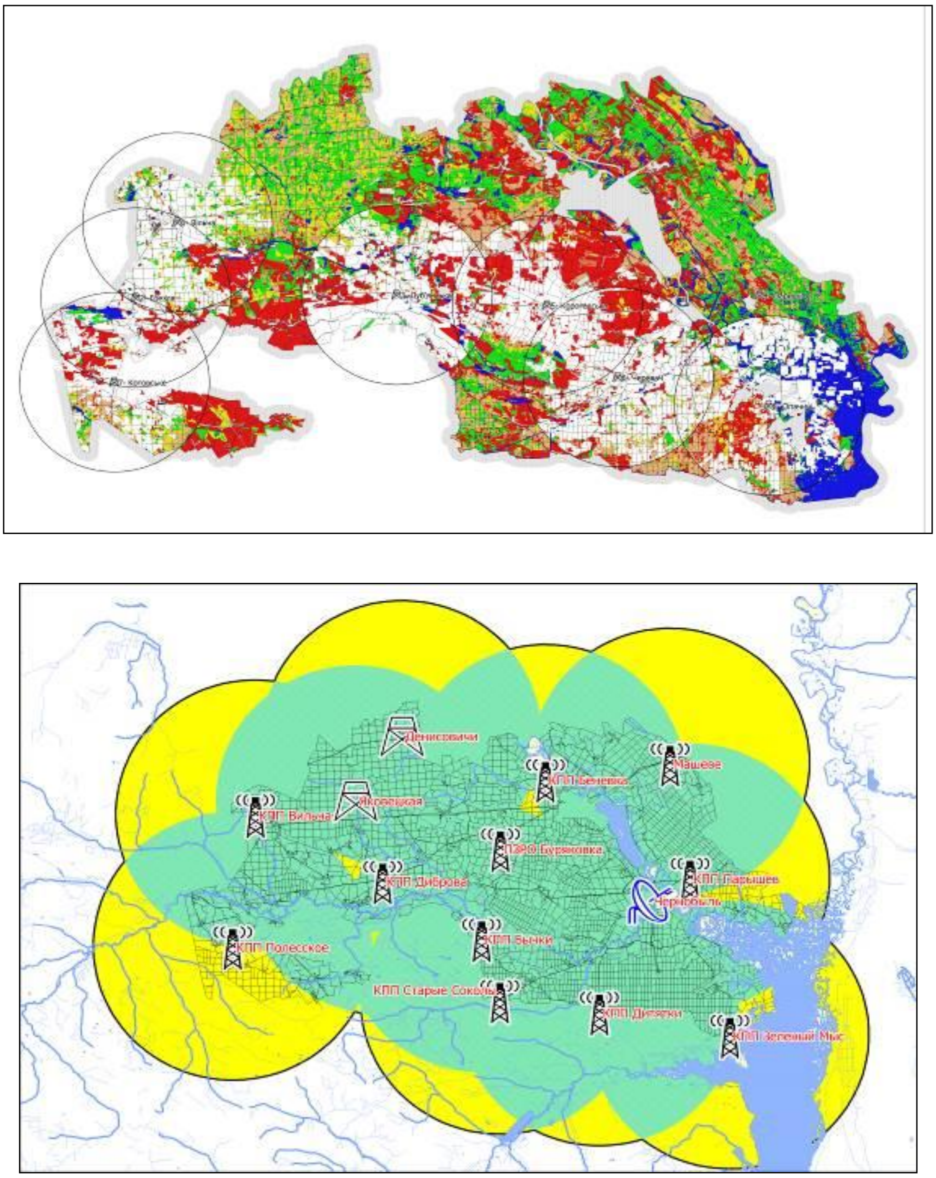

Figure 8. Current fire-detection coverage of the CEZ using the existing seven fire outlook towers (left). The proposed fire detection coverage (right) is based on 13

observation towers with a coverage range of a radius of 15 km each, and one receiving station. Note: On the left map only the white-colored territory is covered by fire detection (26.8 % of the CEZ territory).

The left map reveals that large areas in the central, northern and eastern parts of the CEZ, which include highly contaminated lands with the highest levels of fire hazard, cannot be monitored from the existing towers. An improved monitoring system for early detection of fires in the CEZ must also include buffer zones to prevent the spread of grass and forest fires from outside the CEZ. In order to reduce the exposure of ground personnel to radiation, the lookout system should be based on automatic detection cameras and one receiving station connected to the dispatch center in the town of Chernobyl. However, a lack of funding, secure equipment and adequate power are the most important obstacles to implementing the proposed fire detection system.

11.Fire breaks

The forestry administration in the CEZ pays higher attention to the establishment of fire breaks than to other standard tools of fire prevention. According to recommendations by the Fire Management Plan (1994), a total of 111.9 km of fire breaks were established during the late 1990s, including 1.6 km of 10 meter-wide breaks, 22.5 km of 11-20 m-wide breaks, 44.8 km of 21-30 m-wide breaks, and 43 km of breaks wider than 30 m. Fire breaks were placed mostly along the external perimeter of the CEZ and along main roads. It should be mentioned that since the 1990s, natural fire hazards in the CEZ have changed due to different types of disturbances (fires, wildlife, floods, natural succession, etc.). Most of the above-mentioned fire breaks are no longer maintained by regular removal of fuel and are therefore not able to stop fires. During the past decade, mostly 1.6 m wide fire breaks were built with a total length of 1,750 km. These fire breaks are maintained 2-3 times per year by removing accumulated fuel.

However, there is no digital map reflecting current locations of fire breaks and the main criteria of their establishment is unknown. A special analysis is required to define the effectiveness of the current fire breaks system to mitigate existing fire risks. This will enable the system to be optimized and reduce the risks of large wildfires.

12. Threats to firefighters and fire management personnel from radionuclides contained in smoke and dust

During forest fires in the exclusion zone, radionuclides deposited in forest fuel in 1986 are released into the atmosphere with smoke. Resuspension of ^{90}Sr, ^{137}Cs, and plutonium is occurring in two ways: smoke particles and mineral dust. Dust particles are usually large (range: 2-100 µm in diameter; mean: ~10 µm) (Brasseur et al., 1999) and redeposited close to the source. In contrast, forest and grassland fires emit fine particles with a bimodal size distribution of 0.04-0.07 µm and 0.1-0.3 µm (Chakrabarty et al., 2006). While large particles are usually repelled by the respiratory system, fine particles are inhaled into the lungs. Over time, fine particles in smoke plumes often form large particles through coagulation and are deposited with cloud droplets downwind from the fires.

Data from the Automatic Radiation Monitoring System managed by the "Ecological Center" state enterprise shows a clear increase in the concentration of radionuclides in air in the CEZ during large wildfires. In particular, during the massive CEZ forest fires in the summer of 1992, an increase in the concentration of airborne radionuclides from 0.017 Bq/m^3 to 1.5 Bq/m^3 was recorded in the town of Chernobyl, not far from the fire. The analysis of available information on the 1992 fire and inventories of radionuclides in the biomass burned showed that the ^{137}Cs-activity released into the air in this period was in the range of 28-130 TBq[4]. Hence, wildfires with areas of up to 1 km^2 in forests with a level of soil contamination higher than 40 MBq/m^2 create a potential threat of air release and long-distance transport of up to 40 TBq of ^{137}Cs. Radioactivity levels in the air of ^{90}Sr, ^{137}Cs, and plutonium near an experimental forest fire and two grassland fires in the CEZ were found to be several orders of magnitude higher than normal levels (Yoschenko et al., 2006). The radionuclides emitted, especially plutonium, were concentrated in fine particles, which would increase the inhalation risk for firefighters. The worst-case scenario (i.e. a catastrophic forest fire burning all fuel in the CEZ) shows a direct threat to the

4 TBq = Tera-Becquerel = 10^{12} Becquerel

population and environment across a larger region. Radionuclides could migrate over a distance greater than 100 km, exposing the population to doses in excess of established limits (Hohl et al., 2012; Evangeliou et al., 2014a). The risk of such catastrophic fires increases with climate change and appropriate measures should therefore be considered in emergency planning.

In 2013, an experimental assessment of doses from the resuspension of radionuclides for personnel involved in the establishment of fire breaks was undertaken (Yoschenko et al., 2013). The research showed that the effective resuspension coefficient for all radionuclides, calculated for the air inside the cabin of the tractor, is of the order of 10^{-8} m^{-1}. This means that the air conditioning system reduces the concentration of radionuclides by two orders of magnitude compared to the air outside the cabin. Internal doses to personnel in the cabin of a tractor during the establishment of fire breaks (Figure 9) in the exclusion zone due to inhalation of radionuclides (calculated for a 50-year-old male person, Effective Dose Equivalent) is more than twice as high as the external dose to the body. The inhalation dose is almost entirely due to the intake of transuranic elements. Inhalation doses for personnel located in the plume of dust or in a tractor cabin without an air-conditioning system will be up to two orders of magnitude higher than for staff protected by an air-conditioning system and can reach significant values. All these assessments show the importance and health benefit of cabin air filtering, as the dose contribution through inhalation is the most important pathway.

In the CEZ, the annual dose limit (5 mSv) for personnel involved in the establishment of fire breaks in areas with high contamination levels can be reached within a few weeks. At the moment, not all tractors in the CEZ are equipped with working air-conditioning systems, and air-conditioning systems are not always regularly maintained or new filters provided. In conclusion, doses from inhalation should be taken into account during the planning of fire prevention measures in order to avoid personnel exceeding dose limits. Staying in the plume of dust and using tractors without air-conditioning should be avoided.

Figure 9. Establishment of fire breaks generates radioactive dust that can lead to an increase of inhalation doses for tractor drivers. Photo: V. Yoschenko.

13.Fire suppression capacity

The Chernobyl Forest state enterprise is responsible for prevention, patrolling, fire infrastructure maintenance and initial fire suppression in the CEZ. In the case of a fire larger than 5 ha, professional fire fighters from the Chernobyl Fire Station could also be involved. Common hand tools, water and the construction of fire lines around the fire are usually used for ground fire suppression. The total capacity for vegetation fire suppression includes four Forest Fire Stations located in the central and southern parts of the CEZ (villages Denisovichi, Lubjanske, Paryshem, Opachichi) and seven points for hand tool storage which, however, do not coincide with the highest fire hazard areas. In total, only 33 permanent staff (fire fighters and drivers), with 15 fire trucks (ZIL 131 with a capacity of four tons of water), 19 backpack pumps and hand tools (shovels and fire swatters) are available. The equipment does not even correspond to official Ukrainian minimum requirements for fire stations responsible for regular, non-contaminated forests. Water supply is provided by 16 fire ponds and points for replenishing water tanks.

To assess the effectiveness of the current placing of fire stations in the CEZ in terms of fire fighter response time and water supply, a map was drawn up of the road networks reported officially in 2006, which could be used for fire suppression (Figure 10).

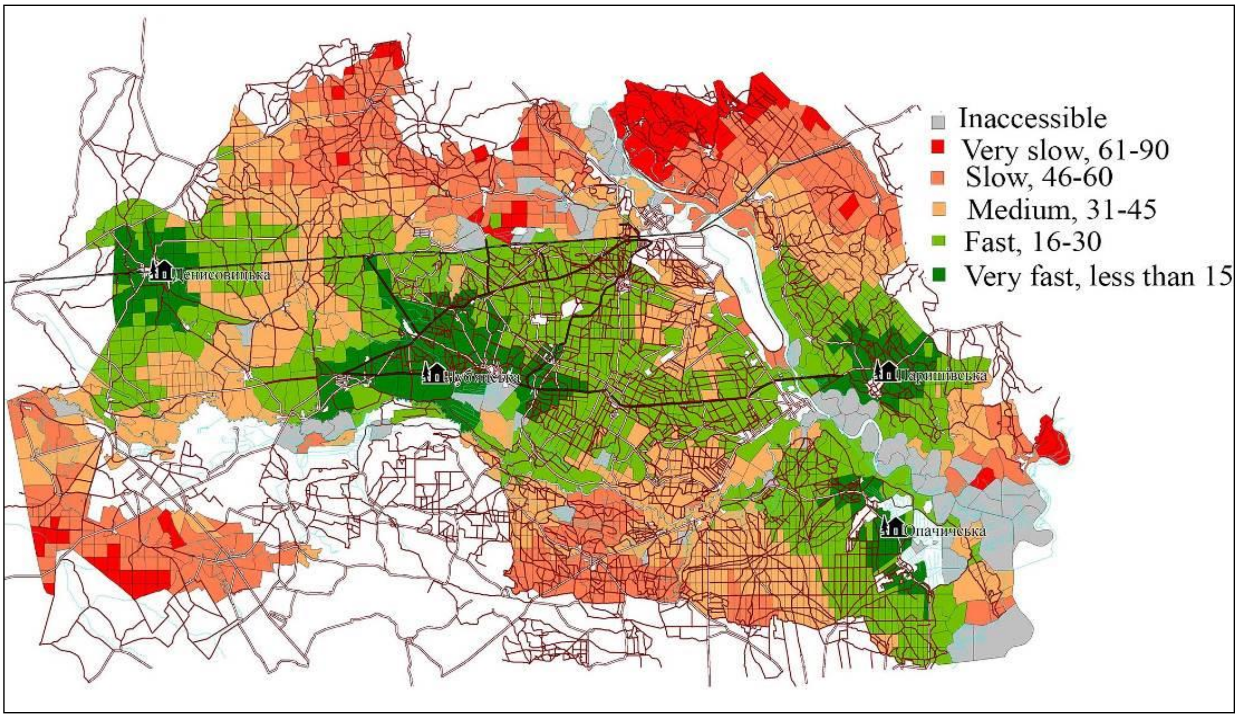

Figure 10. Zones with fire fighter and fire truck response times (minutes) to potential fires from currently operating forest fire stations. Source: Evangeliou et al. (2014b).

On the basis of a statistical analysis of response time from current fire stations, the CEZ can be divided into six main zones (Table 2).

The interpretation of the efficiency assessment needs to take into account that the response time analysis was based on the road network as reported by the Forest Management Plan in 1996. Based on this road network analysis, only 40.9 % of forest lands in the CEZ could be reached by fire brigades within 30 minutes, whereas to reach other sites, where 60 % of the fires have occurred during the past decades, it would take up to 90 minutes. In addition, 6.9 % of forest lands in the CEZ are completely inaccessible to ground transportation. Heavily contaminated lands in the central and northern parts of the zone are also in the category of lands with unsatisfactory response times (30 minutes and more). Furthermore, response time may now be much higher in many cases, as a number of roads from that time no longer exist.

Table 2. Response times from current fire stations to reach potential fire locations

	Efficiency of response	Time of arrival of fire fighters (min)	Average time of arrival of fire fighters (min)	Amount of fires (1993-2012)	Area of the zone (ha)	Share of the zone from total CEZ area (%)
1	**Very fast**	<15	11	150	23,690	9.9
2	**Fast**	16-30	23	190	74,315	31.0
3	**Medium**	31-45	37	259	65,118	27.2
4	**Slow**	46-60	51	193	48,826	20.4
5	**Very slow**	61-90	66	28	11,112	4.6
6	**Inaccessible**	-	-	21	16,627	6.9
Weighted average / Total			**33**	**841**	**239,688**	**100**

14. Needs for fire research to ensure successful prevention and fast response on fires

Information support for the protection of forests from fires should include both spatial information - thematic digital maps of sources of fire hazard and the location of forest areas, as well as a database (database) of components of fire hazards (seismic database of forest stock, database of cases of fire, database of climatic conditions). A necessary direction of information support of detection of forest fires, their monitoring is the use of data of remote sensing of the Earth.

The structure of the common database is thematic blocks, which are interconnected by key fields: address part (enterprise, forestry, quarter, section, subdivision) and time (date of meteorological and fire hazards, forest fires). The information for filling the database will serve as indicators:

- Relational database "Forest Fund of Ukraine" (radiation-contaminated forest lands), developed on the basis of SQL Server database, which includes all forest-taxation information, information on radiation pollution and natural fire danger;

- Chornobyl meteorological station data (index date, air temperature (oC), air humidity (%), wind direction and velocity (rumb, m · s-1), dew point temperature (oC) and precipitation (mm), indicator fire danger);

- data of cases of forest fires according to the following scheme: area, forestry, forestry, quarter, selection, subdivision, date of fire (month, number), time of detection, start of extinguishing, time and date of elimination of fire (number, hours, minutes); area of fire at detection and total area of fire, ha; type of fire, area covered by horseback (or underground) fire, ha; cost of extinguishing and total amount of losses (UAH), cause of fire.

Development of a single database and combination of taxation characteristics, forest fires and meteorological indicators, provides for the accumulation and systematization of:

- information on fires and analysis of forest fires;

- pyrological and forestry information necessary for organization of works on detection and extinguishing of forest fires;

- meteorological information for predicting fire risk;

- reporting information for the assessment of the effects of forest fires;

-information products to support operational management decisions on the detection and extinguishing of forest fires.

The use of geoinformation systems (GIS) for spatial analysis and forecasting of fire hazards is necessary to reduce forest burns in the SPD and to optimize costs for forest protection

As most of the information is made up of the relational database “Forest Fund of Ukraine” based on the SQL Server database and geospatial mapping information -

both developed by Ukrderzhlisproekt - it is advisable to supplement the existing database with the following blocks: data of fire cases, trial data and meteorological data.

For the exchange and updating of the basic data of Ukrderzhlisproekt, the information standard of forestry data has been defined and the exchange format has been developed using an open XML language, which is compatible with most modern GIS programs. The final stage is the integration of all available data and the development of models for assessing the current burning of forests and making decisions on the detection of forest fires in the GIS system "Forest fires in the exclusion zone".

15. Conclusions

The Chernobyl accident led to a dramatic change in the forest management regime in the exclusion zone in the area of 260 thousand hectares, which consists in the cessation of ecological and forestry measures in pine forests. The main feature of the post-forest dynamics of forests of the Exclusion Zone is the development of the processes of forest naturalization over the last years, which include changes in the structure and breed composition of plantations, mass reproduction of pests and diseases of the forest, increasing the fire risk of forests.

The greatest risk of catastrophic fire is in the case of fires with an area of more than 25 hectares, the proportion of which in the area does not exceed 2% by quantity, but reaches 35% by area. Half of these fires occurred in the most polluted 10 km zone. Falcons remain the most dangerous category of land in terms of frequency (58-95%) and area of fires. In the years critical for fire danger (1992, 1996), the area of forest fires exceeds the area in the fields. The mosaic of covered and uncovered lands of the zone causes a high risk of fires in the forest.

The maximum risk of catastrophic fires due to the unfavorable geometry of the location of forest combustible materials exists in low-grade pine young plants with a total area of 17.6 thousand hectares, pine forests with a total area of up to 4 thousand hectares damaged by pine silkworm and rooted silkworm and root to potential sources of fire (stockpile up to 200 m3 · ha-1), as well as in high-density artificial pines located near the area of potential reach of fire.

In 40-60 annual plantations in dry and fresh types of forest plant conditions, a total of about 1.4 million m3 of dry accumulation has been accumulated, which in the event of fire will lead to catastrophic fire. About half of this stock is concentrated in the zone of maximum radiation contamination (10 km). It is expected that the stock of dry land in the critical group of plantings and, accordingly, the risk of catastrophic fires will double over the next 4-7 years, which requires further research and development of a plan of action to reduce the risk of catastrophic fires.

The total stock of forest combustible materials in pine stands naturally increases with age from 110 t · ha-1 (22 years) to 205 (40 years) and 220-280 t · ha-1 (44-64 years). Of these, 13-16% are terrestrial combustible materials that can potentially burn during a grassroots fire and 84-87% are above ground, which will be involved in the burning of a highland fire. In terms of fractional structure, terrestrial fuel is dominated by forest litter 89-92%, wood debris is 8-10%, grasses - up to 1%. The combustion temperature of this mixture will depend on the humidity of the materials and the weather conditions during the fire. In the structure of above ground fuel, wood and bark of the trunks account for 86-90%, which almost do not burn during fires. Potentially riding fire will form branches in crowns - 6.8-8.1% and needles - 4-6%.

Overall, in the exclusion zone in the above-ground fuel group, the most hazardous pines account for 74.6% of the total fuel load. Of these, the most dangerous are concentrated in young animals (10.4%), in which the probability of a high fire is maximum and medieval plantings (50.2%), in which the type of fire will be determined by the weather conditions. The temperature of the riding fire, and therefore the rise of radionuclides, will be maximum in young animals, where the stock of branches and coniferous trees varies within 25-50% of the total amount of fuel in the plantation. In medieval plantations the stock of branches and needles decreases to 15-25%.

The largest stockpile of aboveground forest combustible materials in the Exclusion Zone is concentrated in the Lubyansky Forestry, which accounts for 24% of their total in the Exclusion Zone. This requires priority to be given to the early identification of fires in this forest area in the event of an extreme fire hazard. In other forestry's, 11% (Dityatkovske) to 17% (Denisovetske) are concentrated. 30% of above ground LGM Exclusion Areas are located in forests with very high levels of pollution (more than 15 Ki · km-2), where any forestry activities are prohibited, and 39% in the zone with soil contamination density from 5 to 15 Ki · km- 2, where the activities are limited by the radiation safety requirements.

The rise of radionuclides into the air during a fire will be determined by the concentration of radionuclides in forest combustible materials and the type of fire. The test areas in the near contamination zone (within 5 km of the Chernobyl NPP) in sediment and forest litter, which will completely burn in the event of a persistent grassroots or upland fire, concentrate from 14 to 35% of the total radionuclide content in the litter and soil, which reaches 43 50 kBq · m-2.

The average annual number of fires during 1993-2010 correlates with the annual rainfall. The average annual area of fires is also affected by rainfall, however, the tightness of the connection increased during 93 - 2010, which indicates an increase in the effectiveness of forest protection against fires in the exclusion zone during this period. The wind regime of the exclusion zone causes high probability of development of both moving grass fires and riding. The number of days with wind gusts that can cause low-level fires in the upper reaches (more than 10 m · s-1) is more than 220 on average, including 96 days in a fire-hazardous season.

In the spring season, the average area of fire in the fluctuation of the complex index 500 - 1500 is about 2 hectares, and in the summer - autumn season does not exceed 1 hectare. At the same time, fire peaks are observed at higher Nesterov index values. The current fire hazard scale significantly lowers the fire risk rating, especially for upper grades 4 and 5.

Reducing the risk of catastrophic wildfires is not part of the existing strategy for the rehabilitation of lands in the Exclusion Zone. The previously developed fire control project for does not fully take into account the current ecological and sanitary condition of forests, the presence of forest combustible materials, fire weather, combustibility of forests, features of radiation contamination and access of personnel and the population to the area of technical potential, existing areas fire detection, delivery of forces and fire extinguishing equipment to the fires and needs major refinement.

The existing forest protection system is quite effective in dealing with small fires under normal climatic conditions. At the same time, there are no important links in the current system (early detection and rapid response, training and personnel safety) that will not effectively respond to catastrophic fire in critical climatic conditions.

16.Recommendations

The main purpose of managing the landscapes of the Exclusion Zone is to ensure that they perform a barrier function for the propagation of radionuclides beyond their primary fallout. The vast majority of the Exclusion Zone belongs to forest lands and is a mosaic of forest areas and former agricultural lands. Most of the exclusion zone is represented by automorphic types of landscapes characterized by high fire risk.

The vast majority of the exclusion zone is contaminated with radionuclides with a half-life ranging from 29 to 24 065 years. The most radiation-hazardous are areas with a contamination density of more than 370 kBq · m-2, with a total area of 48% of the exclusion zone. During a wildfire, the following radionuclides will be emitted into the exclusion zone: 90Sr, 137Cs, 154Eu, 238Pu, 239,240Pu, 241Am. The extent of secondary environmental pollution and additional dose exposure will be determined by the area and type of fire. The duration of the radiation contamination of the exclusion zone and the high fire risks necessitate the establishment of a long-term and effective forest fire protection system that will minimize dose burdens on forest firefighters, personnel working in the exclusion zone and the population outside the exclusion zone. Regulations for the protection of forests against fire and individual safety measures during firefighting and fire prevention should take into account the intensity of radioactive contamination of the exclusion zone.

There is currently no evidence that forest fire hazards differ in areas with varying levels of pollution. At the same time, the radiation risk to firefighters and the radiation effects of forest fires on a regional scale depend on the pollution density and the maximum in the conservation zone. According to the literature, in the case of extinguishing a grass fire, the total dose of external and internal exposure of firefighters (without the use of individual means of protection) can reach 12-40 μSv · h-1, and the grassland forest fire - 8 μSv · h-1. In this case, the major part of the dose is formed by the isotopes of the plutonium group due to the inhalation component, which poses a serious health hazard. According to the simulation of the worst case scenario of a catastrophic fire in the exclusion zone, the population will be at risk from additional irradiation at a distance of 30 to 150 km from the place of the probable fire, and the total radiation dose from all paths (inhalation, soil contamination, contamination of foodstuffs) 22 mSv during the first year after the fire.

At the moment, accurate prediction of radiation doses for forest firefighters is impossible due to the lack of information on the total density of contamination at the site of fire, the proportion of individual radionuclides, the concentration of radionuclides in the smoke, and the complexity of the simulation of smoke rise in low and high fires. In this regard, a common forest fire protection strategy in the exclusion zone should be based on minimizing the presence of personnel in the smoke zone.

An important condition for the high efficiency of forest fire protection is the availability of a complete and up-to-date firefighting project for the forest fund, which would take into account all existing fire risks. The latest firefighting project was developed in 1994 and is currently out of date.

The overall strategic goal of protecting forests from fires should be to extinguish the fires in the initial stage and keep the fire near the surface, i.e. prevent the occurrence of riding fires and minimize the risk of an emergency. such a goal can best be achieved by planning and implementing a comprehensive forest protection plan. A key part of this plan should be to reduce the stockpiles of hazardous forest flammable materials (subject to personnel safety requirements), to prevent their accumulation, to prevent fire prevention and to effectively extinguish fires.

Fire prevention

Fire prevention of the exclusion zone should be based on the following elements:

• conducting regular fire safety training in the forest with the personnel of the exclusion zone and the population, which could potentially be responsible for the fire as a result of careless fire management (especially before the onset of spring and summer forest burning peaks);

• equipping all vehicles operating in the exclusion zone and which can cause fire, spark extinguishers;

• determining the list of roads for fire-fighting purposes and maintaining them in the state-of-the-art for special vehicles;

• expansion of the existing network of fire ponds in areas with high fire risk areas. The distance between them should not exceed 2-3 km. Supporting entrances to the reservoirs in functional condition;

• introduction of a fire suppression system for the elements. The basis of such measures should be the creation and maintenance in a functional state of mineralized strips of 1.4-3 m wide at the borders between the former agricultural and forested lands, along the roads with the highest traffic flow, near settlements where the population lives, etc. To optimize the location of mineralized strips, it is advisable to use a forest land burn map. Creating a 30-50 m wide fire break system does not seem appropriate in the exclusion zone because of the low efficiency of their fire-limiting function during riding. According to research and practical experience, in the case of large fires, a zone of vertical turbulence is formed before the fire front, which causes the transfer of particles burning up to 300-500 m in the air direction;

• Reduction of fire risk of critical areas of forestry by forestry measures, in particular the creation of a system of complex fire barriers with a central element in the form of deciduous trees, which delay the spread of fire.

Fire detection

At present, the detection of fires in the exclusion zone is based on ground surveillance (observer duty on 7 fire towers), aviation patrols during periods of high fire risk and ground patrols. The major disadvantage of the existing system is the presence of large areas of high fire risk that are beyond the scope of ground-based surveillance. According to preliminary calculations, 8-9 fire towers 40-45 m high should be additionally installed to fully control the occurrence of fires in the exclusion zone.

One or two aviation patrols per day also do not ensure that the key requirement for a fire detection system in the exclusion zone - early fire detection - is met. Given the above high risks of a large fire, the introduction of an automated early ground fire detection system covering the entire area of the exclusion zone, based on smoke and video surveillance, and allowing round the clock detection of fire within 3-5 minutes after the formation of fire within 3-5 minutes is recommended.

An important prerequisite for early detection and rapid response to fire is ground patrolling of forests during high-risk periods by mobile UAZ-based fire extinguishers with a water supply for the first attack and a team of fire fighters. During periods of extreme fire danger, it is also advisable to use aviation or drones for 3-5 fold aviation patrols during the daylight period.

Response

Large fires are most likely to occur in years with minimal rainfall. The years of fire maximums were 1994, 1999, 2002 and 2003, when the annual number of fires reached 100-120 cases. An important factor that can significantly complicate extinguishing a large fire in the exclusion zone is the wind regime. The number of days with wind gusts that can cause low-level fires in the upper reaches (more than 10 m / s) exceeds 220 on average per year. In order to bind the regulations of the forest fire services to the climatic conditions of the exclusion zone, it is advisable to use the local scale of fire danger under the conditions of the weather, which was developed in the framework of scientific research.

Current scale of fire risk significantly lowers the rating of fire risk, especially for the upper grades 4 and 5, where the values of the complex indicator of fire danger in weather conditions are overestimated several times, while already in the third class (1001 -4000) of the current scale is formed the highest fire danger under the conditions of the weather for the spring-summer period.

Extinguishing of fires

Early detection of fire in combination with its rapid and effective extinguishing should be the basis of a fire fighting strategy in the exclusion zone. An important condition for effective response to possible catastrophic fires is the availability of modern fire extinguishing equipment and communication equipment.

In forestry and forest fire stations, emergency departments there must be a map of radioactive contamination of the protected area. Before leaving for firefighting, personnel should be familiar with the radiation situation at the site of extinguishing.

In order to reduce the dose burden on personnel in zones I and II of radioactive contamination, localization and extinguishing of forest fires with an area of more than 0.5 ha is carried out using a helicopter and a drainage device. In order to increase the efficiency of aviation use in extinguishing radiation natural fires, a Forest Aviation Guidelines should be developed in the exclusion zone, which will regulate the coordination of ground and air forces in extinguishing a fire.

Extinguishing fires of less than 0.5 hectares is mainly carried out using indirect land-based methods, by creating barriers and support lines using soil-borne implements and fire extinguishers. When using tractor units with tillage implements, the direction of travel is selected in such a way as to prevent dust from entering the personnel. Forest fires are extinguished using water and chemicals that increase its fire-fighting ability.

Additional analysis of the causes of high fires in the Parishivsky and Kotovsky Forests and low flammability of the Korogodsky Forestry area should be carried out in order to eliminate the shortcomings and spread positive experience among other units of the enterprise.

As the most important factor affecting the area of fire at the time of its localization and the duration of fire extinguishing is the area of fire at the time of its detection, special attention should be paid to early fire response measures, the introduction of which will avoid large and especially large fires.

In order to improve the interaction of different forces in extinguishing large fires, it is advisable to adapt and put into practice the protection of forests against fire by an integrated emergency management system, an analogue of ICS (USA) or EuroFire.

An important prerequisite for effective firefighting in the exclusion zone is the availability of a command support system for protecting forests from fires, which includes optimization of delivery routes for firefighters and equipment, an electronic map of natural fire hazards, fires development forecasts, models of forest flammable materials fires, a module for calculating radiation doses that can be obtained by forest firefighters.

At least one radio station or satellite installation must be issued for each fire department. It is desirable that each employee has a shortwave device for two-way communication. This will better coordinate the work within the fire department and provide immediate intervention and assistance in emergencies (personal injury, sudden change of direction of fire, etc.). Each fire department must have a GPS (GPS) device to better orient the area's personnel.

Requirements for the organization of radiation control during fire fighting

When extinguishing fires in areas of radioactive contamination, the responsibility for carrying out radiation control rests with the extinguisher. Periodicity of control is established for each area of extinguishing depending on the peculiarities of radiation and fire environment, tactics and methods of extinguishing.

Individual control of external exposure doses includes: measuring the dose rate at the site of extinguishing, individual recording of time spent on extinguishing fires, control of skin radionuclide contamination, individual monitoring of external exposure doses using individual dosimeters.

In each case of extinguishing a fire it is necessary to determine the threshold of the dose rate at which the limitation of working time will be introduced.

Requirements for individual radiation protection of forest firefighters

Each extinguisher is given a set of personal protective equipment that is periodically inspected for surface contamination. When contaminated above the control levels, the remedies are deactivated or replaced.

It is forbidden to carry out work in field conditions related to dust formation or in smoke-free conditions without respirators, special protective clothing, foot and head protection, with removed and unbuttoned means of protection.

Sanitary facilities must meet the requirements of sanitary rules and regulations. Specially equipped rooms (dressing rooms) are provided for storing issued personal protective equipment.

Cabs of drivers of mobile equipment should be sealed as much as possible by sealing windows and doors. The cabins must have an air conditioning and air purification system in place. Air-conditioning filters should be regularly checked for contamination and changed as necessary. In the cabs of drivers, tractors and operators periodically monitored dose rate.

All personnel involved in extinguishing fires in the natural environment must have an individual set of clothing and protective equipment. The following items must be included in this individual kit: forest firefighter suit; special fire-fighting shoes; forest fire-resistant leather gloves resistant to heat; protective helmet with flashlight; goggles; smoker respirator; a compass (GPS) and an extinguishing map; water bottle; mosquito net; personal backpack; individual first aid kit.

Attachment

Report of REEFMC-GFMC within OSCE project https://gfmc.online/globalnetworks/seeurope/OSCE-GFMC-Report-Fire-Management-Contaminated-Terrain-2014-ENG.pdf

Global Fire Monitoring Center (GFMC)
Ukrainian Institute of Agriculture Radiology (UIAR)
National University of Life and Environmental Sciences of Ukraine (NUBiP of Ukraine)
Regional Eastern European Fire Monitoring Center (REEFMC)
Green Cross Switzerland

BEST PRACTICES AND RECOMMENDATIONS FOR WILDFIRE SUPPRESSION IN CONTAMINATED AREAS, WITH FOCUS ON RADIOACTIVE TERRAIN

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