Transport of Radioactive Materials by Wildland fires in the Chernobyl Accident Zone: How to Address the Problem

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Abstract

As a result of failure on the Chernobyl nuclear power plant a total of six million hectares (ha) of forest lands were polluted by radionuclides. The most polluted forest area covers over 2 million ha in Gomel and Mogilev regions of Byelorussia (Belarus), in Kiev region of the Ukraine and in Bryansk region of the Russian Federation. The main contaminator is caesium-137 (^{137}Cs); in the core zones of contamination strontium-90 (^{90}Sr) and plutonium-239 (^{239}Pu) are found in high concentrations. Radioactive emissions from wildfires occurring in contaminated vegetation represent a high risk for firefighters. In addition populations are affected by radioactive smoke particles transported over long distances.

The most contaminated territories are located in the closed zone around Chernobyl in the Ukraine and the Polessky state radiation-ecological reserve in Gomel region of Byelorussia. Here the soils are concentrated with highest contamination by radionuclides. The total area of the reserve is 215,500 ha. Soils contaminated by concentrations ranging from 1517 to 2,960 GBq/km^2 cover 40% of the territory of the reserve. Here there are also sites contaminated by Sr-90 and Pu-239. The closed zone in the Ukraine covers the an area of over 100,000 ha contaminated by Cs-137, Sr-90, Pu-239. The considerable part of forest areas of adjoining districts in Gomel, Mogilev and Bryansk regions have also high level of radioactive contamination.

This region constitutes the largest area in the world with the highest contamination by radionuclides and is located in a fire-prone forest environment in the centre of Europe. Every year several hundred to several thousand of wildfires are occurring here affecting forests, peat fields, extended areas of different deposits and former estates. The population of this area is 4.5 million people.

During fires on the deposits and other open areas the surface fuels contaminated by radionuclides – the grass layer and the surface layer of peat fields - are burnt practically completely. Extended radioactive fires occurred in the closed zones in 1992: In the Ukrainien part 12,000 ha of forest were burnt, in the Byelorussian part – 1,200 ha. Outside the closed zone fires covered 870 ha of forest lands in Gomel and Mogilev regions. In Bryansk region the area of radio-active fires was less than 200 ha. As a result of the fires Cs-137 radionuclides were lifted and transported by the smoke to the territory of Russia, especially in May and August 1992.

In 1993-2001 a total of 770 wildfires in the closed zone of the Ukraine affected 2482 ha (4.4 % forest, > 95 % deposits and agricultural estates. In the period 1993-2000 186 wildfires occurred in the closed zone of Byelorussia and affected an area of 3136 ha including 1458 ha of forest (46.5 %).

A number of measures are proposed to prevent the occurrence of fires in the contaminated areas, thus reducing the emission of radioactive particles and the contamination of fire service personnel and population by ionic radiation. Besides fire prevention measures practical actions include remote detection of forest fires, remote methods of fire suppression, and breathing protection of firefighters.

Introduction

As a result of the failure on the Chernobyl Atomic Power Plant more than 6 million ha of forest lands were contaminated. The most contaminated forest lands are situated in the Gomel and Mogilev Regions of Belarus, the Kiev Region of Ukraine and the Bryansk Region of the Russian Federation. Their total area makes up more than 2 million ha. The main contaminant of all those territories is cesium 137 (^{137}Cs). There are also strontium-90 (^{90}Sr) and plutonium-239 (^{239}Pu) in alienation zones (Figure 1).

The alienation zone around the Chernobyl Atomic Power Plant and the Polessky State Radiation-Ecological Reserve in the Gomel Region of Belarus is of special importance. The most polluted by radionuclides lands are concentrated on these territories. The total area of the Polessky Reserve is 215,500 ha. The density of soil contamination by radionuclides of Cs-137 makes up from 555 to 2960 GBq/km^2 (from 15 to 800 Ci/km^2). The areas with the density of soil contamination from 1517 to 2960 GBq/km^2 (from 41 to 800 Ci/km^2) occupy 40% of the Polessky Reserve's territory. There are also territories contaminated by Sr-90 and Pu-239 in this area (Figure 2). The alienation zone in Ukraine covers the area more than 100,000 ha. The territory is contaminated by Cs-137, Sr-90 and Pu-239. The considerable part of forest areas of adjoining districts of the Gomel, Mogilev and Bryansk Regions has a high level of radioactive contamination as well.

Contamination of Vegetation

The largest in the world areas that are greatly contaminated by radionuclides, as well as fire-risk forests, are situated in the center of Europe. The population of this region is about 4,5 million people. Annually from hundreds to several thousands forest fires are recorded here. They burn out forests, peatlands, former farmsteads, etc. The stock of the most inflammable forest fuel materials (litter and dead trees) is increased considerably in the most contaminated by radionuclides forests, where thinning were stopped. Under such conditions the intensity of forest fires is growing. By 1995 a layer of dry grass mass 15 - 60 cm thick were accumulated on disused areas in the Ukrainian alienation zone of the Chernobyl Atomic Power Plant (Dusha-Gudym 1993, 1996, 1999).

The failure at the Chernobyl Atomic Power Plant took place 17 years ago. The natural dissociation of radionuclides, reduction of the contamination level of environment are observed first of all on the territories, contaminated by Cs-137 and Sr-90 which half-value period is 30 and 28 years correspondingly. It is less than the half-value period of supertransuranic elements (the half-value period of Pu-239 is more than 24,000 years). Their vertical migration takes places simultaneously with the dissociation of radionuclides. The most part of radionuclides moved to forest litter and upper soil layers. These layers are inflammable and burn practically during all types of forest fires. The contamination of underlying peat layers takes place on peatlands. On unused areas and farmsteads radionuclides are present in upper organic and mineral soil layers and in grass (Dusha-Gudym 1999).

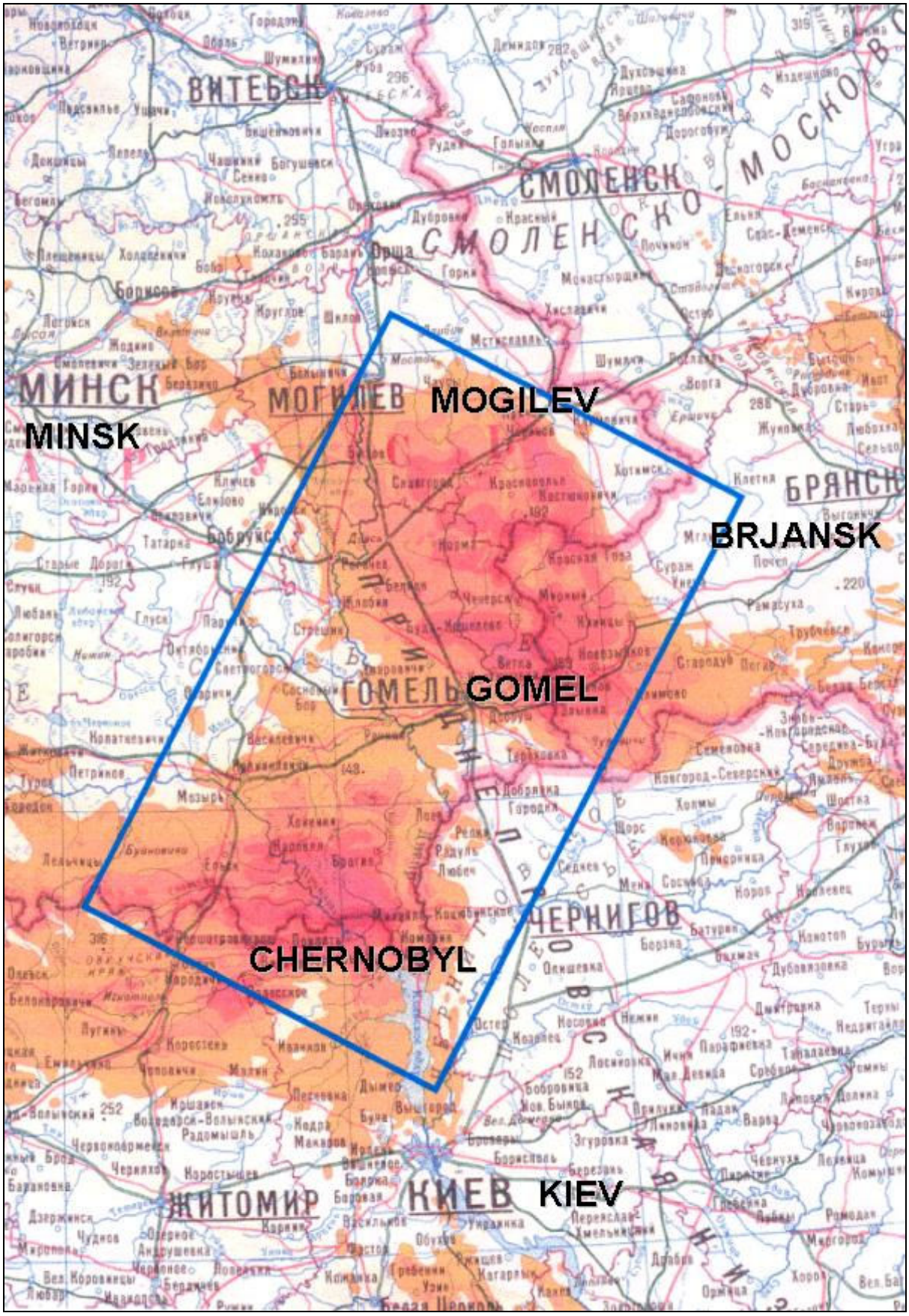

Figure 1. Map of Russia, Belarus and Ukraine most polluted by Cs-137. The area burned by radioactive forest fires in 1992 is 16 000 ha.

Practically all grass mass contaminated by radionuclides and the most contaminated upper layer of peatlands burn during fires on unused areas and on other open places. The combustion products of dry grass mass go away to smoke emission. Investigations reveal that during the forest fire all radionuclides located in the area after the failure at the Chernobyl Atomic Power Plant appear in smoke columns and in aerosols.

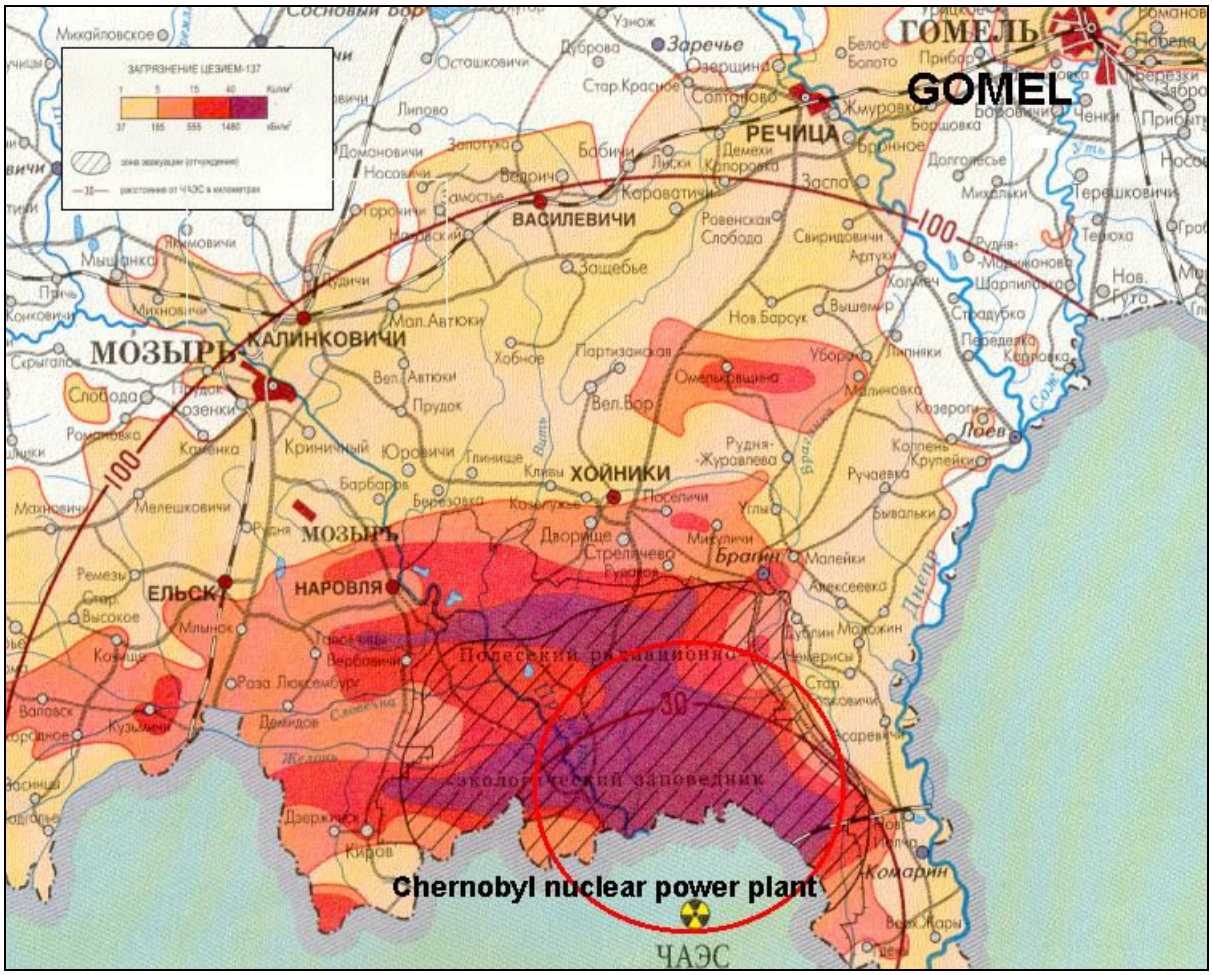

Figure 2. Map of the Polessky State Radiation-Ecological Reserve in the Gomel Region of Belarus.

Radioactive fire emissions

The radionuclide transfer with forest fire smoke to long-range distances and their fallout on large areas were realistically estimated after the forest fires in 1992. In 1992 a great number of radioactive forest fires took place in alienation zones. 12,000 ha of forest lands were burned out in the Ukrainian part of the alienation zone and 1200 ha in Belarus (Kaletnik 2002). Outside the alienation zone in the Gomel and Mogilev Regions of Belarus the forest area burnt by fires made up 870 ha. In the Bryansk Region the area of radioactive fires made up 200 ha. As a result of radionuclide transfer with fire smokes to hundreds of kilometers the content of Cs-137 in the atmosphere increased on the all territory of Russia contaminated by radionuclides. A very high increase took place in May and August during fire peaks (Dusha-Gudym 1996, 1999).

The results of investigations in the Bryansk Region have showed that peaks of fall-out of radioactive Cs on litter followed fire peaks. The fire peaks corresponded with the content of radioactive Cs in the atmosphere. The analyses of forest fire smokes have showed that the content of radionuclides in smokes exceeded the permissible rate for inhabited areas several times. Ash and not fully burnt materials remained after forest fires are open sources of the ionizing radiation. By the contamination level they correspond very often with radioactive waste. Therefore, the suppression of forest fires under the conditions of radioactive contamination should be carried out by remote methods. The suppression of burning fire edge by hand tools, especially putting out the fire with twigs is inadmissible.

The quantitative characteristics of forest fuel materials (FFM) contaminated by radionuclides and their combustion products in all zones of radioactive contamination have been received during the implementation of the first radiation and pyrological investigations in forests of the Russian Federation. The concentration levels of radionuclides in ash and in not fully burnt materials have been established as well. The results of these investigations allowed to develop a scientific basis for the fire protection system of forests contaminated by radionuclides. It could be used also for forests of Belarus and Ukraine. The affecting factors of forest fire, principles of protection and concrete practical measures for their implementation had been determined clearly. The determined dangerous factors of radioactive forest fires were included into the State Standard of Russia. The system of fire protection of forests contaminated by radionuclides is based on the position that the main dangerous factor of fires is solid and gaseous combustion products of FFM. The level of ash contamination in zones with the density of soil contamination by radioactive Cs (more than 15 Ci/km^2) corresponds with the level of contamination of radioactive waste (Dusha-Gudym 1993, 1996, 1999, 2002a).

The largest emission of radionuclides under other equal conditions is possible during general crown forest fires, when all layers of FFM are burnt out, including ground layers, and at the same time the upper mineral soil layer is destroyed. The smallest particles of upper soil layer contaminated by radionuclides accrue to radioactive ash, not fully burnt materials, smoke and aerosols generated from FFM. At the same time the emission of radioactive aerosols and radioactive ash during peat fires is considerably higher than during forest fires due to high peat ash content and large peat volumes on a unit of area. Burning peatlands are the most powerful and long-time acting sources of radioactive smokes. Therefore the prevention of peatland fires and forests fires on peatlands is one of the main measures on the reduction of emissions of radioactive smokes and radionuclide transfer (Dusha-Gudym 2002b).

The general regularities of the nature of forest fires, as well as new for pyrology aspects and physical characteristics of combustion products and processes reflecting the specificity of consequences of fires that generate greatly open sources of ionizing radiation, should serve as a scientific basis of forest fire protection on territories contaminated by radionuclides.

The general radiation characteristics of the territory and forest range, radiation features of burning objects (forest and non-forest lands of the Forest Fund), specific radioactivity of the main groups of FFM of predominant forest types under different density of contamination by radionuclides, general radioactivity of FFM stocks on the examined territory, output of solid and gaseous combustion products of FFM, characteristics of radioactive mass transfer with forest fire smokes, their vertical and horizontal migration on fire sites should be basic materials for quantitative and qualitative characteristics of FFM, solid and gaseous

combustion products, features of air environment on fire sites and working places of firefighters, as well as for ground layer of the atmosphere.

In order to receive these and some other valid materials it is necessary to carry out the permanent monitoring of forest fire situations on the territories contaminated by radionuclides. There are three stages of forest fire situations in the radiation-pyrological monitoring: 1) pre-fire situation, 2) fire, and 3) post-fire situation.

After 1992 on the most territories contaminated by radionuclides the ratio of forest and non-forest lands burnt by fires changed appreciably. In 1993-2001 a total of 770 fires were recorded on the area of 2482 ha in the alienation zone of Ukraine: forest area made up 4.4%, unused areas and estates amounted to more than 95% (Kaletnik 2002). In 1993-2000 186 fires covered the area of 3136 ha, including forest area of 1458 ha (46,5%), in the alienation zone of Belarus (Figure 3).

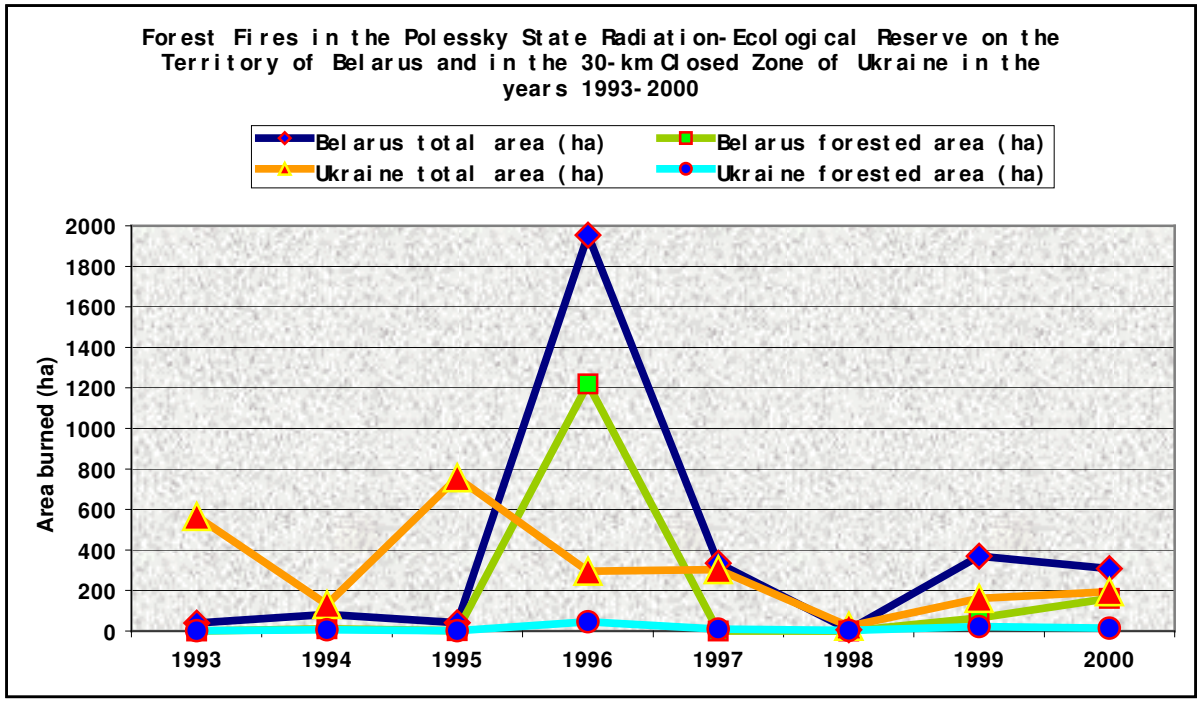

Figure 3. forest fires in the Polessky state radiation-ecological reserve on the territory of Belarus and in the 30-km Closed Zone of Ukraine in the years 1993-2000.

In 2002 a number of regions of the Russian Federation was characterized by a hard situation. In the last years 1015 fires were recorded in the Bryansk Region. The forest land area burnt by fires made up 1986 ha. After that large forest fires (over 25 ha) were prevented on the territory of the Bryansk Region contaminated by radionuclides. In the Zlinkovsky forest management unit Lleskhoz) 42 forest fires took place, the area burnt by fires made up 19.36 ha. 69 fires damaged 49,92 ha in the Klintsevsky Leskhoz. 28 fires were recorded in the Unechski Leskhoz, where the area burnt by fires made up 8.46 ha.

Management of radioactive fires

The system of the protection of forests contaminated by radionuclides should be based on materials of radiation-pyrological monitoring of forests. The monitoring results serve as a database for the forest fire protection system, especially in the organization of protection and in prevention of extraordinary forest fire situations. A special attention should be paid to prediction and registration of preconditions for beginnings of extraordinary forest fire situations (EFFS). The radiation-pyrological models of forest (RPMF) worked out for the Bryansk Region and some other regions of Russia include a basis for predictions of forest fires (Dusha-Gudym et al. 2002). RPMF allow to predict type and category of the fire, volume of burnt biomass, output of combustion products, level of their contamination by radionuclides, volume and character of measures on fire suppression, probability of the secondary radioactive contamination of the territory. Using radiation-pyrological models it is possible to define territories and parcels of the Forest Fund, where radiation consequences of forest fires could be the most severe. At present measures for fire exclusion in such places and their immediate localization are being developed.

For prevention of radionuclide transfer and protection of fire service personnel and population the following *principles of protection* are developed (Dusha-Gudym 2002b):

1. Prevention of large fires – prevention of the destruction of forests that hold radionuclides, prevention of soil destruction; prevention of formation and distribution of contaminated combustion products and soil particles.
2. Exclusion of possible contacts of people with sources of ionizing radiation.

Practical actions:

1. Restricting measures. Protection regime
2. Remote detection of forest fires
3. Remote methods of forest fire suppression.
4. Protection of the respiratory tract of personnel

Reduction of fire number in forests contaminated by radionuclides can be achieved through the reduction of the number of potential fire sources mainly through the restriction and even stopping population access to such forests. These forests are under special protection regime because they relate to the category of high fire risk. The prevention of large forest fires (in Russia – 25 ha and over) is achieved through the detection of a fire on the minimal area and immediate delivery of sufficient forces and fire-extinguishing means. To detect a fire on the minimal area the number of aircraft patrol should be increased, as well as permanent control from forest fire towers provided with TV and remote control equipment should be carried out.

The suppression of forest fires should implemented both by indirect and remote methods. The control of forest fire spread on territories, where the density of soil contamination by Cs-137 makes up 100 Ci/km^2 (3700 MBq/km^2) and where Sr-90 and Pu-239 are present, should be carried out by helicopters with water dropping equipment or by air tankers (Dusha-Gudym 2002b).

The final localization and putting out of fires are carried out by modern fire tanks of high capacity combined with cross-country vehicles, all-terrain fire vehicles and high-pressure

pumps. It is necessary to add fire retardants to water during forest fire suppression. The effectiveness of forest fire suppression by water with retardants is considerably higher than by pure water. The addition of retardants to water is especially important in suppression of peat fires.

Protection of Firefighters

The requirements for protection of forests contaminated by radionuclides are very strong. The State Standard of Russia has established criteria of the occurrence of extraordinary forest fire situation. They include forest fire covering 25 ha; forest fire on the territory contaminated by radionuclides that is not put out on the day of its occurrence; forest fire on the territory contaminated by radionuclides that generates a lot of smoke (Dusha-Gudym 2002b).

The cars and tractors used during suppression of forest fires should be equipped with the gas protection system. The current radiation dosimetric control is carried out during prevention and suppression of fires on working places of personnel. It consists in the determination of dose capacity and contamination level of working clothes, transport, machines and equipment.

The sanitary rules include the following requirements:

- the work should be carried out only in protective clothing. As overalls becomes contaminated it is to be passed to a special laundry;
- the transport used for the delivery of forest service personnel to working places is to be washed every day;
- drinking water and hot food are to be delivered to working places in closed vessels and vacuum bottles; home food should be extra packed in plastic sachets;
- after work completion overalls and footwear should be taken off, washed and packed in special bags. These bags are to be placed in an isolated compartment;
- hands, face, eyes, ears and nasopharynx are to be washed carefully. It is necessary to have some vessels with pure water thereto.

During forest fires on the territories contaminated by radionuclides their concentration in combustion products takes place. Therefore during suppression of fires, inspection of fire places, as well as in the process of fire localization and final putting out it there is need for the protection of the respiratory tract, skin and eyes from solid combustion products (ash, not fully burnt materials, smoke and dust). Hands and feet should be protected from high temperatures.

The models of protective clothes should have a minimal number of places for possible accumulation of radioactive dust. Head-dresses used for the protection of hair should be produced from materials that could be easy decontaminated.

For the protection of the respiratory tract from dust and smoke it is necessary to use disposable respirators. In case of heavy smoke generation or dust raising it is necessary to apply personal protective equipment with air forcing.

The closed protective spectacles are to be used for the protection of eyes from mechanical particles, dust and smoke.

Special foot-wear must be easy decontaminated and stable to impact of detergents. Under especially harmful conditions with a high level of radioactive contamination one should apply extra footwear that covers the main overalls.

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References

Dusha-Gudym S.I., 1993. The forest fires on the territories polluted by radionuclides. Moscow, VNIIClesresurs, 1993, 52 p.

Dusha-Gudym, S.I., 1996. The effects of forest fires on the concentration and transport of radionuclides. In: Fire in ecosystems of boreal Eurasia (J.G. Goldammer, ed.), p. 476-480. Kluwer Academic Publishers, Dordrecht, Boston, London.

Dusha-Gudym, S.I., 1999. Radioactive forest fires. VNIIClesresurs, Moscow, 160 p.

Dusha-Gudym, S.I., 2002a. To the history of the radiation and pyrological forest researches, polluted by radionuclides. In: Fire prevention, liquidation and impacts on the lands polluted by radionuclides, 13-19. Research Work Collection, Edition No. 54, Forestry Institute of the National Academy of Sciences, Belarus, Gomel.

Dusha-Gudym, S.I., 2002b. Radioactive forest fires: particularity, prevention, detection and extinguishing. In: Fire prevention, liquidation and impacts on the lands polluted by radionuclides, p. 92-100. Research Work Collection, Edition No. 54, Forestry Institute of the National Academy of Sciences, Belarus, Gomel.

Dusha-Gudym, S.I., S.E. Ogneva and B.A. Ushakov, 2002. Strategy of estimation and calculation of release of products polluted by radionuclides from forest fires. VNIILM, Moscow, 37 p.

Kaletnik N.N., 2002. Fire prevention and detection in closed zone. In: Fire prevention, liquidation and impacts on the lands polluted by radionuclides, p. 92-100. Research Work Collection, Edition No. 54, Forestry Institute of the National Academy of Sciences, Belarus, Gomel.