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

By:

***Johann Georg Goldammer**, Global Fire Monitoring Center (GFMC)*
***Valeriy Kashparov**, Ukrainian Institute of Agricultural Radiology, National University of Life and Environmental Sciences of Ukraine*
***Sergiy Zibtsev**, Regional Eastern European Fire Monitoring Center (REEFMC), National University of Life and Environmental Sciences of Ukraine*
***Stephan Robinson**, Green Cross Switzerland*

Freiburg – Basel – Kyiv – 2014

Commissioned by

OSCE Organization for Security and Co-operation in Europe

Contents

EXECUTIVE SUMMARY

More than 1250 forest and grassland fires occurred during 1993-2014 in the Chernobyl Exclusion Zone. The largest fire in 1992 burnt 17 000 ha of highly contaminated lands and required hundreds of fire fighters for its suppression. Fires burning in contaminated environments create additional non-standard risks to firefighters and may have negative health impacts on the firefighters and on the local populations. Three main types of contaminated environments are found in Europe:

- vegetation contaminated by radioactivity as a consequence of accidents occurred at nuclear power plants, such as the territories contaminated after the failure of Chernobyl NPP in 1986;
- vegetation around chemical and industrial plants contaminated by regular emissions or as a consequence of accidents, or as collateral damage resulting from armed conflicts;
- zones contaminated by unexploded ammunition in the region of former and current armed conflicts or active and abandoned military exercise and shooting ranges.

The Organization for Security and Cooperation in Europe (OSCE) commissioned the Global Fire Monitoring Center (GFMC), the Ukrainian Institute of Agricultural Radiology and the Regional Eastern European Fire Monitoring Center (REEFMC) of the National University of Life and Environmental Sciences of Ukraine, and the Green Cross Switzerland to identify and review special fire management measures, notably means for the personal protection of firefighters, for safe fire suppression in the abovementioned environments. The main reason for this report is the fact that methods and tools for efficient and safe wildfire suppression over contaminated terrain are scant. While advanced protective equipment is available for the prevention and fighting of fires in contaminated or otherwise dangerous structures, such as nuclear and chemical facilities or ammunition depots, its use for controlling extended wildfires is largely limited and mostly not possible. However, some principles and technologies used in managing fires of hazardous materials (HAZMAT) may be applicable for specific conditions of wildfire management in the Chernobyl exclusion zone, especially during suppression of wildfires near radioactive waste storage sites. Experiences gained in controlling fires over terrain contaminated by unexploded ordnance and land mines could be used for firefighting over radioactively contaminated terrain and will allow reaching better personal safety. This report provides a review of the state-of-the-art practices and equipment for safe wildfire suppression in contaminated areas and includes recommendations for improvement of radioactive safety for the firefighters. With regard to radioactive safety of firefighters the report includes:

- a compilation of best practices and guidelines on fire suppression in contaminated terrain;
- an analysis of the radioactive dose estimate during fire spread;
- an assessment of the best practices to reduce radiation exposure during firefighting and develop recommendations for personal safety.

It has been concluded that controlling wildfire in contaminated terrain is extremely dangerous and difficult. This is why investments need to be prioritized to provide the appropriate equipment and increase the preparedness and capabilities for safe and efficient wildfire control in order to reduce primary and secondary risks to firefighters and the civilian population.

The following recommendations are given:

1. Special fire management measures, personal protection means and tactics as well as appropriate health and environmental monitoring services should be identified, adapted and used for safe fire suppression in the abovementioned environments.
2. The main risks to the health of firefighters are generated by smoke from fires burning in vegetation contaminated by radionuclides and chemicals. In consequence, management has to enforce the use of

breathing protection means, as well as define and enforce exposure time limits for firefighters based on radioactive and chemical risks and prevailing use of indirect attack tactics during suppression.

3. Plans for the short- and long-term reduction of wildfire hazard and fuel management (management of combustible materials) are needed. A strategy should be developed for managing and treating gathered radioactive wood, including special incineration facilities for radioactive wood pieces with associated nuclear waste solidification and long-term storage capacities. Without such long term strategy, it will be difficult to manage forests and reduce fire risks by removing dead wood.
4. Fire service personnel in areas with nuclear or chemical contamination hazards should be properly trained and equipped to fight fires and understand these non-standard risks. A decision support system for fire suppression and air monitoring systems would allow the incident commander to control exposure time of firefighters at the fire line from the point of view of compliance with individual radioactive and chemical safety norms.
5. Firefighting in terrain contaminated by unexploded ordnance (UXO) and landmines require different means of PPE and equipment that ensures personnel protection against ballistic impacts of exploding ammunition. Several options are provided.
6. For all types of contaminated terrain the early detection, monitoring and control of fires require advanced solutions that would reduce the onsite operation and presence of humans. Remote sensing for the early detection of fires (ground-based automated and autonomously operating equipment for the rapid detection of vegetation fire smoke or heat) and unmanned, remotely controlled or autonomously operating ground vehicles or airborne systems (UAV/UAS) provide significant reduction of health risks, injuries or fatalities to firefighters. The most advanced solutions for unmanned aerial and ground firefighting merit attention for use in practice.

1. INTRODUCTION

1.1 Special features of the Chernobyl Exclusion Zone from the viewpoint of risks of vegetation fires [1]

High intensity, wide scale and diversity of modern anthropogenic activities and land use have seriously changed the fire environment by different kinds of contamination that pose additional, unprecedented risk factors to firefighters suppressing vegetation fires. From the viewpoint of vegetation fire management in the Chernobyl Exclusion Zone (ChEZ) three main cases of contamination should be taken into account for improving personal safety: radioactive, chemical and explosives. In all abovementioned cases different factors pose risks to the health of firefighters that need to be taken into account for proper training and preparedness of fire brigades, selection of personal protection means and decision making on strategies and tactics of fire suppression that will prioritize and guarantee personal safety.

Nuclear incidents with high environment contamination have a very significant impact on the fire environment. Since the 1950s, three major nuclear incidents have led to wide-scale radioactive contamination of the environment: releases from the Mayak Production Association in the region of Chelyabinsk (Southern Ural Mountains), Russia (Trabalka et al., 1980); the Chernobyl Nuclear Power Plant (ChNPP), USSR (1986); and the Fukushima NPP (2011) (Steinhauser et al., 2014). In the last two cases, exclusion zones were established for the most contaminated areas around the damaged reactors. The Chernobyl disaster case is the most dangerous and problematic one from the viewpoint of fire management due to the large scale, high levels and long-term nature of contamination. Most of the contaminated areas covered with fire prone Scotch pine forests and grasses are located on the territories of Ukraine, Belarus and Russia. The rapid growth of numbers of newly constructed nuclear energy facilities, particularly in the Asia-Pacific Area, leads to an increasing probability of accidents in the future and therefore calls for better documentation of available experience of the management of existing radioactive contaminated territories.

Current fire regime and risks in the Chernobyl Exclusion Zone (ChEZ) are determined by ignition sources, vegetation types, their distribution and dynamics, as well as intensity and aspects of forest and fire management. Recently, climate change became another important factor that does not allow the prediction of maximums severity and consequences of fires. Additional factors that need to be taken into account during suppression are intensity of radioactive and chemical contamination of soil, vegetation and debris that determine level of smoke contamination and impact on personal safety.

A special permission regime was established after the disaster of 1986 delimiting the most contaminated 10-km zone as well as 30-km zone around the ChEZ. Later the EZ was extended toward the west side and currently covers an area of 260,000 ha. At the moment around 60-70 % of the EZ is fenced while the rest is freely accessible, thus creating favorable conditions for illegal crossing of vehicles or visitors into the EZ territory. To avoid illegal penetration of visitors, the police regularly patrols the perimeter, which is still not very effective in keeping the exclusion regime. More than 1250 vegetation fires of different types, severity and scale were registered officially in ChEZ from 1993 to 2014. The most severe fires occurred in August 1992 when up to 17,000 ha of grass and forest fires (including crown fire with an area of more than 5,000 ha) burned all over the territory of the ChEZ including the most contaminated core part (Fig. 1).

[1] Author: S. Zibtsev

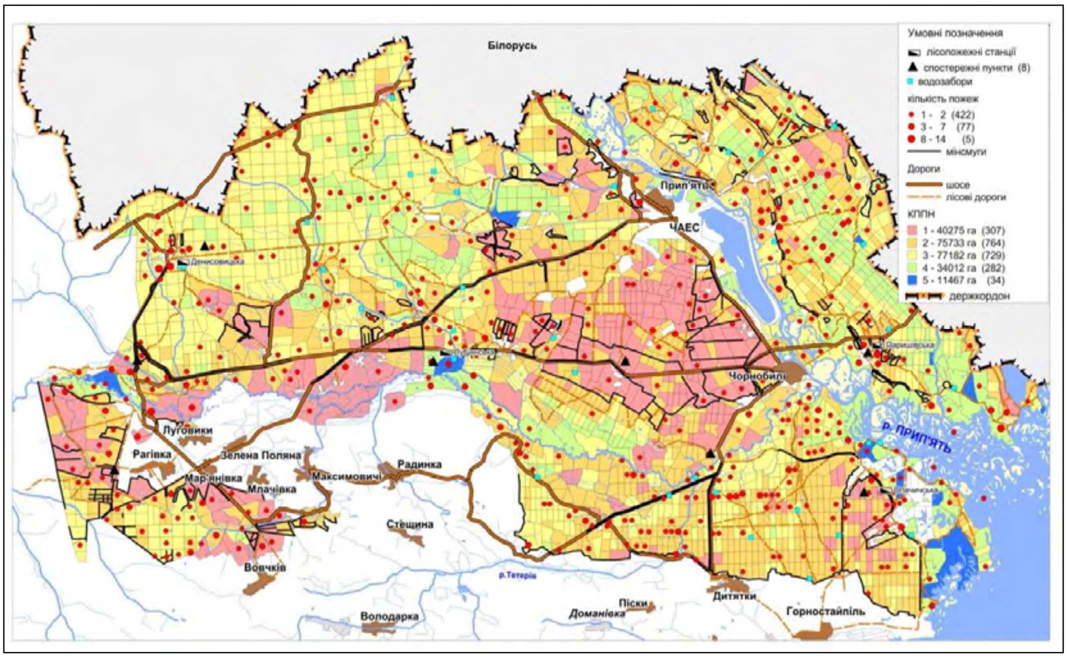


Figure 1. *Fire locations and land distribution of the ChEZ according to Ukrainian fire hazard classes*

Satellite images in May 2003 show numerous forest fires in the ChEZ and surrounding territories with different contamination levels, which brought radioactive smoke toward the city of Kyiv (Fig. 2). The vegetation in the ChEZ is a mosaic of forested (65 %) and grass lands that is fire-prone during all seasons with the maximum fire hazard being in April-May and in August (Fig. 3).

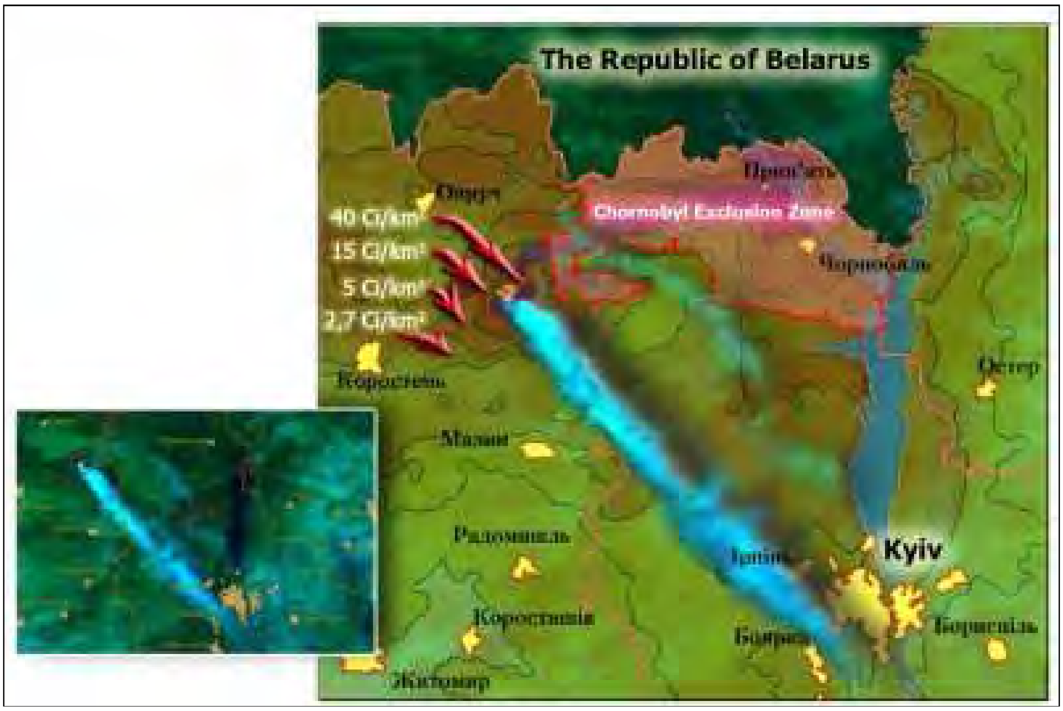


Figure 2. *Fires burning in and around the ChEZ over lands with different levels of contamination as well as smoke plume toward Kyiv*

Figure 3. *Typical fire prone vegetation types in the ChEZ: pine forests and grasslands with developing natural regeneration of trees. Nuclear facilities are located in the forested territories*

Due to the absence of any use of lands in the ChEZ, dynamics of most vegetation types follows typical succession pathways that lead to intensive fuel accumulation. Large areas of middle-aged pure pine plantations are destroyed by diseases and insects and then remain overcrowded with high loads of surface fuels due to the absence of thinning (Fig. 4). In many cases, this has resulted in the formation of a new generation of forests that are more fire prone due to larger continuous unthinned areas of vertical fuels as compared with previous stand generations (Fig. 5).

The lack of thinning in the ChEZ (less than 10 % of the required levels) determines overcrowding of pine forests all over the territory and increases the risks of high-intensity fires, crown fires and large wildfires. Existing fire management capacity, structure and location do not correspond to this high fire hazard and will not guarantee fast response and effective suppression in case of critical weather conditions. For example, one fire station with 2-3 fire trucks and up to 5-7 firefighters holds responsibility for an area of more than 65,000 ha, while outside the ChEZ, the area of responsibility value is 15-20 times less (3-5,000 ha). Only around 70 % of the area is covered by a fire detection system (lookout towers with observers). Nearly 23,000 ha of fire prone forests in the ChEZ is not accessible to fire trucks or fire brigades at all. All of the abovementioned factors determine high risks for the personal safety of firefighters, which requires special attention to their Personal Protection Equipment (PPE), the use of special equipment and also the strategy and tactics of firefighting.

Figure 4. *Pine forests (55 years old) destroyed by insects resulting in high surface fuel load (Leliv Forest Ranger District, 10-km Zone)*

Figure 5. *Fire prone complex of vertical, well-structured pine forests damaged by snowfall with natural regeneration of pine*

2.1 Challenges for policy makers[2]

There are only a few countries in the world that have a systematic approach in place to address the problem of the consequences of wildfire burning on terrain contaminated by radionuclides, chemicals and weapons – be it relevant policies or technologies. This is why an international dialogue on “Dangerous Fires on Contaminated Terrain” was initiated in 2009. An international seminar made history by addressing the problem of “Wildfires and Human Security: Fire Management on Terrain Contaminated by Radioactivity, Unexploded Ordnance (UXO) and Land Mines” (October 2009, in Kyiv and Chernobyl, Ukraine). It provided new insights into phenomena and problems arising from fires burning in radioactively contaminated terrain in the Eurasia biota. The most severe problems are in the territories of Ukraine, Russia, and Belarus, which were highly contaminated by the failure of Reactor 4 of the Chernobyl Nuclear Power Plant. Traces of radioactivity from Chernobyl are found in emissions from wildfires burning in Siberia and Central Asia and are transported long-range and intercontinentally. Wildfire incidents in the U.S.A. have threatened nuclear test facilities but so far have not resulted in severe contamination.

Reports from post-war countries revealed the magnitude of unexploded ammunition and land mine contamination in forested and other lands. Reports on fires burning in former military exercise and shooting ranges reveal that unexploded ordnance is potentially very dangerous and has repeatedly resulted in firefighter casualties.

The seminar called on its host – the government of Ukraine – and the auspices of the seminar, the Global Fire Monitoring Center (GFMC), the Council of Europe (CoE), OSCE / ENVSEC, the UNISDR Regional Southeast Europe / Caucasus and Central Asia Wildland Fire Networks, and the UNECE / FAO Team of Specialists on Forest Fire to address the problems. The 2009 “Chernobyl Resolution on Wildfires and Human Security: Challenges and Priorities for Action to address Problems of Wildfires burning on Terrain Contaminated by Radioactivity, Unexploded Ordnance (UXO) and Land Mines“ recommended to develop policies and practices related to fire management on contaminated terrain. [3] Since then, decisive steps have been taken to explore methods and technologies to deal with fires on contaminated terrain.

[2] Author: Dr. Goldammer

[3] See summary of seminar contributions and the Chernobyl Resolution published in UNECE / FAO International Forest Fire News (IFFN) No. 40 (2010), pp. 76-113. (http://www.fire.uni-freiburg.de/iffn/iffn_40/content40.htm)

2. DANGEROUS FACTORS FOR FIREFIGHTERS SUPPRESSING VEGETATION FIRES OVER CONTAMINATED TERRAIN AND POTENTIALLY NEGATIVE HEALTH EFFECTS

2.1 Heat [4]

Heat is one of the main threats to firefighter's health during fire suppression. A large number of studies were performed to study physiological responses of the body to continuous exposure to heat of different intensity levels (Adolph, 1947; Cuddy et al. 2008; Hendrie et al., 1997; Ruby et al., 2003; Sharkey, 2004). The highest threat of heat impact on a firefighter starts when the ratio between heat gain and heat loss is out of balance. As a result, a number of serious injuries and illnesses can occur, in particular heat cramps, heat exhaustion and heat stroke. Symptoms and factors of the above-mentioned heat induced injuries were described by Domitrovich and Sharkey (2010).

Heat cramps take place both during and after suppression in the arms and legs. The main cause is dehydration and electrolyte imbalance. Dehydration, sweating, muscle cramps, and fatigue are observed. In such case, the firefighter should be suspended from activities. For recovery it is recommended to: rest in the shade to rule out muscle injury, stretch and massage the affected muscles, check the amount of water the firefighter has consumed. In case of dehydration, unhurried consumption of sports drinks with electrolytes and carbohydrates and/or salty foods is also recommended. In most cases, affected firefighters will be able to return to work during the shift after they are properly hydrated and have had some rest.

When the cardiovascular system is unable to maintain adequate blood and water circulation, heat exhaustion is usually observed. Usually a firefighter is not feeling strong enough to fight the fire around the fire line. From a physiological point of view, heat impact stimulates sweating, followed by depletion of water and electrolytes and a decrease in total blood volume. As a result, this radically reduces the ability of the blood to transport oxygen and nutrients to the muscles. Symptoms are more serious and include dehydration, headache, profuse sweating, lightheadedness or dizziness, nausea, cool, clammy skin, fatigue or weakness. Actions needed to recover include the following: withdrawing the firefighter from the fire line, resting in the shade, removing the firefighter's clothing, laying down and elevating the firefighter's legs. Heart rate, blood pressure, respiratory rate and level of alertness must be monitored. If the firefighter can safely swallow and is not vomiting – slowly give fluids. Most firefighters with mild heat exhaustion will recover with no need for accommodation in a health care facility if they stop working, but they should return to work not earlier than in 24-48 hours. Firefighters with severe heat exhaustion should be seen by a physician.

Heat stroke can have much more serious effects. It is characterized by the loss of the body's ability to use its temperature regulating system. Heat stroke is life threatening. As a result of heat stroke, body temperature increases above 40°C. Heat stroke impacts cell functions and results in the release of cytokines that break cellular communication, causing local or whole body inflammation. Among the typical symptoms observed are irrational behavior, loss of alertness, weakness, hot, wet or dry skin, tachycardia with rates higher than 100 while resting. The blood pressure decreases while hyperventilation increases. Immediate actions must include: suspending the firefighter from work, placing the firefighter in the shade, removing the firefighter's clothing, immersing the firefighter in water (in a stream or water tank). The firefighter should be immediately evacuated from the fire line, assuming it can be done safely. Returning to work, at the earliest, may take place after one week following doctor examination and rehabilitation.

Summarizing the abovementioned, it needs to be underlined that when fighting a fire in a contaminated environment, **heat, most of the time, is a minor factor affecting the health of firefighters compared to contaminated smoke directly affecting respiratory organs** (radioactive, chemical) or explosives directly

[4] Author: S. Zibtsev

affecting physical life. Therefore, firefighters need to be aware and trained to avoid heat stress but most attention needs to be directed toward smoke, radiation and explosion protection.

2.2 Chemical elements [5]

There are a number of extended researches devoted to the issue of contamination of vegetation fire smoke (VFS) by different chemical elements and gases (Kelly, 1992; Reh and Deitchman, 1992; Lacaux, 1995, Ward, 1999; McDonald et al., 2000; Muraleedharan et al., 2000; Heil and Goldammer, 2001; Shauer et al., 2001; Ward and Smith, 2001; Radojevic, 2003; Booze et al., 2004; Miranda, 2004; Reinhardt and Ottmar, 2004; Koppmann et al., 2005; Statheropoulos and Karma, 2007; Bytnerowicz et al., 2009; Goldammer et al., 2009).

According to recent studies, vegetation fire smoke includes many elements and their compositions. Among them, most importantly, are water vapor, permanent gases, volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs) and different particles. Permanent gases are CO_2, CO, NO_x, SO_x and NH_3. Due to usually low sulfur concentration, SO_x is a relatively low health risk. But at the same time if vegetation grows on soils with a high content of chemically available sulfur (both naturally occurring [volcanic] or artificial [contaminated land near coal burning power plants and other industrial complexes]) high amounts of sulfur-based compounds are released. For example, considerable concentrations of SO_2 and H_2S were produced during fires burning in Yellowstone National Park. NH_3 has been detected in Savannah fires. The emission ratio of NH_3 relative to CO_2 has been identified and found to be at low levels; NH_3 is mostly emitted during the smoldering and not during the flaming phase of combustion.

Methane and various VOCs are actively formed during fires. In particular, such chemicals as alkanes, alkenes and alkynes were identified, which temporary appeared during formation of ethane, heptane, decane, propene, acetylene and other gases. More dangerous to health are benzene and alkylbenzenes, in particular toluene, xylene and ethyl-benzene. The interaction of abovementioned chemicals with oxygen during burning processes results in the generation of phenol, m-cresol, p-cresol, guaiacol, aldehydes (formaldehyde, acetaldehyde, benzaldehyde), ketones including acetone, acetic acid, benzoic acid, methyl ester, etc. In addition, during fires in pine forests, chloromethane was detected in the produced smoke. Chloromethane has been identified as the most abundant halogenated hydrocarbon emitted during biomass burning, mainly consisting of dead and living vegetation. Among the SVOC groups, generated by vegetation fires with high amount of smoke, the most dangerous for health is benzo[a]pyrene.

If a fire occurs on soils with considerable salt contents, the thermal separation of the chlorine atom from the salt molecule (NaCl) will lead during the cooling process to the formation of dioxins, one of the strongest known cancer-causing substances.

During burning vegetation fires, large amounts of particles with different sizes are created. The impact of particles very much depends on their size. Depending on the fire intensity and vegetation type, particle sizes can vary from coarse (>PM10) to fine (PM2.5, PM1, >PM1).[6] From a chemical point of view, particles consist of carbon or organic carbon particles. The latter one, known as black carbon (soot), is a product of the incomplete combustion of carbon-based materials and fuels (CEPA, 1999). Recently, the long distance impact on Arctic ice by black carbon was studied. **The health impact of smoke largely depends on fire temperature.**

[5] Author: S. Zibtsev

[6] Particulate matter (PM) or particulates is microscopic solid or liquid matter suspended in the atmosphere. Subtypes of atmospheric particle matter include *suspended particulate matter* (*SPM*), *respirable suspended particle* (*RSP*; particles with diameter of 10 micrometers [µm] or less), *fine particles* (diameter of 2.5 µm or less), *ultrafine particles* (less than 100 nanometers [nm, or 0.1 µm] in diameter) and *soot* (impure carbon particles resulting from the incomplete combustion of a hydrocarbon).

During combustion processes hot vapors are produced. The latter interact with chemicals in the air, thereby forming new particles, usually below 0.1 µm in diameter which are especially dangerous to the lungs. Low-volatility products including some radionuclides either nucleate or condense on the surfaces of particles, yielding particles in the size range of 0.1-1.0 µm, which pose additional threats. Most trace elements, both of natural or anthropogenic origin, migrate with particles during vegetation fires, such as Na, Mg, AL Si, P, S. CI, K, Ca, Ti, Mn, Fe, Zn, Rb, Sr, V, Pb, Cu, Ni, Br, Cr and others. **These elements usually concentrate in fine fraction and therefore easily reach the lungs and the blood system of firefighters**.

During vegetation fires inside the 5-6 km zone around chemical industrial plants (fertilizer production and others) more complicated mixtures may be formed depending on the fire intensity. **In case of crown fires followed by high temperature, most smoke rises up to the upper layers of the atmosphere and the level of chemical impact on firefighters is lower.** In contrast, during **ground fires of low intensity, most of the smoke stays near the ground thus exposing firefighters**, especially from the side of the flame-front expansion. Other types of fuels and/or materials may contribute to chemical loads in the smoke, when for example, vegetation fire is expanding to former agriculture fields, nuclear infrastructure and waste storage places. Other waste materials buried in forests like wood, plastics, fertilizers may burn, and materials, such as pulverized glass, cement dust, asbestos or plaster and other chemical compounds may appear in the produced smoke. This requires taking into account spatial distribution of chemical contamination when tactics of firefighting are developed and applied.

2.3 Smoke [7]

According to the definition, vegetation fire smoke (VFS) is an aerosol in the form of a colloidal system composed from a mixture of dispersed phase and solid or liquid particles in the air (Johnson, 1999). The threat level posed by smoke to firefighter health depends on many factors and their combination. First of all, it is the chemical toxicity itself, followed by the intensity of burning and level, duration and frequency of the exposure. The heaviest impact on the firefighters is taking place during the front flame attack. Extended analysis and overview of the main dangerous factors from smoke is provided in a number of publications (Malilay, 1998; Heil and Goldammer, 2001; Radojevic, 2003; Bytnerowicz et al., 2009; Goldammer et al., 2009). Some background information about the main smoke causes is presented below that should be taken into account when organizing the suppression of vegetation fires and most importantly on terrain with chemical contamination.

Particles in smoke are one of the main factors impacting the breathing apparatus and require Personal Protection Equipment (PPE). The solid components of smoke with respirable size particles easily migrate inside the body with the breathing air. As was mentioned above, particles are differentiated into two categories: fine particles with an average diameter of 0.3 micrometers (µm) and coarse particles with an average diameter larger than 10 µm. Even at low concentrations, fine particles may cause changes in lung functions that in the long term can lead to a higher possibility of development of respiratory and cardiovascular illnesses including asthma. Fine particles usually affect alveoli and concentrate there. Under the conditions when the lungs are not sufficiently cleared naturally, high pollutant concentrations may enter the bloodstream or remain in the lungs, resulting in chronic lung diseases such as emphysema. As it was mentioned earlier, chemicals absorbed by airborne particulates contain numerous toxic elements which have considerable carcinogenic effects.

The impact of smoke on health directly depends on the size and type of the vegetation fire. According to the assessments, particles during the fire are produced very intensively – at least 0.6 tons per second and higher rates, and thus, the **health impact depends on the intensity of the fire and the wind direction**. **40 to 70 % of fine particles consist of organic carbon material, containing known carcinogens.** 2-5 % is graphitic carbon; the remainder is inorganic ash. Particles carry absorbed and condensed toxicants and free radicals, for

[7] Author: S. Zibtsev

example, polycyclic aromatic hydrocarbons (PAH). Their health effects are determined by their chemical composition, consisting of a group of organic compounds with two or more benzene rings, such as methyl anthracene, pyrene, chrysene, benzo[a]anthracene, fluroranthene, and methylchrysene. Benzo[a]pyrene is considered the most carcinogenic compound. Low intensity backing fires (upwind direction) are found to produce larger amounts of benzo[a]pyrene than heading fires, which move into new fuel in the same direction as the wind movement. This fact essentially decreases the possible tactics of suppression and requires to minimize the amount of time the firefighters are exposed to smoke even in cases when backfires are used. Fuel characteristics also affect the production of PAHs during combustion. The emission of benzo[a]pyrene increases as the density of live vegetation covering the fire area thickens. **The emission rates for PAHs were observed to be highest for temperatures in the range of 500-800°**C, and were consistent with the results from a study of PAHs released in low intensity backing fires.

Carbon monoxide (CO) is the main cause of fatalities during vegetation fires. It is related both to firefighters and civil population that are sometimes trapped by the fire. The mechanism of health impact by carbon monoxide gas is related to tissue hypoxia preventing the blood from carrying sufficient oxygen. The threat level depends on the concentration. Low and medium concentrations result in impaired thinking, headaches, slow reflexes, reduced manual dexterity, decreased exercise capacity, and drowsiness. High concentrations may cause fatality. Carbon monoxide concentration closely correlates with concentration of other compounds in the smoke, including particles and formaldehyde. In most cases, CO concentrations depend on fire intensity and range from 60 g/kg in low intensity fires to more than 300 g/kg of fuel consumed during high intensity fires. Among the important factors that determine the intensity of emission is the type of vegetation and moisture content. In every country there is an official health risk threshold. In Ukraine, if the duration of exposure is less than 1 hour, the limit is 50 mg/m^3, less than 30 minutes – 100 mg/m^3, and less than 15 minutes – less than 200 mg/m^3.

Aldehydes that rise into the atmosphere during the fire are primarily irritating the mucous membrane. Most dangerous is formaldehyde, which may be carcinogenic in combination with other chemicals such as PAHs. Formaldehyde and acrolein are the main aldehydes released during vegetation burning. Formaldehyde, which is probably the most abundantly produced chemical compound of this class, causes eye, nose, and throat irritation during smoke exposure. It is highly likely that acrolein is an irritant in smoke near fire lines, with concentrations as high as 0.1 ppm to 10 ppm near fires.

During the active phase of vegetation fire, organic acids are formed as a result of formaldehyde oxidation. Health effects mostly include irritation of mucous membranes. **Using water for suppression, or under conditions of high humidity, can stimulate production of such organic acids as formic acid, acetic acid and others.**

SVOCs and VOCs cause skin and eye irritation, drowsiness, coughing and wheezing. Most dangerous are benzene, benzo[a]pyrene, 1.3-butadiene as they are genetoxic carcinogens and their impact may have long term carcinogenic effects on firefighter health.

One of the most important chemical processes that impacts health is free radicals that intensively form during vegetation fires. Free radicals, firstly, migrate to human tissues within 20 minutes after burning and pose a problem for firefighters exposed to freshly formed aerosols.

While fuel is combusting during vegetation fires, ozone is an extremely reactive oxidant that forms in the breathing zone near the fire line. **In case of the ozone concentration exceeding the allowable threshold, it negatively impacts lung functions, essentially reducing the resistance to infectious diseases. Firefighters with chronic respiratory illnesses should not be called to fight fires in this case**. Several hours of intensive physical activity at the fire line, even in case of only low concentration of ozone, has negative effects: as ozone is accumulated in tissues, the respiratory rate increases. In this case, ozone causes such symptoms as coughing, shortness of breath, excess sputum, throat tickle, raspy throat, nausea, and impaired lung function. In the long-term, perspective impact of ozone on health may consist of suppressed lung functions and chronic obstructive pulmonary disease. The highest threat of ozone impact is related to grass fires with low flame length under the condition of sunlight and when smoke is concentrated in valleys or in places with a temperature inversion.

Inorganic elements may cause certain effects on health. Surface fuel on the territories near big cities or around industrial plants is usually contaminated by heavy metals, in particular lead, asbestos, and sulfur. The health impact of inorganic elements is usually low, as they are present in trace concentrations in fuel and smoke particles, but at the same time it largely depends on the chemistry of fuels burned and the intensity of the vegetation fire. As most of the roofing in rural areas of Ukraine is done using asbestos, this compound is widely distributed in surface fuel and in the air around settlements. During vegetation fires, asbestos fibers are carried with the smoke and produce a secondary contamination of the environment. Of other trace elements, potassium is registered in relatively high concentrations primarily in cases when branches are burning in the wood. **The migration of the most part of these elements into the breathing pathways of firefighters in most cases can be reduced essentially by using proper PPE, first of all, special face masks or respirators**.

2.4 Radiation[8]

Radioactivity is a natural phenomenon and natural sources of radiation are features of the environment. Radiation and radioactive material may also be of artificial origin after nuclear and radiological accidents.
Three main types of radiation after contamination of environment, each with different properties and health pathways and impacts, exist:

- alpha (α) particles: is a particle radiation consisting of helium nuclei. Alpha particles have a low penetration depth and can be stopped by a few centimeters of air or by the skin. They are a major health risk if inhaled or ingested, because large exposures can result in nearby tissues, such as the lining of the lung or stomach.
- beta (β) particles: is a particle radiation consisting of high energy electrons. They have a medium penetration depth, shielding materials with low atomic numbers are more efficient for stopping them (plastic, glass, or metal). Such emitter does not normally penetrate beyond the top layer of skin. However large exposures to high-energy beta emitters can cause skin burns. Beta particles are a major health risk if inhaled or ingested.
- gamma (γ) rays: is very high energy electromagnetic radiation with a high penetration depth, reuiring potentially massive shielding (e.g. lead). Gamma rays pose mainly a risk of external irradiation to internal organs without inhalation or ingestion.

Radiation doses of different sizes, delivered at different rates to different parts of the body, can cause different types of health effect at different times. The amount of energy that ionizing radiation deposits in a unit mass of matter, such as human tissue, is called the ***absorbed dose***. It is expressed in a unit called the gray, symbol Gy (1 Gy=1 joule per kilogram, 1 mGy=0.001 Gy). 1 Gy to tissue from α-radiation is more harmful than 1 Gy from β- or γ-radiation, because an α-particle, being slower and more heavily charged, loses its energy much more densely along its path. The ***equivalent dose*** is equal to the absorbed dose multiplied by a factor that takes into account the relative effectiveness to cause biological harm of different radiation types. This radiation-weighting factor is 1 for β- or γ-radiation and 20 - for α-radiation. The equivalent dose is exp equivalent ressed in a unit called the Sievert, symbol Sv (1 Sv=1000 mSv= 1000000 µSv). For example, the average effective dose rate from all natural sources of radiation (background level) is 0.1-0.3 µSv per hour. Such levels of equivalent dose rate observed in Europe and in most parts of Chernobyl exclusion zone, including the Chernobyl town. Now the maximum values of equivalent dose rate are on the most

[8] Authors: St. Robinson (health risks) and V. Kashparov (internal and external doses)

contaminated areas (up to 100 µSv per hour) near ChNPP. Effects of exposure of different human organs can be very different, for example, due to the different distribution of radionuclide in the body. The sum of weighted equivalent doses (the equivalent dose in each of the major tissues and organs of the body multiplied by a weighting factor related to the risk associated with tissue or organ) is a quantity called the ***effective dose***: it allows us to represent the various dose equivalents in the body as a single number. The effective dose also takes account of the energy and type of radiation, and therefore gives a broad indication of the detriment to health. Moreover, it applies equally to external and internal exposure and to uniform or non-uniform irradiation. The effective dose unit also is the Sievert, symbol Sv (1 Sv=1000 mSv=1 000 000 µSv). For example, the effective dose from all natural sources of radiation is, on average, 2.4 mSv in a year.

Radiation can destroy molecules in the body, thereby disturbing the proper functioning of its metabolism. It can also generate DNA modifications, which can potentially have long-term consequences. The two types of radiation impacts are distinguished:

- short-term consequences: appear only above a threshold equivalent dose. The damage is in the function of the absorbed radiation dose. This can include (in growing order of severity) headaches, increased risks of infections, lack of appetite, fatigue, loss of hair, sterility, diarrhea, collapse of body functions, death. These types of effect are called deterministic effects;
- long-term consequences: may appear years after absorbing a small effective dose. According to the existing knowledge, there is no threshold dose. The changes in DNA can lead to cancer or genetic anomalies. These types of effect are called stochastic effects. The 'detriment-adjusted nominal risk coefficient of dose', which includes the risks of all cancers and hereditary effects, is 5% per sievert (Sv).

The radiation risks to people and the environment must be assessed and controlled through the application of standards of safety (International Basic Safety Standards -BSS) by means of dose limits for planned exposure situations to ensure:

- preventing the occurrence of deterministic effects in individuals exposed to radiation;
- restriction on the acceptable level of probability of occurrence of stochastic effects.

For occupational exposure of workers over the age of 18 years, the dose limits are:

- an effective dose of **20 mSv** per year averaged over five consecutive years (**100 mSv in 5 years**), and of **50 mSv** in any single year;
- an equivalent dose to the lens of the eye of 20 mSv per year averaged over 5 consecutive years (100 mSv in 5 years) and of 50 mSv in any single year;
- an equivalent dose to the extremities (hands and feet) or the skin of 500 mSv in a year.

There are additional restrictions apply to occupational exposure for a female worker who has notified pregnancy or is breast-feeding.

For public exposure, the dose limits are:

- an effective dose of **1 mSv** in a year;
- in special circumstances, a higher value of effective dose in a single year could apply, provided that the average effective dose over five consecutive years does not exceed 1 mSv per year;
- an equivalent dose to the lens of the eye of 15 mSv in a year;
- an equivalent dose to the skin of 50 mSv in a year.

The effective dose limits apply to the sum of the relevant doses from external exposure in the specified period and the relevant committed doses from intakes in the same period.

Different radionuclides are especially relevant from a health perspective. In the ChEZ, radiation levels are dominated by radiocesium (^{137}Cs) and radiostrontium (^{90}Sr), which are both beta-emitters, barium (^{137m} Ba), a gamma-emitter, and plutonium (^{238,239,240}Pu) with americium (^{241}Am), which are alpha-emitters. External dose rate depends on the density of contamination territory with ^{137}Cs. The airborne radionuclide concentration during fires may increase. Inhalation of alpha-emitting radionuclides (^{238,239,240}Pu and ^{241}Am) is the main source of internal radiation doses. The proper protection of firefighters shall include:

- protection from incorporation of particles through the mouth, nose and eyes (by wearing face masks and protective clothing),
- protection from external gamma-radiation (through limiting the time of stay and reducing work outside of vehicles as much as possible), as well as
- immediate and proper decontamination of clothing and equipment at the end of operations.

Protective actions to reduce existing or unregulated radiation risks must be justified and optimized.

As a result of ChNPP accident, the 30-km exclusion zone (EZ), and a zone of absolute resettlement prohibition (ZAR) of ChNPP has received the greatest radioactive contamination. Medium-living and long-living radionuclides ^{90}Sr, ^{137}Cs, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Am (Tab. 1) are expected to be the main radiological hazard at present and in the coming future decades. At the moment of release, the main share of ^{90}Sr, ^{238}Pu, ^{239}Pu, ^{240}Pu and ^{241}Am was contained inside the matrix of the irradiated nuclear fuel particles – fuel components of the Chernobyl radioactive fallout (Kashparov et al., 2001; Kashparov et al., 2003). Due to this fact, maps on contamination density of the ChNPP near zone area with theses radionuclides seem to be similar (Fig. 8 a, c, d).

Fuel particles (FP) were formed as a result of nuclear fuel dispersion at the moment of initial explosion and further oxidation in the air (Kuriny et al., 1993; Kashparov et al., 1996). The density of fuel particles in size ranges from a few to hundreds of microns reached 8-10 g/cm^3. That resulted in a high fallout rate of FP from the radioactive cloud, and a rapid decrease of radioactive contamination by heavy FPs of the ChNPP zone over distance.

As opposed to heavy radionuclides of the nuclear fuel, volatile high-mobile ^{137}Cs evaporated mainly at the high-temperature annealing of nuclear fuel, and the following condensation on various carriers (condensed component of the Chernobyl radioactive fallout); that has brought to a principally diverse pattern of radioactive contamination of the terrain (Fig.8b).

The density of area contamination with the i-th radionuclide at the specific moment of time (A_s^i) is a basic initial information to assess the levels of radioactive contamination of flammable material and evaporation of radionuclides during burning; and the same, as well, for calculating equivalent dose rates for external irradiation, and effective doses of internal irradiation formed due to inhalation intake of radionuclides in cases of forest and meadow fires.

External dose of irradiation of firefighters is created mainly (more than 99 %) by gamma-irradiation by ^{137}Cs and ^{137m}Ba contained in litter, forest stand and top, mineral soil layer (Table 1). **At present, pine forests litter may contain up to 50 % of ^{137}Cs activity and up to 20 % of ^{90}Sr from their total content in biogeocoenosis** (Ipatiev, 1999; Yoschenko et al., 1996; Shityuk, 2011). Full-profile thick litters of coniferous forests are characterized by the biggest retentive capacity (up to 50 % of activity), and thin litters of deciduous forest by the minimum (less than 1 % of activity). At present time, more than 75 % of radionuclide activity in litter is concentrated in a layer adjoined to the mineral layer of soil, namely, in decayed or half-decayed layers (Sheglov, 2000; Perevolotsky, 2006).

In addition, currently, up to 20% of ^{137}Cs activity in mature pine forests may be found in forest stands (more than 50% in wood and about 20% in bark). Together with the high content of radiocaesium in litter, characterized by its weak shielding of gamma-irradiation, it can significantly affect the formation of equivalent dose rates (EDR) for external human irradiation (Kashparov, 2014).

In an area homogenously contaminated with ^{137}Cs, EDR content in the air of such forests may be up to 1.5 times higher than in woods and meadows, where the main part of radiocaesium is contained in the top 5-cm mineral layer of soil.

The effective dose rate from external gamma-irradiation of radionuclides P_{ext} (µSv/hr) contained in 5-cm mineral layer of soil can be calculated as:

$$P_{ext} = 0.77 \cdot k \cdot \sum_{i=1}^{6} A_s^i \cdot B_{s\gamma}^i , \quad (1)$$

Where 0.77 – factor of equivalent dose conversion to effective dose per adult human; k – shielding factor equal to k=1 in open space, and k=0.1÷0.5 inside transport (tractor, auto et al.); $B_{s\gamma}^{i1}$ - dose factor equal to ratio of EDR (µSv/hr) to density of area contamination with the i-th radionuclide (A_s^i , kBq/m^2) accumulated in the 5 cm mineral layer of soil (Eckerman and Ryman, 1993) – Table 1.

The expected effective dose from external gamma-irradiation D_{ext} (µSv) of radionuclides contained in the 5-cm soil layer, during **t** hours period for an adult human, is equal to:

$$D_{ext}(t) = P_{ext} \cdot t \, . \quad (2)$$

The dose of internal irradiation for firefighters can be formed due to inhalation intake of radionuclides through respiratory organs. At the time of fire, high-temperature evaporation of radionuclides occurs as well as small-dispersed radioactive aerosol appears due to ash-formation and radionuclides condensation on various carriers (Yoschenko et al., 2006; Kashparov et al., 2000). All these facts are accompanied by a rise of above-ground radionuclide concentration in the air, up to hundreds and thousands times higher than the normal levels (Kashparov et al., 2000; Yoschenko et al., 2006).

Currently, large parts of ChEZ and ChZAR territory are covered with forests, where ordinary pine and birch trees prevail (64% and 23%, respectively). Specific activity of the i-th radionuclide in grass and structural components of forest stands (wood, bark, branches, needles/leaves) can be estimated based on the data of the areal density of contamination with the i-th radionuclide and its transfer factor values from soil to dried components of flammable material for various species of trees or meadow grasses (IAEA, 2010).

In cases of meadow and forest fires, forest litter or a layer of meadow litter represented by non-mineralized grasses of meadow is an important source of radionuclides release. The yield of dry crops in meadows of ChEZ and ChZAR reaches 0.2-0.3 kg/m^2 usually; ^{90}Sr and ^{137}Cs content in crops and litter in regard to respective soils does not exceed 1 %; ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Am content would be even more than 10 times lower due to small values of soil-plant transfer factor (IAEA, 2010; Paskevich, 2006). **The part of flammable material, which is burnt, depends on the type of fire and fire risk at various weather conditions, and varies from 0% for wood to 97% for needles/leaves. Evaporation of most volatile ^{137}Cs from the burnt flammable material will range from 25 to 75%.**

To estimate the expected internal effective dose of human irradiation due to radionuclides inhalation intake into human organism, at the forest fire in the period of time ***t***, it is necessary to know the integral, medium concentration of the i-th radionuclide in the area of human respiration, dispersed composition and the class of radioactive aerosols solubility, related dose coefficients, and the volume of air inhaled by a human in time ***t***, that is depended on age, and intensity of respiration.

Dose coefficients, equal to an expected effective dose forming due to inhalation intake of 1 Bq of the i-th radionuclide to human organism can vary significantly depending on human age (size of organs, body and metabolism changes with age), the class of solubility (aerosol solubility determines metabolism of the i-th radionuclide in an organism) and the Activity Median Aerodynamic Diameter (AMAD), determining radionuclides transport and deposition in the respiratory system (IAEA 2011). Coarse aerosols are accumulated in the upper airways, small ones can fall into the alveoli of lungs. Radionuclides of soluble aerosols are absorbed quickly into human organism, but insoluble ones can be removed very slowly out of the respiratory system depending on place of their deposition.

Based on the data on radionuclide contents in flammable material and on the release of the i-th radionuclide from the unit of surface in dependence on fire behavior type and the class of fire risk, an integral/medium over-ground concentration of the i-th radionuclide in the air at various distances from a source and different meteorological conditions can be estimated. To calculate such concentrations, various models describing convective rise and dispersion of radioactive aerosol in the atmosphere are usually used (Yoschenko et al., 2006; Evangeliou et al., 2014, 2015). Nevertheless, these models do not permit to calculate the radionuclides concentration in the respiration area of the firefighter at the immediate vicinity of the fire front.

During experiments in the exclusion zone of the ChNPP, with meadow fires (burning of dry crops) and ground fires transiting into crown fires (Fig.7), the following ratios have been established (Kashparov et al., 2000; Yoschenko et al., 2006):

- meadow fires: the ratio of the airborn 90Sr and 137Cs median over ground volume concentration (A^{i}_{Rvs} , Bq/m3) to the reserves in flammable material (Bq/ m2) was 10-6-10-5 1/m and for Pu and 241Am from 10-7-10-6 1/m.
- in case of heavy ground fires transiting into crown fires, the ratio of the airborn concentration of all radionuclides in the air to the reserves in flammable material at the surface was from 10-7-10-6 1/m. That allows to estimate the medium concentration of the i-th radionuclide in the area of where the firefighter is working (A^{i}_{Rvs} ,Bq/m3).

The expected effective internal dose of irradiation due to inhalation intake of radionuclides D_{int} (µSv) per adult human during intensive work in ***t*** hours can be calculated as:

$$D_{\text{int}}(t) = \sum_{i=1}^{6} A^{i}_{Rvs} \cdot B^{i}_{inh} \cdot t \cdot v, \qquad (3)$$

Where ***v*** – volume of inhaled air: **3 m^3/hr** at hard physical activity of an adult human, and **1.5 m^3/hr** at easy work.

B^{i}_{inh} -dose coefficient is equal to expected effective dose forming due to inhalation intake of 1 Bq of the i-th radionuclide in the organism of an adult human in µSv/Bq (see Table 1).

The total expected effective dose for adult human irradiation D_{Tot} (µSv) at the forest fire suppression during ***t*** hours has to be equal to the sum of effective doses, resulting from external and internal irradiation:

$$D_{Tot}(t) = D_{ext}(t) + D_{\text{int}}(t) \qquad (4)$$

This allows to evaluate the possibility of exceeding the reference levels of the external (2.3 mSv/year) and internal (0.7 mSv/year) effective dose of participants firefighting in the 30-km Exclusion Zone (Anonymous, 2008b).

During the grassland fires the released radionuclide fraction from the fuel material (litter and grass) into the atmosphere can be estimated as follows: ^{137}Cs and ^{90}Sr up to some %; Pu - up to 1 %. During the forest fires, up to 3-4% of ^{137}Cs and ^{90}Sr and up to 1% of the Pu isotopes can be released from the forest litter. The released fraction of the radionuclides during the forest fires may even be bigger if the source of release is a large-scale and is a very intensive fire, since in this case a bigger burn-up of the combustible material can be expected (Yoschenko, 2006b). Experimental and calculated data demonstrate that, **even under the most unfavorable conditions, radionuclide resuspension during forest fires will not provide a significant contribution to terrestrial contamination**. Additional terrestrial contamination due to a forest fire can be estimated to be in the range of 10^{-4}-10^{-5} of its background value (Kashparov, 2000).

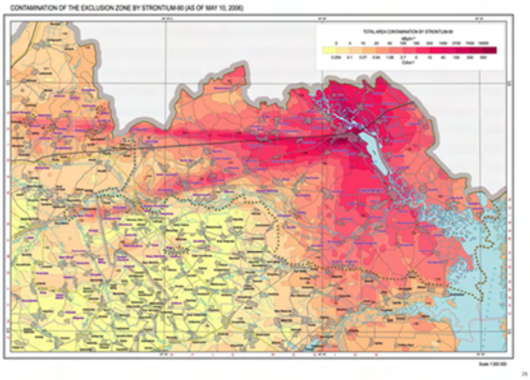
For a wide range of forest fire scenarios related to the Chernobyl ^{137}Cs radioactive fallout, the contribution of the inhalation dose to the total dose does not exceed several percent. **The presence of alpha-emitting radionuclides** (during forest fires in the 30 km ChNPP exclusion zone) **causes a considerable increase of the inhalation component,** which can be comparable with external exposure doses (Yoschenko, 2006a). **The additional inhalation dose for firefighters exposed in the affected area can reach the level of additional external irradiation in the period of their mission**. For example, during meadow and forest fires on the most contaminated areas of the Chernobyl exclusion zone with the equivalent dose rate of external radiation 4-16 µSv/h the additional committed effective internal inhalation doses of the firemen due to a 1-h stay in the fire zone was 8-40 µSv. The plutonium and americium nuclides constitute the dominating contribution to the inhalation dose (>99%).

At the same time, taking into account the sharp decrease of the airborne radionuclide concentration with the distance from the source of release, it can stated that the inhalation component of the total dose (as well as the external irradiation from radionuclides in air) is not important for the personnel of the exclusion zone which is not involved in the fire fighting and for the population outside of the exclusion zone (Yoschenko, 2006a).

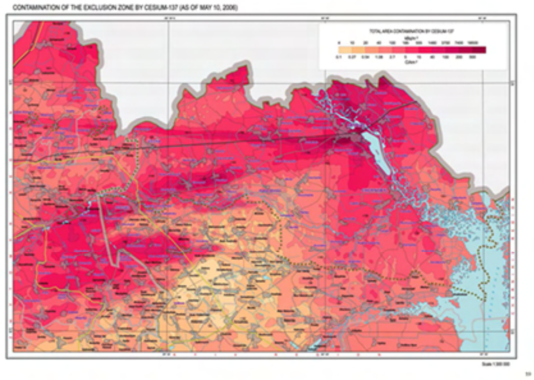
Table 1. Main characteristics of radionuclides and their dose coefficients. Source: IAEA (2011)

#	i-th radionuclide	Half life-time ($T_{1/2}$)	Specific activity of the i-th radionuclide in Chernobyl nuclear fuel (as of 2014), Bq/g	Main type of radiation	$B^{i}_{s\gamma}$, (µSv/hr)/(kBq/m^2)	B^{i}_{inh}, µSv /Bq
1	$^{90}Sr \rightarrow ^{90}Y$	29 years (64,26 hours)	6.19E+08	β	6.2E-6	3.2E-2
2	$^{137}Cs \rightarrow ^{137m}Ba$	30.17 years (2.5 min.)	7.35E+08	β, γ	7.9E-4 [9]	6.7E-3
3	^{238}Pu	87.74 years	6.41E+06	α	5.8E-8	43
4	^{239}Pu	24 100 years	5.07E+06	α	1.2E-7	47
5	^{240}Pu	6 563 years	7.77E+06	α	5.7E-8	47
6	^{241}Am	432.8 years	2.42E+07	α	1.7E-5	39

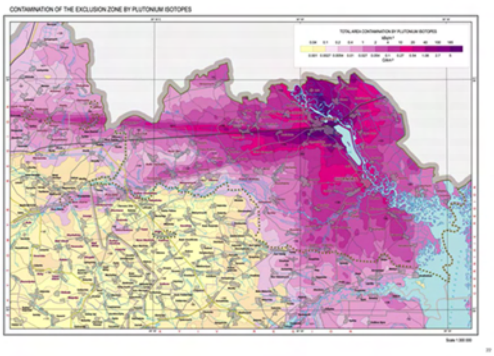
[9] Up to 1.5 times higher in mature pine forests (B2, B3) with thick litter layer



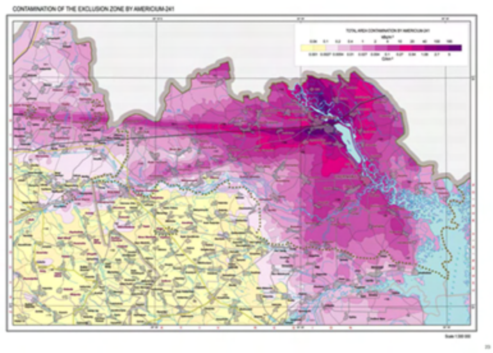
a



b



c



d

Figure 6. *Density of EZ and ZAR terrain contamination with ^{90}Sr (a), ^{137}Cs (b), $^{238\text{-}240}Pu$ (c) u^{241}Am (d) for May 10th 2006 (Anonymous, 2008b)*

2.5 Explosives [10]

In many countries of Western, Eastern and Southeastern Europe, including the territories of the former Soviet Union, large areas of forests and other ecosystems are contaminated by unexploded ordnance (UXO) – artillery and mortar grenades, bombs and other ammunition – and land mines stemming from armed conflicts (Explosive Remnants of War – ERW) or from former military exercise areas and shooting ranges. Most of the ordnance was initially buried subsurface but moving gradually to the soil surface due to frost effect (*pedoturbation*). Wildfires occurring on those terrain may trigger uncontrolled explosions and threats of collateral damages – injury and the death of firefighters.

Another problem is the wildfire threats to ammunitions depots. In Ukraine two major events occurred in 2004 and 2008. A forest fire entered ammunitions depot in southern Ukraine in 2004 killed five people. In 2008 artillery shells and other ammunition at a storage facility in Ukraine exploded when a forest fire swept into the depot. In 2008 similar events occurred in Kagan, Uzbekistan, where explosions killed three people and injured 21 others; and a fire burnt an arsenal near Ulyanovsk (720 kilometers east of Moscow) in November 2009. The latest incident of this kind resulted in a large ammunition depot fire in Russia, which was attributed by some to be caused by a wildfire in May 2011 nearby the village of Urman (Bashkortostan).

On the other side, there is also a need for the use of fire to maintain UXO-contaminated sites of high conservation value. Historically in Europe, active and former military training areas and shooting ranges have been shaped by wildfires in such a way that open land ecosystems of high biodiversity value have been created or maintained by recurrent fires. The Atlantic and continental *Calluna vulgaris* heathlands of Germany are a classic example of sub-climax ecosystems that historically had been maintained by intensive cultivation

[10] Author: J.G. Goldammer

(grazing, mowing, biomass export) and intentionally or accidentally lit fires on military training grounds. In the wake of demilitarization at the end of the Cold War and the unification of Germany in the 1990s and into the first decade of the 21st Century, the use of former military ranges was largely abandoned, and subsidized maintenance of open land habitats has reached critical limitations due to the lack of appropriate policies and funding prioritization. The recent introduction of prescribed fire in Germany to maintain open heathland habitats is based on traditional burning practices and coincides with new ecological insights of applied fire research that are receiving increased acceptance from nature conservation groups and the public. The *White Paper on Use of Prescribed Fire in Land Management, Nature Conservation and Forestry in Temperate-Boreal Eurasia* (Goldammer, 2009, 2013b) is indeed calling for a widespread application of prescribed fire to maintain the conservation value of former military training sites.

The presence of UXO, however, is a limiting factor for the application of prescribed fire on approximately 250,000 ha of high conservation value terrain. A pilot project (research and development project) has been conducted in the Heidehof-Golmberg Nature Reserve in the State of Brandenburg, Germany, a former military shooting range, to test safe application methods of using armored vehicles (demilitarized tanks) for prescribed fire ignition and control. Monitoring and controlling the fire operations by an unmanned aerial system (helicopter drone with real-time video downlink to the control center) allows navigation as well as safe and efficient ignition and control of the armored vehicles. This project provided key expertise for fire suppression on UXO-contaminated terrain (Goldammer et al., 2012).

3. JUSTIFICATION OF NEEDS AND TYPES OF PERSONAL PROTECTION EQUIPMENT FOR SAFELY FIGHTING VEGETATION FIRES ON CONTAMINATED TERRAIN

3.1 Radioactive contamination [11]

The effective dose of irradiation for firefighting personnel in the area of ChEZ and ChZAR is formed by external irradiation from radionuclides found outside the human body (soil, litter, forest stand et al.) plus internal irradiation of the organism after radionuclide inhalation intake through respiratory organs, eyes, mouth, open wounds, etc.. All personnel participating in works in the Exclusion zone is therefore subject to individual dosimetric control (Anonymous, 2008a).

The external dose of irradiation for firefighters can be reduced by means of minimizing the time of personnel staying in an area with high density of ^{137}Cs contamination, shielding gamma-irradiation by material of car cabins (up to 10 times), using technical (remote-controlled) tools (auto, tractors, etc.), and through keeping a distance by means of aviation (airplanes, helicopters) applied for forest fire suppression.

The internal dose of irradiation for firefighters formed by inhalation of alpha-irradiating radionuclides, may be comparable with the contribution of external irradiation in the 10-km zone of ChNPP, on the fuel traces of radioactive fallout.

In cases of meadow and forest fires, radioactive aerosols of micron and submicron sizes are found in the air at short distances from the fire front (Fig.9). Volatile ^{137}Cs, and partially ^{90}Sr, are mainly found in the pitch particles of smoke. The most harmful alpha-irradiating radionuclides, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Am, are re-suspended into the air with ashes particles of micron size. The retention efficiency of these particles by Petrjanov cloth, used in respirators, exceeds 98 %. Therefore, aiming to protect the respiratory tract during firefighting, it seems expedient to apply various types of respirators and other individual protective tools for

[11] Author: V. Kashparov

respiratory organs, as well as using sealed and, if necessary, shielded car cabins. Inhalation intake of radionuclides can be reduced tens and hundreds times by the use of respirators etc.

The contamination of skin and clothes of the firefighters due to the radioactive aerosols deposition is estimated as much lower than the permitted levels of surface contamination (Anonymous, 1997).

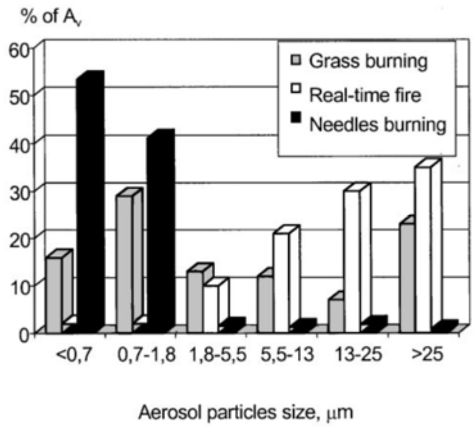


Figure 7. *Distributions of ^{137}Cs on aerosol particles of different sizes, observed during the forest fire, (Kashparov, 2000)*

3.1.1 Personal protection equipment for radiation protection [12]

When fighting fires in a contaminated zone, the choice of appropriate Personal Protective Equipment (PPE) depends on:[13]

- the response role and specific tasks;
- the risk of contamination.

PPE can protect against:

- external contamination and partially against irradiation;
- internal contamination via inhalation, ingestion, absorption through open wounds;
- other physical hazards (e.g., debris, fire/heat, or chemicals).

PPE cannot protect against exposure from high energy, highly penetrating forms of ionizing radiation.

PPE should include:

- a personal radiation dosimeter whenever there is a concern about exposure to penetrating ionizing radiation. Direct-reading personal radiation dosimeters may be used to monitor the radiation dose and can help workers stay within the recommended Dose Limits for Emergency Workers. Direct-reading dosimeters should be worn so that a worker can easily see the read-out and/or hear warning alarms.
- recommended respiratory PPE includes a full-face piece air purifying respirator with a P-100 or High Efficiency Particulate Air (HEPA) filter. Other respiratory protective equipment (e.g., a simple surgical facemask, N-95 respirators), non-fit tested respirators, or ad hoc respiratory protection do not deliver appropriate or sufficient respiratory protection.

Protective clothing with the ability to protect not only from aggressive substances but also from ionising radiation has been developed. Russian standards foresee an attenuation factor of external beta radiation with

[12] Author: St. Robinson
[13] http://www.remm.nlm.gov/radiation_ppe.htm

energies up to 2 MeV (Sr-90) of not less than 150x and an attenuation factor of external gamma radiation with an energy of 122 keV (Co-57) of not less than 5.5x.

In the following, different samples of Russian and American radiation-protection clothing sets for firefighters are given:

Russian radiation-protection clothing set "RZK-T" (TU 8570-025-46840277-2003 with AI 005-2011)

Designed for comprehensive protection of personnel during firefighting and rescue operations in areas with beta-gamma radiation. The set is designed to protect against external radiation, elevated temperatures, heat flux, incorporation of radioactive gases and aerosols via the respiratory and digestive tract, and skin contamination of mucous membranes. It is possible to attach individual dosimeters.

Specifications of "RZK-T":

- temperature range in which the set can be used: -40°C .to. +150°C;
- operating time: from -40°C to +40°C: 20 minutes; from +40°C to +100°C: 15 minutes; from +100°C to +150°C: 3 minutes;
- attenuation factor of external beta radiation with energies up to 2 MeV (Sr-90) of not less than 150 x; attenuation factor of external gamma radiation with an energy of 122 keV (Co-57) of not less than 5.5 x;
- time to put the set on (with help by one assistant): max. 3 minutes;
- time to take the set off: not more than 20 minutes;
- weight: not more than 25 kg.

Included items in the set: insulating outer suit with a hood, windows, bay-contained breathing apparatus, rubber gloves and boots, boots and leggings; overall internal thermal insulation; hood with a heat-insulating inner protective helmet; heat-radiation-protective clothing; radiation protection cape, overalls, pants, boots insoles; hygienic liquid-absorbent underwear.

Russian radiation- and heat-protection clothing set "RZK-MT" (TU 8570-025-46840277-2003 with AI 005-2011), complies with GOST R 53264-2009

Designed for comprehensive protection of personnel during firefighting and rescue operations in areas with beta-gamma radiation. The set is designed to protect against external radiation, elevated temperatures, heat flux, incorporation of radioactive gases and aerosols via the respiratory and digestive tract, and skin contamination of mucous membranes.

A breathing apparatus with compressed air is worn over the suit; the operating time can be increased by a quick change of cylinders. The suit protects against heat fluxes up to 14 kW/m^2 (at least 180 seconds).

The suit does not restrict the freedom of movement and allows to overcome hatches and manholes of a diameter of 600 mm. The presence of the face seal allows the use of individual full-face masks. Protective cloaks, shoe covers, and leggings provide additional protection in chemically aggressive environments and against heat fluxes.

Specifications "RZK-MT":

- Temperature range in which the set can be used: -40°C to +150°C;

- Operating time: from -40°C to + 40°C: 20 minutes; from +40°C to +100°C: 15 minutes; from +100°C to +150°C: 3 minutes;
- Attenuation factor of external beta radiation with energies up to 2 MeV (Sr-90) of not less than 150 x; attenuation factor of external gamma radiation with an energy of 122 keV (Co-57) of not less than 5.5 x;
- Protects against a broad spectrum of aggressive environments, including propellant and chemical warfare agent, as well as high intensity heat fluxes up to 14 kW/m2;
- Time to put the set on (with help by one assistant): max. 3 minutes;
- Time to take the set off: not more than 20 minutes;
- Weight: not more than 18 kg.

Included items: External jumpsuit with hood, rubber boots, gloves; heat- and radiation-protection overalls; radiation-protection cape, vest, pants, boots; hygienic liquid-absorbent underwear.

<u>Russian radiation- and heat-protection clothing set "RZK-M" (TU 8570-047-38996367-2004 with AI 005-2011)</u> complies with GOST R 53264-2009

This mobile radiation protection suit is based on the lightweight aggressive chemicals protection suit "TASK-M".

It is designed for comprehensive protection of personnel during firefighting and rescue operations in areas with beta-gamma radiation, especially in confined areas with thick walls like civil and military ships with nuclear power engines. A breathing apparatus with compressed air is worn over the suit, the operating time can be increased by a quick change of cylinders. The suit does not restrict the freedom of movement and allows to overcome hatches and manholes of a diameter of 600 mm. The presence of the face seal allows the use of individual full-face masks.

Specifications of "RZK-M":

- Temperature range in which the set can be used: -40°C to +150°C;
- Operating time: from -40°C to +40°C: 20 minutes; from +40°C to +100°C: 15 minutes; from +100°C to +150°C: 3 minutes;
- Attenuation factor of external beta radiation with energies up to 2 MeV (Sr-90) of not less than 150 x; attenuation factor of external gamma radiation with an energy of 122 keV (Co-57) of not less than 5.5 x;
- Time to put the set on: max. 3 minutes;
- Weight: not more than 18 kg.

Included items: Hygienic sweat-absorbing underwear; radiation-protection vest, cape, pants and boots; heat- and radiation-protection overalls; outer suit with gloves and boots.

<u>American radiation-protection suit with “Demron” fabric (www.radshield.com)</u>

The New York City Fire Department (FDNY) has decided in 2010 to “incorporate Demron in its chemical protective clothing (CPC) upgrade program to enhance its response capabilities with universal protection. Hazardous Materials Company 1, one of the first FDNY teams to deploy Demron, is using RST’s Demron Two-Ply Radiation Torso Vest, Demron-W High Energy Nuclear/Ballistic IED RDD RED Shield, and Crew Protection

Blanket. These technologies maximize safety while minimizing the time, manpower and resources required to respond to potential emergencies. The vest may be worn under most hazmat suits to protect vital organs, the thyroid and groin. It proved in tests by the U.S. Department of Energy to shield against X-Ray and low energy Gamma emissions, and against high- and low-energy Beta and Alpha particles. The nuclear/ballistic shield is a flame- and acid-resistant blanket that helps contain blasts and high-energy radiation sources and can help prevent or minimize catastrophes. The blanket proved in tests by H.P. White Laboratory to provide Level IIIA ballistic protection and the highest fragmentation protection. The Crew Protection Blanket, which RST custom-created specifically for FDNY, provides complete nuclear shielding for first responders and may also be used to transport radiation victims without contaminating others."

Tests of the radiation protection capability of Demron fabric undertaken by the Lawrence Livermore National Laborator in 2003 showed:

- "Demron is effective as a radiation shield, comparable to lead in terms of g/cm2 and tantalum according to the mass attenuation coefficient, against gamma, x-ray and beta emissions."
- "For Demron, with a density of 3.14 g/cm3, the thickness would be 0.8 mm corresponding to 2 layers for the present sample. For lead with a density of 11.3 g/cm3, the thickness would be 0.2 mm."
- "Demron's physical characteristics as a flexible, malleable fabric make it much easier to work with and handle than lead."
- "Unlike lead, according to Radiation Shield Technologies, Demron is non-toxic, contains no dermal or inhalation risks to the user, and requires no special or restrictive conditions for disposal."
- "At the current sample thickness (0.38 mm), Demron provides a factor 3 protection against beta and a factor of 10 against low energy gamma emissions."
- "The mass attenuation coefficients can be used to determine the thickness of Demron fabric required to successfully shield against higher energy/intensity gamma radiation. While the exact composition and construction of the Demron fabric is proprietary, it can be concluded that for radiation shielding purposes, Demron shields similar to lead by weight, yet poses none of lead's environmental or biological dangers."

3.1.2 Radiation survey instruments and radiation monitoring

There is a large number of devices existing to measure both radiation levels as well as the absorbed dose. In the following, a selection of Russian devices is given:

<u>Radiation levels measurement devices</u>

- DP-5V (A, B), IPD-5: designed to measure the levels of beta and gamma radiation (0.05 mR/h to 200 R/h). There are six sub-band measurements. Unit weight: 3.2 kg.
- DP-3B: can be installed on mobile devices like cars, boats and so on. Designed to measure the levels of gamma radiation (0.1 to 500 R/h). The device has four sub-bands. Unit weight: 4.4 kg.
- IPD-21, IPD-22: can be installed on mobile devices like cars, boats and so on. Designed to measure the levels of gamma and neutron radiation (0.01 to 104 R/h).

<u>Dosimeters</u>

- DP-70MP: measurement of gamma and neutron radiation dose in the range of 50 to 800 rad. It is a glass vial containing a colorless solution. The ampoule is placed in a plastic (DP-70MP) or steel (DP-70M) case. The case cover inside has a reference color corresponding to the color of the solution at a dose of 100 rad. With irradiation, the solution changes its color. In order to determine the received radiation dose the vial is removed from the case body and inserted into a colorimeter. Rotating disc filters help to match the color with the color of the ampoule and define the dose.
- ID-1: Set with ten individual dosimeters to measure gamma and neutron radiation doses in the range of 20 to 500 rad.

- PH-11: Set with 500 individual dosimeters to measure gamma and neutron radiation doses in the range of 10 to 1 500 rad. Doses can be summarized over a period of 12 months. It has a digital countdown indicator on the front panel.

3.1.3 Organizational questions

Protective equipment for firefighters is only a means to win time and extend the span they can work in a radiating environment. However, firefighting in nuclear contaminated areas must be paralleled by other organizational measures to reduce risks of exposure.

I. Organization

Fighting fires in contaminated forests may result in:

- exposure to dangerous levels of radiation → absorption of dangerous dose levels by external irradiation;
- heavy smoke with radioactive particles → breathing of smoke can result in internal exposure and irradiation of firefighters, radioactive particles can be transported by wind over considerable distances.

Therefore, when organizing firefighting in contaminated areas one must have a clear idea of the amount and type of combustible materials in the forest, contamination types and levels, the available firefighter force and their training levels and protective equipment and heavy equipment which is available. All these factors will define the intervention strategy. At all times it should be ensured that personnel and equipment are not located downwind of the fire zone.

II. Training

Training on chemical and nuclear protection needs to address several aspects in addition to the basic training of each firefighter.[14] This includes:

- basic understanding of properties of chemicals and of radiation, basic approaches for personal protection / safety;
- types of individual (PPE) and collective protection materials;
- correct use, servicing and disposal of protection materials;
- fundamentals of nuclear dosimetry and radiation protection (see below);
- risk minimization approaches during deployment of firefighters in contaminated zones;
- radio communication procedures to prioritize transmission of emergency messages;
- when utilizing aviation, especially helicopters: Prescribe to leave aerial transport means only after the deposition of the dust in the landing area;
- decontamination, zoning, signals and symbols.

The standard principles of radiation protection are:

- avoid exposure resp. keep exposure time to a minimum;
- stay as far away from the source as possible;
- establish shielding screens (materials used depend on the type of radiation to protect against);
- do not smoke, drink or eat in a contaminated area;
- do not touch your mouth, eyes, nose, open wounds with your hands when in a contaminated area;
- check hands and feet with a radiation monitor before leaving a contaminated area;
- at minimum, wash your hands when leaving a contaminated area.

[14] For details see handbooks such as the Swiss handbook for ABC incident management (FKS, 2014)

III. Radiation protection services

Organizational measures

In addition to the normal firefighter teams, a radiation monitoring service checking exposure of firefighters needs to be established with at least following tasks:

- registration of daily received doses of all firefighters (including new arrivals) in a special journal;
- organization of regular health checks for all firefighters;
- setting up an area for taking off clothes and of a decontamination area for equipment;
- setting up a collection and disposal strategy for contaminated materials (e.g. PPE, masks, equipment, etc.);
- development of strategies leading to minimum radiation exposure to a minimum number of firefighters;
- (re-)training firefighters on the basics of radiation protection;
- preparation firefighter work plans for the next days (including allowable work time and organization of shifts) taking into account previously received radiation doses, heat exposure, and predicted wind direction;
- participation of dosimetric personnel in firefighting operations, measurement of radiation levels in the zone of operations;
- calibration and servicing of radiation monitoring devices;
- daily reporting of dose information to operation management and to a national dose register;
- procurement of maps for the fire departments, which present the radioactive contamination (including plutonium contamination) of the territories;

Personal measures:

- a personal, direct-reading radiation dosimeter should be carried by each emergency responder. Direct-reading dosimeters help workers stay within recommended dose limits. They should be worn so that a worker can easily see the read-out and/or hear warning alarms;
- in addition to the personal dosimeter, the following personal protective equipment should be provided: respirators, lightweight protective suits, and protective cloaks;
- supply reliable communication tools to all firefighter units;
- use of anti-radiation drugs in areas with intense external radiation levels can be evaluated. This can be e.g. antibiotics, filgrastim (commercial name Neupogen), CBLB502 (by Cleveland BioLabs), Ex-RAD (by Onconova Therapeutics), CLT-008 (by Cellerant Therapeutics). Latter drugs are still in a clinical study stage;
- the absorbed dose as well as the cumulative absorbed dose of each emergency responder must be controlled (individual dosimetric monitoring);
- national legislation on radiation safety, and in absence of such, the emergency management team, must define an absorbed dose above which an emergency responder must be withdrawn from the inner perimeter (see below, "Zoning"). Decision dose in the U.S. is 0.5 Sv and in Russia 0.2 Sv;
- firefighters shall observe and minimize the periods of exposure in the smoke plume, in order to minimize the individual inhalation doses.

IV. Zoning

Zoning is important to ensure a clear understanding of risks levels and related protection measures to take as well as to prevent the spread of contamination from a dangerous zone to the outside.

Zoning (example of the Russian Federation)

1. In an area with a Cs-137 soil contamination level of 37-185 kBq/m^2 (1-5 Ci/km^2) and of a Sr-90 soil contamination level of 5.55 - 37 kBq/m^2 (0.15-1 Ci/km^2) the following measures apply:

- firefighting is carried out mainly by conventional methods with the adoption of additional measures to protect workers from the harmful effects of dust and combustion products;
- fire can be fought by stop-fires, ground- or air-based equipment using water and/or chemical extinguishing agents and flame-retardants.

2. In an area with a Cs-137 soil contamination level of 185-555 kBq/m^2 (5-15 Ci/km^2) the following measures apply:

- firefighting is carried out using fire trucks with a mounted water monitor as well as air based equipment. Chemical barriers can be erected.

3. In an area with a Cs-137 soil contamination level of 555-1 480 kBq/m^2 (15-40 Ci/km^2) the following measures apply:

- firefighting is carried out in accordance with specially designed plans taking into account the requirements of radiation safety;
- air-based equipment should be used;
- for final putting out of a fire, firefighters and fire trucks with mounted water monitor as well as air based equipment can be used.

4. In an area with a Cs-137 soil contamination level exceeding 1 480 kBq/m^2 (40 Ci/km^2) the following measures apply:

- air-based equipment has to be used;
- for final putting out of a fire, firefighters and fire trucks with mounted water monitor as well as air based equipment can be used.

Zoning (example from the US) [15]

Establish an *outer* perimeter if any of the following values are exceeded:

- 10 mR/h exposure rate;
- 60,000 dpm/cm2 for beta and gamma surface contamination; 16
- 6,000 dpm/cm2 for alpha surface contamination.
- the appropriate actions inside this perimeter are:
- evacuate members of the public;
- isolate the area;
- ensure all emergency workers inside the area minimize the time spent in the area and follow the appropriate protection guidelines.

Establish an *inner* perimeter at:

- 10 R/h exposure rate.

The appropriate actions inside this perimeter are:

- exposure and activities within this perimeter have the potential to produce acute radiation injury. Actions should be restricted to time-sensitive, mission-critical activities (e.g., lifesaving).

V. Health services

[15] http://www.ncrponline.org/Publications/Commentaries/Commentary%20No%2019%20Overview.pdf

16 pm = disintegrations per minute or particles per minute

Appropriate medical services (on site, in nearby hospitals, in specialized hospitals for treatment of heavily irradiated patients) must be organized. At the end of a firefighting campaign, all involved staff need to undergo medical investigation at a specialized medical facility and the total accumulated dose needs to be recorded in a central, national register.

VI. Regulations

In absence of existing national legislation, standards set by the International Atomic Energy Agency (IAEA) can be consulted. Regulations should include the following key issues:

- a list of radioactive substances and their properties;
- organization and means of radiation monitoring services;
- measures and procedures for the protection of personnel from radiation exposure;
- maximum allowable exposure levels for firefighters, first responders and forestry personnel under normal conditions and during a fire;
- measures and procedures for decontamination of personnel and equipment and for final storage of disposed of, contaminated materials;
- information of personnel on received radiation doses;
- organization of medical services;
- radiation exposure to firefighting personnel above permissible dose limits can be allowed for a certain time and within limits defined by sanitary regulations. E.g. a planned heightened irradiation of personnel can be allowed once during a lifetime with their voluntary consent and with prior notification of potential doses to be received and associated health risks. Irradiation of the personnel should not exceed 10 times the dose limits set for radiation workers (in most countries 20 mSv/y).

Sample legislation on dose limits is e.g. SanPin 2.6.1.2523-9 "Radiation Safety Standards (NRB-99/2009)", approved by the Resolution #47 of the Chief State Sanitary Doctor of the Russian Federation dated July 7th 2009.

3.2 Chemical contamination [17]

Personal Protective equipment (PPE) is a critical tool to avoid negative health effects by contaminated smoke on firefighters. Unavailability of PPE may cause serious health effects to firefighters and also drastically reduce their effective work time at the fire line. In the end, the lack of proper PPE can lead to failing in fire suppression as well as some serious injuries or even cases of death. Concept model of PPE use is shown in Figure 10.

[17] Author: S. Zibtsev

Figure 8. *Conceptual model of vegetation fire smoke health impact. Source: Dokas et al. (2007)*

At the moment, there is no solution for a comprehensive protection from all chemical hazards by vegetation fires for forest firefighters. In severe cases with high levels of chemical contamination special breathing equipment like air emergency systems for forest firefighters need to be used for a relatively short time (Fig.11a). Emergency air systems provide firefighters with clean and cold air necessary for self-protection maneuvers, reducing intoxication and respiratory tract burns. This equipment helps to avoid inhaling big amounts of smoke at some specific moments of fire. In addition, the system can be used in assisting other people by means of a valve to deliver positive pressure air. Usually it guarantees 6-7 minutes of air to escape from a situation when firefighters are trapped.

(a) (b) (c)

Figure 9. *(a) Emergency air system, (b) half face masks with filter, and (c) helmet for protection from particles*

Half-face masks (e.g. particle filter masks) or full-face masks with filters can provide protection levels up to 50 and 200 times, respectively, over the permissible exposure limits for particles according to European standards (Fig. 11 b, c). At the same time, it needs to be stressed that particle filter masks do not protect against the most dangerous chemical factor in vegetation fire – carbon monoxide. Full-face masks with filters can partially protect from respiratory irritants (aldehydes) and CO.

3.3 Explosives[18]

3.3.1 Standard personal protective equipment (PPE) for non-dangerous situations

The availability and training in the proper use of basic personal protective equipment (PPE) is a prerequisite for all personnel involved in fire suppression, regardless of additional protective equipment for firefighting operations on contaminated terrain. Key requirements for PPE include the following conditions:

- must not contribute to fatigue;
- must not fail prematurely;
- must be functional, durable, comfortable and economical.

The comfort concern is primarily one of heat stress and PPE weight, since the firefighter is often working for a prolonged period of 12-16 hours in a high-temperature environment.

The basic components of basic PPE include the following:[19]

Helmets

A critical piece of PPE, hardhats have saved many lives and prevented serious injuries by protecting the wearers against falling trees and rolling rocks. Current models must meet EU fire safety regulations EN 397, EN 443 and EN 12492.[20] A wildfire helmet should be made from one piece of ABS/PC and include the following external elements:

- ventilation system;
- anchorage system for glasses;
- tweezers for front light system;
- anchorage for lantern;
- anchorage system for folding screens;
- anchorage system for neck protectors;
- anchorage system for radio and video systems; and
- should be designed to be used together with ear protectors.

The internal harness should have an adjustment system along with a breathing padded fabric.

Jackets / shirts, pants and boots

In general, yellow shirts and green pants are made of aramid fabric (Nomex IIIR). Aramid fabrics are durable and provide good thermal protection. Like most fabrics, aramid bums if exposed to flame, but stops burning

18 Author: J.G. Goldammer

19 For illustrations: See Annex

20 http://ec.europa.eu/enterprise/policies/european-standards/harmonised-standards/personal-protective-equipment/index_en.htm

when the flame is removed. Instead of melting or burning to ash, it forms a char that helps to protect the skin. Extensive experience on wildfires has shown that loose-fitting clothing is more important in preventing serious bum injuries than the fire resistance of materials. Clothing that is tight-fitting poses a danger from radiant heat and heat stress, and at the same time reduces the firefighter's ability to perform. Flame-resistant clothing should be designed so that the movement of the wearer induces ventilation, which reduces moisture by a billows effect. Most advantageous are fire coats with the following characteristics:

- up to four frontal pockets with an easy-opening-system designed especially for gloves. One of the pockets can also carry a portable radio transmitter;
- one waterproof inside pocket designed especially for documents;
- velcro to hold the ID (name of the firefighter) on the chest;
- a hooking ring for a radio transmitter on the shoulder;
- cuffs can be adjusted from inside or outside by Velcro;
- raised collar on the back to ensure neck protection;
- lapel for neck protection adjustable by Velcro;
- fixing system for a smoke mask;
- central easily-opened zipper, quick and secure;
- bright yellow fabric (to ensure good ground and aerial visibility of the firefighter in the vegetated terrain) based on Nomex fibers and three-layered 265 gr/cm3 VISCOSA FR to guarantee sufficient thermal isolation and protection from radiation;
- Nomex stitches and is highly resistant to rubbing and wearing out caused by the forest environment;
- bright high-visibility reflecting stripes will ensure enhanced visibility.

Trousers should be made of fire-resistant fabric (yellow or any other colour) and should be of wide design which facilitates the freedom of movement.

Firefighting in densely vegetated, sometimes steep and uneven terrain requires stable boots. Slips and falls account for more than 15 percent of all injuries in wildland fires. Thus, non-slip soles are essential. Boots should be made of fire-resistant leather and with a waterproof layer.

Gloves

Gloves must be specially designed to protect the firefighter's hands against blisters, cuts, scratches and minor bums during routine firefighting. They also play a major fire protection role in the event of an aircraft accident or fire entrapment. Reviews of past fire entrapments have shown that, without gloves, a firefighter risks the loss of fingers from serious bums. This also may be true with conventional oil-tanned work gloves that bum or shrink in intense heat. Individuals entrapped in fire shelters also report that gloves are necessary to hold the hot shelter material to the ground without being burned.

Eye Protection

The protection from smoke, dust and small flying objects is essential. Glasses should be comfortable to wear for 8-16 hour shifts. Fixing the glasses to the fire protection helmet is preferable. Glasses have the following characteristics:

- lower and upper ventilation;
- open pore foam that traps all kinds of dust;
- rapid fitting system (elastic band with rapid lateral unlocking mechanism);
- double polycarbonate lens, anti-fog treatment inside and anti-scratch coating outside;
- soft, antiallergenic foam band closely adhesive to the face for protection from coarse powder and molten metals;

- all of the materials of these glasses need to be fire retardant and meet certification standards (CE Standards - ANSI Z87.1-2003/MIL-V-43511C Clause 3.5.10 STANAG 2920/4296).

Fire protection mask

A fire protection mask will protect the face from radiation, helps to prevent burns and reduce smoke and ash particles inhalation, due to its particle filter inserted inside the mask. The mask should have:

- an activated carbon filter;
- exhalation valve;
- high-visibility reflective strips;
- fabric: Nomex;
- mask certification standards: EN 531 (A B1 C1) EN 15614;
- filter certification standards: EN 149:2001 FFP1.

Neck shield

Neck shields are used to protect the forest firefighter’s neck from high temperatures and flames and must meet certification standards (EN 340/03 EN ISO 11612/08 EN 15614/0).

Fire Shelter

The fire shelter has become an important component of the PPE. The tent-like shelter is the only piece of equipment that offers lifesaving protection in the event of an entrapment. The shelters are made of aluminum, fiberglass and Textar, reflect radiating heat, provide breathable air, and protect the lungs and airways from flames and hot gases, the leading killers in entrapment. Certification standards to be met: UNE - EN ISO9151:1995, EN ISO11612:2010 and EN ISO6942:2002.

3.3.2 Personal protective equipment (PPE) for fighting fires on terrain with a high risk of explosions

Firefighting on terrain contaminated by radioactivity, chemicals and explosives / land mines will require additional protection. In contrast to the protection of firefighters against chemicals, the protection against explosives requires strong physical armor designed to absorb and/or deflect the impacts of fragments. For firefighters, hard-plate reinforced modular tactical vests, similar to the armor used by combat soldiers or mine disposal teams, are required in situations of rescue under high-risk conditions or in case of needing to control a fire nearby, a fire-subjected UXO (standards to be met: NIJ-3A). Ballistic helmets designed for demining are usually equipped with a ballistic visor.

4. FIRE CONTROL EQUIPMENT AS WELL AS THE BEST AND SAFEST PRACTICES OF FIREFIGHTING ON CONTAMINATED TERRAIN

4.1 Radioactive contamination [21]

The 10-km Exclusion Zone of the ChNPP is characterized by the highest level of radioactive contamination related dose rates threatening the health of firefighters (Fig.1). Owing to that fact, remote instrumental techniques for fire suppression are necessary with the aim of minimizing the stay of personnel in a highly contaminated area.

The methods and tools used for fire suppression on radioactive contaminated territory have to be selected with the aim of minimizing the release of radioactive aerosols containing alpha-irradiating radionuclides (^{238}Pu, ^{239}Pu, ^{240}Pu и^{241}Am) from the soil surface, as well as the time of personnel being exposed to the smoke. Higher fuel moisture content reduces the release of radioactive aerosols. Using cars and heavy machinery equipped with sealed cabs (pressurized filtered air) permits to decrease, up to tens and even hundreds times the inhalation intake of radionuclides by firefighters.

The biggest reduction of expected doses of external, as well as of internal irradiation is reached, if airborne equipment (helicopters, airplanes) is applied for firefighting. If after finishing the work on fire suppression radioactive contamination is exceeding the permissible levels, decontamination of equipment and tools must be undertaken.

In heavily radiating environments, armored vehicles and combat reconnaissance patrol vehicles adapted to specific tasks can be used. The risk of activating materials is low due to the absence of large neutron streams (except during the immediate period of a nuclear reactor catastrophe), however, decontamination of the equipment at the end of service remains important.

4.1.1 Decontamination

The ultimate goal of decontamination is to eliminate or reduce the harmful effects of ionizing radiation on the human body. A characteristic feature of decontamination is a strictly differentiated approach to the definition of the items to be decontaminated. This allows to prioritize activities according to the risks for life and to use in an optimum way limited manpower and equipment.

Contamination may be adhesive, superficial and deep. In the case of adhesive contamination, it is easily removed from a surface if the separation force is greater than the force of adhesion. In an aquatic environment, the adhesive force is significantly reduced, so the use of water for decontamination is common.

Less commonly, you may encounter cases of superficial and deep contamination. They are caused by processes of adsorption, ion exchange and diffusion. In these cases, the entire top layer needs to be removed along with the radioactive substances.

All methods of decontamination can be divided into liquid and dry.

- Liquid: removal of contamination with a jet of water or steam, or as a result of physical and chemical processes between a liquid medium and the contaminant. The efficiency depends on the flow of liquid, distance to the surface to be treated and additives used. The highest decontamination factor is

[21] Authors: J.G. Goldammer, St. Robinson and S. Zibtsev

achieved when the direction of the jet is at an angle of 30-45° to the work piece. To reduce volumes of water, used brushes should be used.

- Dry: mechanical removal through sweeping, suction, blowing, removal of the contaminated layer, tilling of soil.
- Additives can enhance decontamination efficiency:
    - Detergency of water can be improved by adding 0.1-0.5 % of surfactants like common soap, gardinol (powder of white or cream color, readily soluble in water to form a mildly alkaline medium), sulfonol (paste or in the form of brown plates brown), OP-7 and OP-10 (industrial wetting agents and emulsifiers).
    - Complexing solutions can be made with sodium phosphates, oxalic acid, citric acid, tartaric acid and their salts, sodium hexametaphosphate, and other salts of phosphoric acids.
- Organic solvents (dichloroethane, benzene, kerosene, diesel fuel) can be used to decontaminate metal surfaces (machines, equipment, means of transport).
- Sorbent material and resins (ion exchangers) can be used to remove radionuclides from solution. A common sorbent is specially treated, fine-grained activated carbon (e.g. karboferrogel).
- Decontamination of vehicles and equipment can be partial or complete. Partial decontamination would be only of components with which humans come into contact with during the operation. When decontaminating a vehicle, it is necessary, first of all, to clean the tent. Then the cab top, motor hood, front glass, mud flaps and footboard are wiped with a cloth. Thereafter, the inner surface is treated including cockpit instruments and controls. If the machine is supposed to transport people, then the loading area is further cleaned. Complete decontamination is carried out outside the contaminated zone at specialized stations with off-water treatment capacity.
- Decontamination of clothing, footwear and PPE may also be partial or complete. It all depends on the specific conditions, the degree of contamination and the prevailing situation. Partial decontamination can be done by removing clothes, shoes, etc. and by hanging them on boards, ropes, trees and then thoroughly beating them for 20-30 minutes with a broom, brush or sticks (while wearing PPE to exclude incorporation of released dust particles). Rubber, rubber-coated materials, synthetic films and the skin must be wiped with a cloth dampened in water or decontamination solution.
- Decontamination of equipment should be undertaken near or in the contaminated area in order to prevent the spread of contamination.
- In case of forest fires, activation of materials is an unlikely issue. Therefore, decontamination is mainly a task of cleaning equipment from radioactive dust particles. This can be done using water and detergents or other solving agents as discussed above.
- While firefighting is ongoing, contact parts of equipment should be regularly decontaminated. At the end of the mission, the equipment needs to be fully decontaminated. Materials which cannot be decontaminated need to be sent for final disposal.
- Initial personal monitoring and decontamination efforts at the scene should focus on preventing acute radiation effects.
- Cross contamination is a secondary concern, especially when the contaminated site and the number of evacuees is large. E.g. there is a risk of radioactive aerosols emanating from dirty clothes.
- Individuals with spot contamination > 2.2 x 10 6 dpm should be given priority for decontamination.
- In complex circumstances, the support of military chemical-radiological defense units can be requested.

4.1.2 Final disposal

Radioactive wastes from decontamination or firefighting activities need to be disposed of in special facilities. Liquids, for example, can be brought to radioactive waste stores at nuclear power plants or other nuclear facilities.

4.2 Chemical contamination [22]

Fire control equipment and firefighting tactics used in case of suppression of vegetation fires in zones of chemical contamination depend on terrain conditions, the type and severity of the fire, the fuel load and the level of personal training. Usually, chemical enterprises are located near rivers on plain terrain – so forests around them are easily accessible even for heavy fire trucks and middle- and small-size fire engines. This allows to minimize the direct contact of fire brigades with fire lines and minimize contact with smoke contaminated by chemical elements.

In case of small size (up to 5 ha) ground vegetation fires of low and middle intensity, classic techniques of fire suppression may be applied with the localization of fire development on the first stage followed by using plain water or water with retardants or a foaming agent, or by using tractors to make fire breaks ahead of the fire front. In the latter case, an important condition is that the tractor cabin has to be equipped with air conditioning and filtering systems. Hand tools teams may be applied for making fire breaks in case the tractors could not reach the potential borders of fires.

Direct, parallel or indirect attacks depending on the situation could be used for small size fire suppression (Fig.12-14). In case of middle fire sizes (5-25 ha), indirect attacks should be used based on natural or artificial fire barriers. The technology is described in the EuroFire Competency Standards.[23]

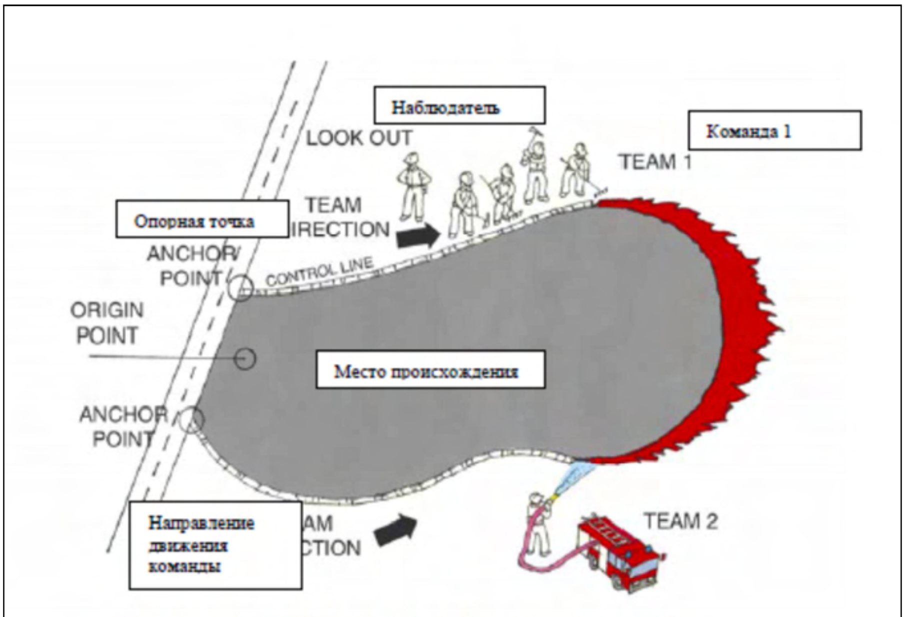


Рисунок 2.25. Прямая атака (охват с флангов)

Figure 10. *Scheme 1 of a direct attack*

[22] Author: S. Zibtsev

[23] The EuroFire Competency Standards (http://www.euro-fire.eu/) for firefighters were developed by the Global Fire Monitoring Center and are available in Ukrainian language (http://www.fire.uni-freiburg.de/eurofire/ef_ukr.html)

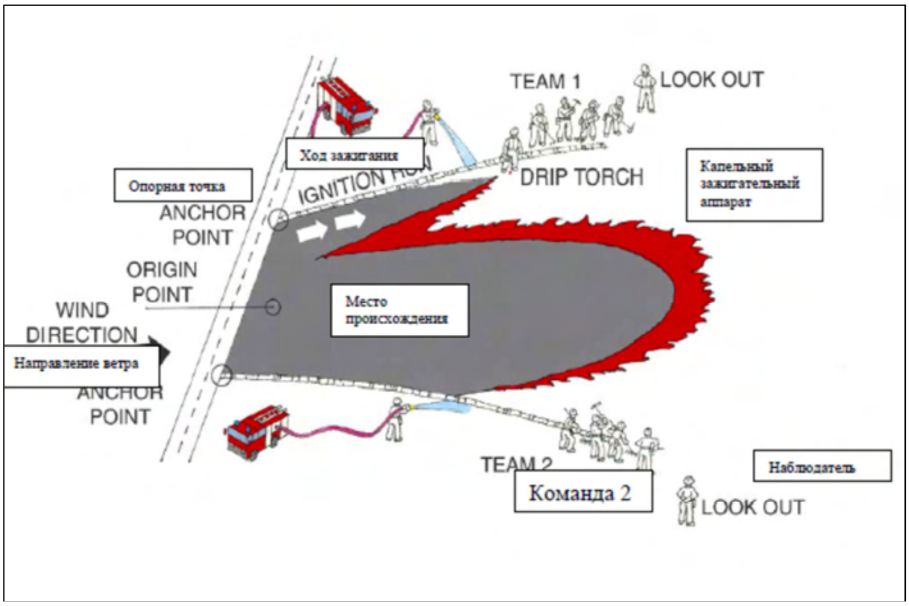


Figure 11. *Scheme 2 of a direct attack*

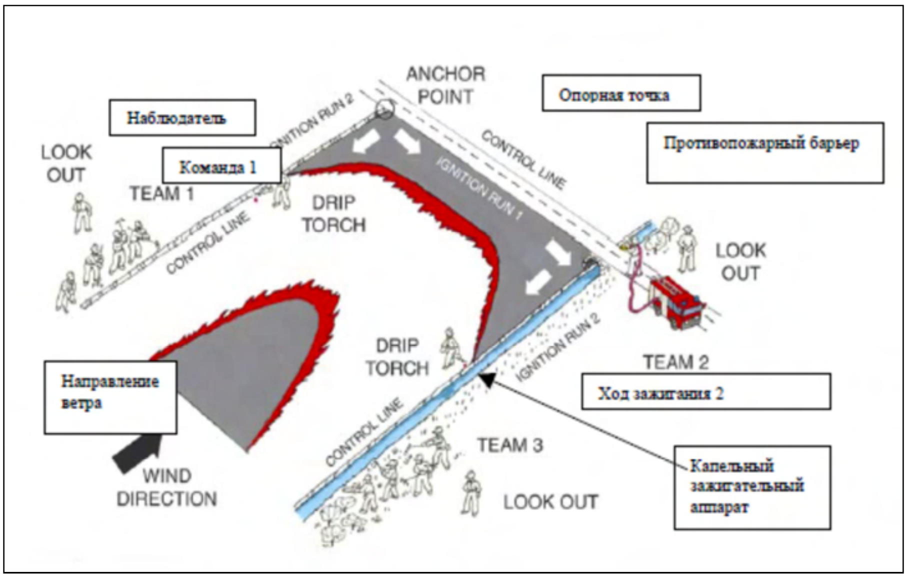


Figure 12. *Scheme of an indirect attack*

The main goal of any fire suppression tactic is the minimizing the contact of hand crews with smoke during the creation of fire breaks by the compulsory use of a half face mask with filter by personal working at the fire line. In case of large fires, only fire trucks and retardants should be used to stop a fire through the long-distance application of suppression agents.

4.3 Explosives [24]

Fire-triggered explosions of UXOs and land mines depend on the history of the contaminated sites. In general the highest threats exist on lands in which armed conflicts had taken place previously, as all ammunition (including artillery grenades, rockets, cluster bombs and bombs) and land mines used had explosive charges / warheads (armed / live ammunition). This may also be the case in active or abandoned military training areas

[24] Author: J.G. Goldammer

or shooting ranges where live ammunition was used. On some military training areas, however, only handguns or exercise ammunition has been used, resulting in a lower risk of harmful detonations.

The experience of the GFMC in the use of prescribed fire on UXO-contaminated terrain in Germany and evaluating the narratives of wildfire incidents have led to the following conclusions (without having a sufficiently large database that could prove these observations statistically):

Fire Season
It has been observed that fires burning during the cold season, i.e. the Northern Hemispheric winter season, result in less fire-triggered explosions. On the other side, fires burning during the generally hot spring or summer fire season result in high number of explosions. The reason for this may be the general environmental temperature of the soil and the lower air layer influencing cooling or pre-heating of the UXO.

Fire behavior
A surface fire driven by the wind, especially in light fuels (e.g. grasslands or grass understory in open pine forest stands) in general leads to marginal heating of the soil surface due to its short residence time at the UXO location. The UXO may become exposed to higher temperatures only for a short time and may be completely unaffected by the heat, especially during the cold winter season.

A fire burning slowly against the wind, however, has a longer residence time and thus resulting in an increased time span of the UXO or land mine being exposed to higher temperatures.

In addition to the wind, the topography also influences the residence time of a fire, i.e. a fire rapidly spreading upslope has a shorter residence time than a fire slowly burning downslope.

Fuel load
The amount of living or dead combustible materials (fuels) on the surface / ground determines the energy release and, together with fire behavior and topography, the residence time and energy release on the UXO location. A fire burning rapidly in a light grass layer will release less heat to the soil surface as compared to a fire advancing slowly in a fuel layer consisting of a high load of combustible materials (dead tree logs, branches, twigs, needles, understory vegetation) or in organic layers (raw humus or duff).

In Germany the above-mentioned research and development (2009 – 2014) addressed the use of fire on former military terrain contaminated by unexploded ordnance. While this project primarily focused on the use of prescribed fire for maintaining disturbance-generated high-value conservation areas, the spin-off products of the project allow the use of the concepts and technologies in fighting wildfires on contaminated terrain. While the final findings of this project, which was technically led by the GFMC, are not yet published, the preliminary experiences and conclusions are manifested by Goldammer et al. (2012).

The readiness of a UXO to explode also depends on the age and the state of corrosion of the metal case of the explosive charge. Corroded metal cases and chemical reactions with ambient air, including ambient heat, may result in faster self-ignition, e.g. of phosphor ammunition (tracer bullets and phosphor bombs).

Safety standards concerning wildfires burning in UXO-contaminated terrain are prescribed in some countries. For instance, in Germany the general fire service law prescribes a safety distance of 500 m to fires burning on sites bearing explosives. Explosive Ordnance Disposal (EOD) / safety rules require even a vertical and horizontal safety distance of 1,000 m to burning UXO sites. Regardless of the safety rules in other countries: Keeping such distances from a fire will not allow any intervention, neither on the ground, nor by aerial response (aerial dropping of water, retardants or foam from distances in the magnitude of hundreds of meters would not result in any effective fire suppression).

Thus, there are three options for suppressing wildfires on UXO- / land-mine contaminated terrain:

- under weather conditions of low fire danger and intensity (e.g. during the winter and early spring), prevailing light fuels, and surface fires burning with low to moderate intensity on terrain contaminated by exercise and other small arms ammunition, the local incident manager may decide to allow conventional approaches in fire control by creating fire lines and backburning at a safe distance. For fire suppression, aerial means could be involved.
- in high-risk situations (high fire danger and intensity; expected explosions of high-impact UXO) ground personnel may be dispatched only if armored firefighting equipment and / or special ballistic PPE is available, or
- remotely controlled or autonomously operating ground and aerial fire suppression means are used for fire suppression.

4.3.1 Ground operations with armored equipment

Armored fire suppression vehicles, notably converted former military tanks, have been developed by a number of countries and enterprises over the past decades, notable in the early post-Cold War period at a time when large numbers of surplus military hardware was available for potential civilian use. The above-mentioned research and development project (cf. sections 2.5.4 and 2.5.5; Goldammer et al., 2012) involved three main components for the safe use of prescribed fire and for fighting wildfires on UXO-contaminated terrain:

Armored fire suppression equipment

An existing fire suppression tank SPOT-55, produced in and for the Armed Force of the Czech Republic, was used with its fully maintained armored structure. This tank provides a water container mounted in place of the turret with a capacity of 11,000 L of water, a high-pressure firefighting pump and nozzles. The tank, which was further developed in Germany for the use of firefighting in dangerous terrain, was further equipped with a camera system, satellite navigation / GPS system and radio communication. This equipment allows the tank crew to operate fully protected by armor, navigate in terrain without opening the hatch, and stay connected via a communication link with the incident commander.

The incident commander directs the tank to the critical locations where suppression intervention is needed. Navigation is supported by the use of an unmanned aerial vehicle / system (UAV/UAS) described below. For illustrations: See Figures 2.27 and 2.28 in the Annex.

In case of the need of firefighters or rescue teams entering a dangerous wildfire site the provision of ballistic protective clothing must be ensured (cf. Section 3.3.2 and Figures 2.6 and 2.7 in the Annex).

Armored fire ignition equipment

For setting prescribed fires, e.g. for conservation purposes, for creating black fire lines / buffer zones around a wildfire, or for backfiring, an armored ignition tank has been developed. The German project converted a former Czech BMP-OT-R5 command post vehicle to an ignition tank with full personal safety by leaving the armor unmodified (Annex, Figure 2.22).

For ignitions over distances up to 80 m, a Pyroshot Green Dragon® system was mounted on the BMP as a launcher for ignition devices (Plastic Sphere Dispenser – PSD) (Figure 2.23). The PSD have the size of a pingpong ball and are filled with potassium permanganate ($KMnO_4$). At the moment of firing, a glycol injection leads to a chemical reaction with $KMnO_4$ and leads to the ignition of the capsule after ca. 20 seconds. The burning capsule ignites the vegetation. In addition, the BMP is equipped with an all-terrain vehicle (ATV) drip torch which offers ignition at the port side of the BMP up to a distance of 6 meters using a 4:1 diesel-gasoline mixture (Annex, Figures 2.24 to 2.25).

4.3.2 Unmanned Aerial Vehicle / System (UAV/UAS) for operations control and coordination

Since the incident commander of a prescribed burning or wildfire fighting operation needs to stay in a post outside the safety zone of up to 1,000 m and given the same restrictions imposed on manned aerial flights, it is mandatory to use an Unmanned Aerial Vehicle / System (UAV/UAS) for obtaining real-time visual / tactical information on the state of the fire, the positions and movement of armored ground forces and the reconnaissance of situations requiring intervention. In the above-mentioned project in Germany, an unmanned small helicopter of type CT BEE 6B® was used to obtain a permanent aerial video and still photo footage, transmitted to the incident command post in real time. The aerial reconnaissance component, due to aerial safety considerations preferably by UAV/UAS, is a prerequisite for any fire operation on terrain contaminated by land mines and UXO (Annex, Figures 2.27 to 2.30).

Unmanned ground vehicles for firefighting support on dangerous terrain

A recent development of a remotely controlled blade-weeding machine allows indirect forest fire attack by creating a fire line. The technology allows control personnel to stay outside the impact zone of exploding ammunition or radioactive dust. The prototype, developed by Vallfirest (VF Dronster) allows the remote control of fire line creation in vegetation types with fuels up to 8 cm in diameter (Annex, Figures 2.17 to 2.18).

UAV/UAS for aerial firefighting

The development of drones for aerial firefighting has received recently a significant push by Lockheed Martin Corporation (U.S.A.), which has successfully tested K-MAX unmanned helicopters at Griffiss International Airport, airlifting and dumping water on fires. In November 2014, a team led by Lockheed Martin Corp. has successfully tested a pair of unmanned aerial drones to put out large or dangerous fires without endangering the lives of pilots.

It is aimed that the unmanned UAV can work to fight fires day and night, in all weather, reaching dangerous areas without risking lives. Kaman manufactures the K-MAX helicopter, outfitted with Lockheed sensors that allow autonomous collection of water from a pond and delivery to the fire location (Annex, Figures 2.31 and 2.32).

UAV/UAS for aerial ignition

With the risk of wildfire-triggered UXO explosions affecting manned aerial platforms, the development of UAV for aerial ignition is currently underway. It is expected that in 2015 the next generation of UAV (helicopter) will be available for aerial ignition of prescribed area fires and backfiring (Figures 2.33 to 2.36).

5. CONCLUSIONS AND RECOMMENDATIONS

Fires burning in contaminated environments create additional, non-standard risks to firefighters and may have negative health impacts on the firefighters and on the local populations. Three main types of contaminated environments were considered in this report: (a) vegetation contaminated by radioactivity as a consequence of accidents of nuclear power plants, such as the territories contaminated after the failure of Reactor 4 of the Chernobyl NPP in 1986; (b) vegetation around chemical and industrial plants contaminated by regular emissions or as a consequence of accidents or as collateral damages of armed conflicts; (c) zones contaminated by unexploded ammunition in the region of former and current armed conflicts or active and abandoned military exercise and shooting ranges.

It is concluded that wildfire control on contaminated terrain is extremely dangerous and difficult. This is why investments need to be prioritized to provide the appropriate equipment and increase preparedness and capabilities for safe and efficient wildfire control in order to reduce primary and secondary risks to firefighters and civilian populations.

The following recommendations are given.

1. Special fire management measures, personal protection means and tactics as well as appropriate health and environmental monitoring services should be identified, adapted and used for safe fire suppression in the abovementioned environments.

2. The main risks to firefighter's health are generated by smoke from fires burning in vegetation contaminated by radionuclides and chemicals. In consequence, management has to enforce the use of breathing protection means, and define and enforce exposure time limits to firefighters based on radioactive and chemical risks and the prevailing use of indirect attack tactics during suppression.

3. Plans for the long-term reduction of wildfire hazard and fuel management (management of combustible materials) are needed. In the short term this includes the application of silvicultural and forest utilization methods using harvester / forwarder machines properly equipped with filters to avoid inhaling doses for operators. In addition, strategically placed and regularly maintained firebreaks and fuel breaks will reduce the risk of uncontrolled spread of wildfires. In the long term, a strategy needs to be developed for the management and treatment of harvested radioactive wood, including special incineration facilities for radioactive wood parts with associated nuclear waste solidification and long-term storage capacities. Without such a long term strategy, it will be difficult to manage forests and reduce fire risks through the removal of dead wood.

4. Fire service personnel in areas with nuclear or chemical contamination hazards should be properly trained and equipped to fight fires and understand these non-standard risks. A decision support system for fire suppression and air monitoring systems would allow the incident commander to control the exposure time of firefighters at the fire line from the point of view of compliance with individual radioactive and chemical safety norms.

5. Firefighting on terrain contaminated by unexploded ordnance (UXO) and landmines require different means of PPE and equipment that ensure the protection of personnel again ballistic impacts of exploding ammunition. There are three options for suppressing wildfires on UXO- / land-mine contaminated terrain:
   - under weather conditions of low fire danger and intensity (e.g. during the winter and early spring),prevailing light fuels, and surface fires burning with low to moderate intensity on terrain contaminated by exercise and other small arms ammunition, the local incident manager may

decide to allow conventional approaches in fire control by creating fire lines and backburning at a safe distance. For fire suppression, aerial means could be involved.

- in high-risk situations (high fire danger and intensity; expected explosions of high-impact UXO) ground personnel may be dispatched only if armored firefighting equipment and / or special ballistic PPE is available, or
- remotely controlled or autonomously operating ground and aerial fire suppression means are used for fire suppression.

6. For all types of contaminated terrain the early detection, monitoring and control of fires requires advanced solutions that would reduce the onsite operation and presence by humans. Remote sensing for the early detection of fires (ground-based automated and autonomously operating equipment for the rapid detection of vegetation fire smoke or heat) and unmanned, remotely controlled or autonomously operating ground vehicles or airborne systems (UAV/UAS) provide a significant reduction of health risks, injuries or fatalities to firefighters. The most advanced solutions for unmanned aerial and ground firefighting merit attention for use in practice.

REFERENCES

Adolph, E. F. 1947. Physiology of man in the desert. Interscience. 53 p.

Anonymous. 1997. Radiation safety norms of Ukraine (RSNU-97).Kyiv. (in Ukr.).

Anonymous. 2008a. Radiation safety rules during carrying out of works in the exclusion zone and zone of absolute resettlement, implemented by the order of MH and ME of 04.04. 2008 № 179/276. (Ukr.).

Anonymous. 2008b. The basic control level, level and release level action on radioactive contamination of the Exclusion zone, Ministry of Ukraine, Kyiv, 2008, 11p. (Ukr.).

Booze, T.F., Reinhardt, T.E., Quiring, S.J., and Ottmar, R.D. 2004. A screening-level assessment of health risks of chronic smoke exposure for wildland fire-fighters. J. Occup. Environ. Hyg. 1, 296-305.

Bytnerowicz, A., Arbaugh, M., Riebau, A., and Andersen, C. (eds.). 2009. Wildland fires and air pollution. Elsevier B.V., Developments in Environmental Science, Vol. 8, Amsterdam-Boston, 687 p.

CEPA (Canadian Environmental Protection Act). 1999. National Ambient Air Quality Objectives of particulate matter Part 1, Science Assessment document. Minister Public Works and Government Services, Cat. No. H46-2/98-220-1E. Cesti, G. 2006. Effects of forest fire smoke. FFNet 4, 113-126.

Cuddy, J.S., Ham, J.A., Harger, S. (and others). 2008. Effects of an electrolyte additive on hydration and drinking behavior during wildfire suppression. Wilderness and Environmental Medicine 19 (3), 172-180.

Domitrovich, J., and Sharkey, B. 2010. Heat Illness Basics for Wildland Firefighters. In: Fire Tech Tips. Technology and development program. U.S. Department of Agriculture, Forest Service, 8 p.

Eckerman K.F. and Ryman, J.C. 1993. External exposure to radionuclides in air, water, and soil. Federal Guidance Report No. 12, EPA-402-R-93-081, Oak Ridge National Laboratory, USA, 238 p.

Evangeliou N., Balkanski Y., Cozic A., Hao, W., and Møller A. 2014. Wildfires in Chernobyl – contaminated forests and risks to the population and the environment: A new nuclear disaster about to happen? Environment International 73, 346-358.

Evangeliou, N., Balkanski, Y., Cozic, A., Hao, W. M., Mouillot, F., Thonicke, K., Paugam, R., Zibtsev, S., Mousseau, T. A., Wang, R., Poulter, B., Petkov, A., Yue, C., Cadule, P., Koffi, B., Kaiser, J. W., and Møller, A.P. 2015. Fire evolution in the radioactive forests of Ukraine and Belarus: Future risks for the population and the environment. Ecological Monographs 85 (1), 49-72.

FKS (Feuerwehr Koordination Schweiz). 2014. Handbuch für ABC-Einsätze. Version 04.2014 (German and French). Available online: http://www.feukos.ch/de/abc-einsatze/handbuch-fur-abc-einsatze/

Goldammer, J.G. (ed.) 2009. White Paper on Use of Prescribed Fire in Land Management, Nature Conservation and Forestry in Temperate-Boreal Eurasia. Results and recommendations of the Symposium on Fire Management in Cultural and Natural Landscapes, Nature Conservation and Forestry in Temperate-Boreal Eurasia and members of the Eurasian Fire in Nature Conservation Network (EFNCN), Freiburg, Germany, 25-27 January 2008. Fire Ecology Research Group/ Global Fire Monitoring Center, 28 p. UNECE/FAO International Forest Fire News No. 38, 133-152.

Goldammer, J.G. 2013a. Beyond Climate Change: Wildland Fires and Human Security in Cultural Landscapes in Transition – Examples from Temperate-Boreal Eurasia. Chapter 22 in: Vegetation Fires and Global Change: Challenges for Concerted International Action. A White Paper directed to the United Nations and International Organizations (J.G. Goldammer, ed.), 285-311. A publication of the Global Fire Monitoring Center (GFMC). Kessel Publishing House, Remagen-Oberwinter, 398 p.

Goldammer, J.G. (ed.) 2013b. Prescribed Burning in Russia and Neighbouring Temperate-Boreal Eurasia. A publication of the Global Fire Monitoring Center (GFMC). Kessel Publishing House, 326 p.

Goldammer, J.G., M. Statheropoulos, and M.O. Andreae. 2009. Impacts of vegetation fire emissions on the environment, human health and security – A global perspective. In: Wildland fires and air pollution (A. Bytnerowicz, M. Arbaugh, A. Riebau, and C. Andersen, eds.), 3-36. Elsevier B.V., Developments in Environmental Science, Vol. 8, Amsterdam-Boston, 687 p.

Goldammer, J.G., E. Brunn, A. Held, A. Johst, S. Kathke, F. Meyer, K. Pahl, A. Restas, and J. Schulz. 2012. Kontrolliertes Brennen zur Pflege von Zwergstrauchheiden (*Calluna vulgaris*) auf munitionsbelasteten

Flächen: Problemstellung, bisherige Erfahrungen und geplantes Vorgehen im Pilotvorhaben im Naturschutzgebiet „Heidehof-Golmberg“ (Landkreis Teltow-Fläming). Naturschutz und Biologische Vielfalt 127, 65-95.

Heil, A., and Goldammer, J.G. 2001. Smoke-haze pollution: A review of the 1997 episode in Southeast Asia. Reg. Environ. Change 2, 24-37.

Hendrie, A.L., Brotherhood, J.R., Budd, G.M. (and others). 1997. Project Aquarius 8. Sweating, drinking, and dehydration in men suppressing wildland fires. International Journal of Wildland Fire 7(2), 145-158.

IAEA. 2010. Handbook of parameter values for the prediction of radionuclide transfer in terrestrial and fresh-water environments. Vienna: IAEA-TRS-472. - 194p.

IAEA. 2011. Radiation protection and safety of radiation sources : international basic safety standards: general safety requirements. – Interim edition. – Vienna : International Atomic Energy Agency, 303 p.

Ipatiev V.A. (eds.). 1999. Forest. People. Chernobyl. Forest ecosystems after the Chernobyl accident: The state, the forecast, the reaction of the population, ways of rehabilitation. Gomel: Institute of Forest of NAS of Belarus, 452 p. (Rus.).

Johnson, R. 1999. Guidance on measures in forest fire emergency cases. In: Goh, K.-T., Schwela, D., Goldammer, J.G., and Simpson, O., eds. Health guidelines for vegetation fire events-background papers, 6–9 October 1998. Lima, Peru, WHO/UNEP/WMO, pp. 411-465.

Kashparov V.A. 2014. Experimental biogenic fluxes 137Cs in forest ecosystems. The scientific and research Report. NUBiP Ukraine, Kyiv, 81p. (Ukr.).

Kashparov, V.A., Ahamdach N., Zvarich S.I., Yoschenko, V.I., Maloshtan, I.N., and Dewiere, L. 2004. Kinetics of dissolution of Chernobyl fuel particles in soil in natural conditions. //Journal of Environmental Radioactivity 72 (3), 335-353.

Kashparov, V.A., Ivanov, Yu.A., Zvarich, S.I., Protsak, V.P., Khomutinin, Yu.V., Kurepin, A.D., and Pazukhin E.M. 1996. Formation of Hot Particles During the Chernobyl Nuclear Power Plant Accident. Nuclear Technology 114 (1), 246-253.

Kashparov, V.A., Lundin, S.M, Kadygrib, A.M., Protsak, V.P., Levtchuk, S.E., Yoschenko, V.I., Kashpur, V.A., and Talerko, N.M. 2000. Forest fires in the territory contaminated as a result of the Chernobyl accident: radioactive aerosol resuspension and exposure of fire-fighters. Journal of Environmental Radioiactivity 51, 281-298.

Kashparov, V.A., Lundin, S.M., Khomutinin, Yu.V., Kaminsky, S.P., Levtchuk, S.E., .Protsak, V.P., Kadygrib, A.M., Zvarich, S.I., Yoschenko, V.I., and Tschiersch, J. 2001. Soil contamination with 90Sr in the near zone of the Chernobyl accident. Journal of Environment Radioactivity 56 (3), 285-298.

Kashparov, V.A., Lundin, S.M., Zvarich, S.I., Yoschenko, V.I., Levtchuk, S.E., Khomutinin, Yu.V., Maloshtan, I.N., and Protsak, V.P. 2003. Territory contamination with the radionuclides representing the fuel component of Chernobyl fallout. The Science of the Total Environment 317 (1-3), 105-119.

Kelly, J. 1992. U.S. Department of the Interior National Park Service, Health Hazard Evaluation Report, Heta 92-045-2260, NIOSH. http://www.cdc.gov/niosh/topics/firefighting.

Koppmann, R., Czapiewski, K.von., and Reid, J.S. 2005. A review of biomass burning emissions, part I: Gaseous emissions of carbon monoxide, methane, volatile organic compounds, and nitrogen containing compounds. Atmos. Chem. Phys. Discuss. 5, 10455-10516.

Krasnov, V.P. 1999. Scientific basis of the use of forest products in terms of radioactive contamination of forests. Doctoral thesis, 39 p. (Ukr.).

Kuriny, V.D., Ivanov, Yu.A., Kashparov, V.A., Loshchilov, N.A., Protsak, V.P., Yudin, E.B., Zhyrba, M.A., and Parshakov, A.E. 1993. Particle-associated Chernobyl fall-out in the local and intermediate zones. Annals of Nuclear Energy 20 (6), 415-420.

Lacaux, J.P., Brustet, J.M., Delmas, R., Menaut, J.C., Abbadie, L., Bonsang, B., Cachier,H., Baudet, J., Andreae, M.O., and Helas, G. 1995. Biomass burning in the tropical savannas of Ivory Coast: An overview of the field experiment fire of savannas (FOS/DECAFE 91). J. Atmos. Chem. 22, 195-216.

Muraleedharan, T.R., Radojevic, M., Waugh, A., and Caruana, A. 2000. Chemical characterisation of the haze in Brunei Darussalam during the 1998 episode. Atmos. Environ. 34, 2725-2731.

Malilay, J. 1998. A review, of factors affecting the human health impacts, of air pollutants from forest fires. In: Goh, K.-T., Schwela, D., Goldammer, J.G., and Simpson, O., eds. Health guidelines for vegetation fire events-background papers, 6–9 October 1998. Lima, Peru, WHO/UNEP/WMO 1999: Health Guidelines for Vegetation Fire Events, Lima, Peru, October 6–9, pp. 255-270.

McDonald, J.D., Zielinska, B., Fujita, E., Sagebiel, J., and Chow, J. 2000. Fine particle and gaseous emission rates from residential wood combustion. Environ. Sci. Technol. 34, 2080-2091.

Miranda, A.I. 2004. An integrated numerical system to estimate air quality effects of forest fires. Int. J. Wildland Fire 13, 217-226.

Muraleedharan, T.R., Radojevic, M., Waugh, A., and Caruana, A. 2000. Chemical characterisation of the haze in Brunei Darussalam during the 1998 episode. Atmos. Environ. 34, 2725-2731.

Paskevich, S.A. 2006. Radiation importance of phytocoenoses meadows and fallow Exclusion Zone to stage a late phase of the accident. Doctoral thesis. Kiev National University, 22 p. (Ukr.).

Perevolotsky, A.N. 2006. Distribution of 137Cs and 90Sr in the forest Biogeocenoses. Gomel: RSRUE "Institute of Radiology", 255 p. (Rus.).

Petrilli, T., Ackerman, M. 2008. Tests of undergarments exposed to fire. Tech Tip 0851–2348–MTDC. Missoula, MT: U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center. 10 p.

Radojevic, M. 2003. Chemistry of forest fires and regional haze with emphasis on Southeast Asia. Pure Appl. Geophys. 160, 157-187.

Reh, C.M., and Deitchman, S.D. 1992. U.S. Department of the Interior National Park Service, Health Hazard Evaluation Report, Heta 88-320-2176, NIOSH. http://www.cdc.gov/niosh/topics/firefighting/

Reinhardt, T.E., and Ottmar, R.D. 2004. Baseline measurements of smoke exposure among wildland fire-fighters. J. Occup. Environ. Hyg. 1, 593-606.

Ruby, B.C., Scholler, D.A., Sharkey, B.J. (and others). 2003. Water turnover and changes in body composition during arduous wildfire suppression. Medicine & Science in Sports & Exercise 35 (10), 1760-1765.

Sharkey, B. 2004. Wildland firefighter health and safety report: No. 8. Tech Rep. 0451–2802–MTDC. Missoula, MT: U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center. 12 p.

Shauer, J.J., Kleeman, M.J., Cass, G., and Simoneit, B.T. 2001. Measurement of emissions from air pollution sources. 3. C1–C29 organic compounds from fireplace combustion of wood. Environ. Sci. Technol. 35, 1716-1728.

Sheglov A.I. 2000. Biogeochemistry of artificial radionuclides in forest ecosystems: materials 10 years of research in the area of influence of the Chernobyl accident. Nauka, 268 p. (Rus.).

Shityuk K.F. 2011. Evaluate forest management in the area of radiation exposure from Chernobyl patterns of behavior of radionuclides in forest ecosystems. Doctoral thesis, NUBiP Ukraine, 24 p. (Ukr.).

Statheropoulos, M., and Karma, S. 2007. Complexity and origin of the smoke components as measured near the flame-front of a real forest fire incident: A case study. J. Anal. Appl. Pyrolysis 78, 430-437.

Steinhauser, G., Brandl, A., and Johnson, T. 2014. Comparison of the Chernobyl and Fukushima nuclear accidents: A review of the environmental impacts. Science of the Total Environment 470-471, 800-817.

Trabalka, J., Eyman, L., and Auerbach, S. 1980. Analysis of the 1957-1958 Soviet nuclear accidents. Science 209 (4454), 345-53.

Ward, D.E., 1999. Smoke from wildland fires. In: Goh, K.-T., Schwela, D., Goldammer, J.G., and Simpson, O., eds. Health guidelines for vegetation fire events-background papers, 6-9 October 1998. Lima, Peru, WHO/UNEP/WMO, pp. 70-85.

Ward, T.J., and Smith, G.C., 2001. Air sampling study of the 2000 Montana Wildfire Season. Paper No 113. In: Proceedings of the Air and Waste Management. Conference, Orlando, Florida, USA.

Yoschenko, V.I., Kashparov, V.A., Levchuk, S.E., Glukhovskiy, A.S., Khomutinin, Yu.V., Protsak, V.P., Lundin, S.M., and Tschiersch, J. 2006. Resuspension and redistribution of radionuclides during grassland and forest fires in the Chernobyl Exclusion Zone: Part II. Modeling the transport process. Journal of Environmental Radioactivity 87 (3), 260-278.

Yoschenko, V.I., Kashparov, V.A., Protsak, V.P., Lundin, S.M., Levchuk, S.E., Kadygrib, A.M., Zvarich, S.I., Khomutinin, Yu.V., Maloshtan, I.M., Lanshin, V.P., Kovtun, M.V., and Tschiersch, J. 2006. Resuspension and redistribution of radionuclides during grassland and forest fires in the Chernobyl Exclusion Zone: Part I. Fire experiments. Journal of Environmental Radioactivity 86 (2), 143-163.

ANNEX. Illustrations of fire problems and fire management technologies on terrain contaminated by radioactivity, unexploded ordnance (UXO) and land mines

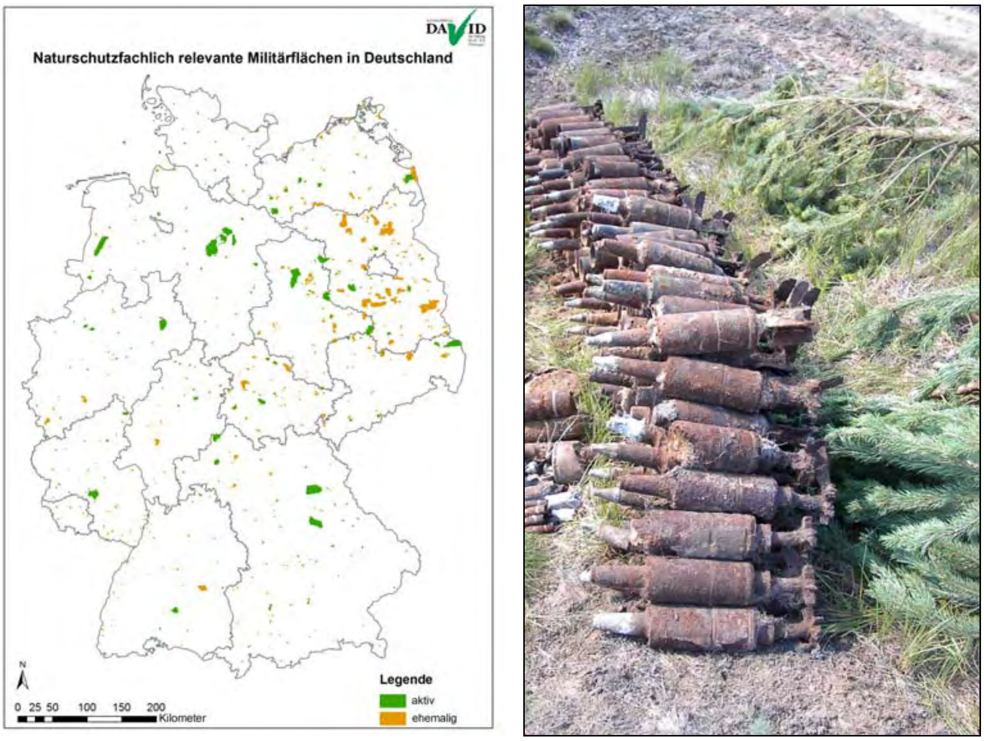
See next page

Annex:

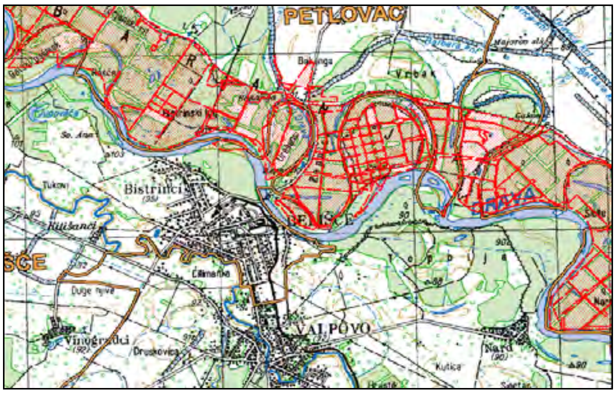
Illustrations of Fire Problems and Fire Management Technologies on Terrain Contaminated by Radioactivity, Unexploded Ordnance (UXO) and Land Mines

1) Examples of Explosive Remnants of War (ERW) / UXO and land mines with potential threats to firefighters and forestry personnel

Figures 1.1 to 1.3. ERW / UXO warning sign in the South Caucasus (left). Unexploded grenade embedded in organic layer, hardly visible (middle). Unexploded bomb embedded in sandy soil, a few centimeters below the surface – a threat to vehicles maneuvering on the terrain (Brandenburg State, Germany). Photos: GFMC.

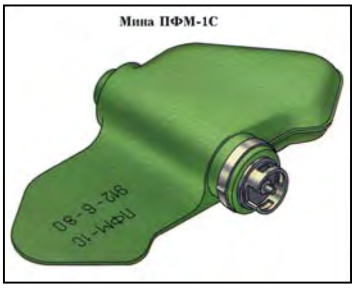


Figures 1.4 to 1.5. Maps of former and active military training areas and shooting ranges in Germany (Source: Foundation David) and UXO waiting for disposal by EOD Team (Brandenburg State, former Military Training Range Jüterbog Ost. Photo: GFMC.



Figures 1.6 and 1.7. Maps of land mine contamination in Croatia stemming from the armed conflict in the 1990s. Source: Croatian Mine Action Center.





Figures 1.8 to 1.10. Land mine contamination in Armenia. Source: Ministry of Emergency Situations, Armenia.


Figures 1.11 and 1.12. UXO explosions on former Soviet military training range in Brandenburg State, Germany. Photos: Brandenburg State Forest Service.



Figures 1.13 to 1.14. Unexploded grenades and bombs exposed after fire in Brandenburg State, East Germany (left and middle) and in the South Caucasus (Nagorno Karabakh) (right). Photos: GFMC.

2) Examples of general personal protection equipment (PPE) for safe fighting vegetation fires and specialized armored PPE


Figures 2.1 to 2.3. Protective vests, trousers and light firefighter helmets with glasses and smoke mask as used by the Global Fire Monitoring Center (GFMC) operations. Photos: GFMC.

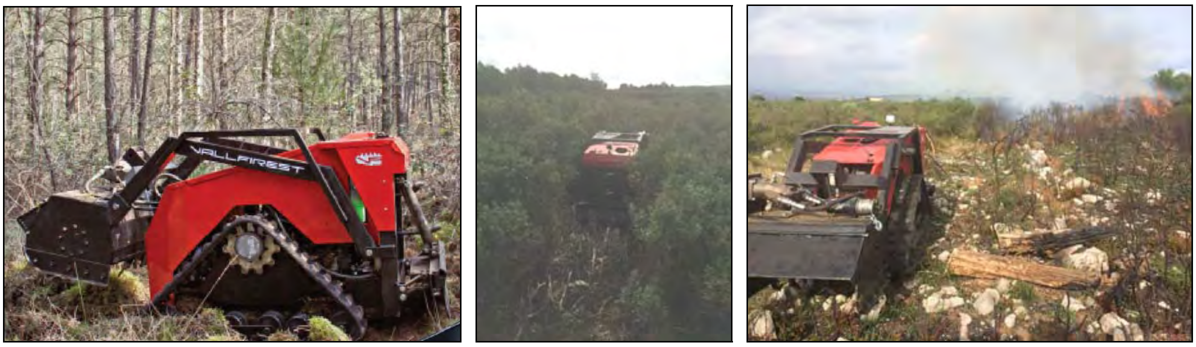

Figures 2.4 to 2.5. PPE in use by Global Fire Monitoring Center (GFMC) and partners in Germany and Brazil. Photos: GFMC.

Figures 2.6 to 2.7. Protective ballistic vest, helmet and visor for protecting control and rescue teams on UXO- and mine-contaminated terrain as used by the Global Fire Monitoring Center (GFMC) operations. Photos: GFMC.

Figures 2.8 to 2.10. Training in the use of the drip torch to set a prescribed fire for creating a “black buffer zone” without using hand tools digging and scraping, involving the risk of hitting UXO, land mines or releasing contaminated dust. Photos: GFMC.

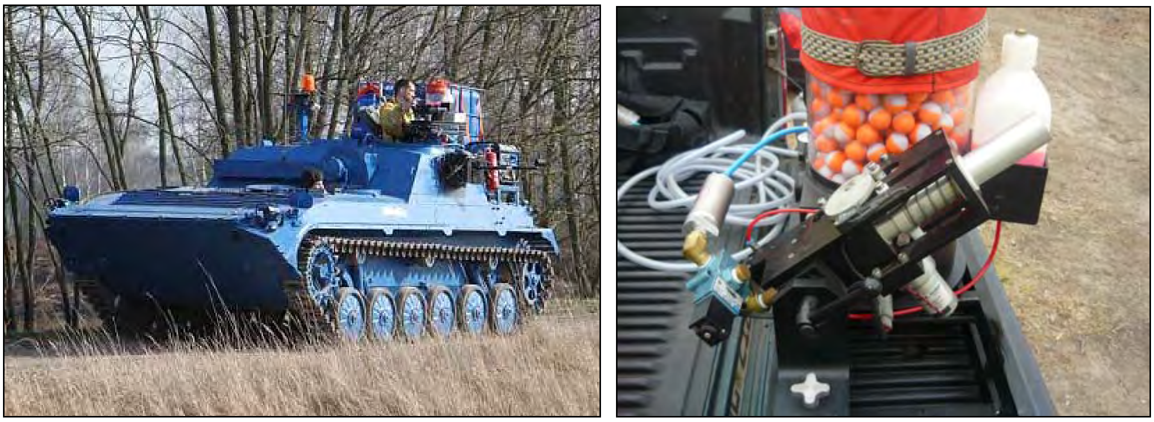
Figures 2.11 to 2.13. Training in the use of the drip torch to set a prescribed fire for creating a “black buffer zone” or to reduce flammable materials on the surface of the forests with high wildfire hazard. Boyarka Forest Research Station and Regional Eastern European Fire Monitoring Center, Kyiv, Ukraine. Photos: GFMC.

Figures 2.14 to 2.16. Standard firefighting situation involving hand tools for suppressing surface fires of low to moderate intensity in Brazil (left) and Germany (middle and right). Photos: GFMC.



Figures 2.17 to 2.18. Remotely controlled blade weeding machine designed to perform indirect forest fire attack by creating a fire line. This technology allows control personnel to stay outside of the impact zone of exploding ammunition or radioactive dust. Photos: Vallfirest.

Figures 2.19 to 2.21. Use of the SPOT-55 firefighting tank, a converted T-55 with 11,000 l of fire suppressant (water, foam) operated by DiBuKa, Germany, to safely control prescribed fires or wildfires on UXO- and radioactivity-contaminated terrain. Photos: GFMC.



Figures 2.22 to 2.23. Converted BMP-OT-R5 tank for use as armored ignition tank, equipped with the Pyroshot Green Dragon® for firing ignition devices to set prescribed or back fires. Photos: GFMC.

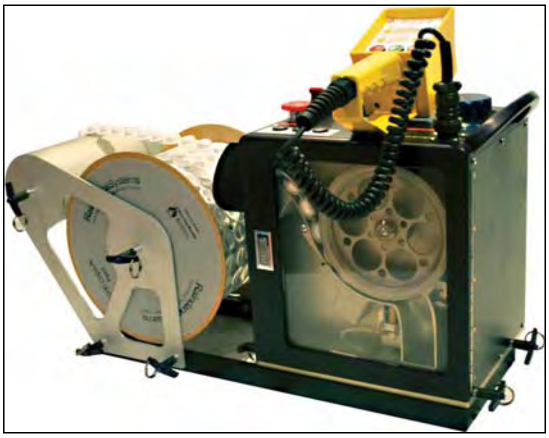
Figures 2.24 to 2.25. Converted BMP-OT-R5 tank for use as armored ignition tank, equipped additionally with an ATV drip torch to set prescribed or back fires. Photos: GFMC.

Figure 2.26. BMP-OT-R5 ignition tank setting a prescribed fire on UXO-contaminated terrain. Photo: GFMC.

Figures 2.27 to 2.28. Unmanned aerial systems (UAV), including fixed-wing and helicopter drones or tethered balloons, are prerequisite for wildfire incident management or prescribed burning on contaminated terrain in Germany. Real-time transmission of aerial observations of the fire allow the incident manager to control the operation from safe distance and to direct the manned armored or unmanned ground vehicles to the fire site. Photos: GFMC.

Figures 2.29 to 2.30. UAV-supported ground operations: The manned, armored ignition tank (blue) and the fire suppression tank (red-white) are directed via drone control. GFMC operations in Brandenburg State, Germany, on former military shooting ranges and WW-II combat theatres. Photos: GFMC.

Figures 2.31 to 2.32. Lockheed Martin Corporation (U.S.A.) has successfully tested K-MAX unmanned helicopters at Griffiss International Airport, airlifting and dumping water onto a controlled fire on 6 November 2014. Photos: Lockheed Martin Corporation.



Figures 2.33 to 2.34. Aerial ignition of backfires or prescribed fires by manned or unmanned small helicopters using the Raindance® miniaturized aerial ignition system will allow safe unmanned operations over dangerous contaminated terrains. Photos: Rainbow Services.

Figures 2.35 to 2.36. Aerial ignition pattern. Photos: Working on Fire International.