The Global Fire Monitoring Center (GFMC)

SNV Netherlands Development Organisation

THE BASICS OF FOREST FIRE PROTECTION

Guide for private forest owners

Prof. Nikola Nikolov PhD

ПРИВАТНИ ШУМИ

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наменето за сопственици на приватни шуми“

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INTRODUCTION

Forest fires are one of the factors which damage or destroy large areas of forests in a very short period of time. This has been evident in Macedonia, especially in the last fifteen years. The situation with the forest fires was most critical in the years 2000 and 2007 when approximately 80 000ha of forest and forestland were caught in fire and the number of forest fires was about 1100. A lot of direct damage was caused; burned wood, infrastructure damaged (electricity lines), fire suppression expenses etc, but there was also some serious indirect damage; soil erosion, diseases (dead trees give increased insects living under the tree bark. Very often, insects living under the tree bark at the fire sites of coniferous tree types may present a bigger and longer lasting problem than the fire itself.) This results in a loss of economic, environmental as well as social (recreational) values of forests.

All this implies that forest fire protection warrants more attention. The capacities of all participants involved (government and non-government, professional and volunteering) should be built. Fires recognize neither borderlines between states and municipalities, nor borderlines between state and private property.

This basic guide on forest fire protection is prepared on the basis of the past problems with forest fires, and the need to pay increased attention to forest fire protection. This guide is mainly aimed at private forest owners. However, this can also be used by other people directly engaged in forest or natural resources. It provides the basic and simple knowledge on forest fire protection with the aim to raise the level of forest fire protection and have people better prepared to find their respective place within the

system for protection of forests fire again. In the past, systems of forest fire protection included the involvement of local level structures (villages). This is at present not currently functioning in Macedonia anymore. This has resulted in non-effective forest protection and failure to make proper use of the existing human resources based on private forest owners. This guide hopes to contribute to prepare private forest owners in the future in finding their relevant place in the system for protection of forests against fire and should give their maximum contribution. Thus, they will not only protect their forests from fire, but thry will also contribute to the protection of our forests in general.

This guide has been developed under a wider programme for forest fire protection and education between the National Association of Private Forest Owners in Macedonia, Global Fire Monitoring Centre and SNV Netherland Development Organisation. The programme included basic training for private forest owners in three pilot areas in Macedonia, as well as discussion and analysis with all stakeholders regarding how to better involve private forest owners in the system of forest fire protection. This has resulted in recommendations and field practice at a municipal level in the pilot areas involving the private forest owners.

The guide firstly gives some basic theory and explains the causes of forest fires and forest fire classification (chapters 1-3). Chapters 4 and 5, which describe the protective measures and ways of forest fires suppression, are the core of the guide.

1. COMBUSTION

In the XVIII century, when developing the physics principles on indestructibility of matter, Lavoisier concluded that combustion is a chemical reaction in which oxygen unites with the fuel. The chemical process of oxygen bonding with other matter is known as oxidization, and its products are called oxides. Heat is released, during oxidization. Oxygen easily bonds with other matters; oxidization is a very common occurrence in nature.

Combustion is a fast and explosive chemical reaction, accompanied by light (flame) and the release of large quantity of energy (high temperature). Based on the state of the oxydator and the fuel, there are two types of combustion: homogenous and heterogeneous.

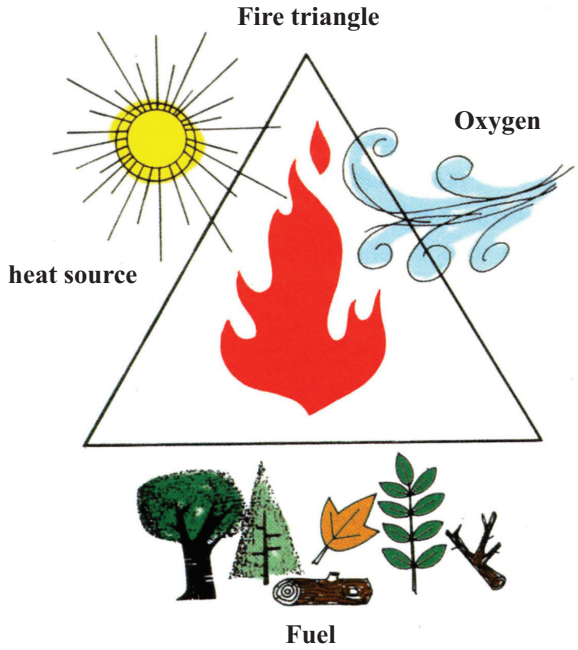
Homogenous combustion occurs when the fuel is a gas. This kind of combustion happens only under a certain ratio between the oxydator and the matter burning. When the ratio is misbalanced i.e. the presence of oxygen or the fuel is changed, there will be no burning even if these two elements are in larger quantities.

Heterogeneous combustion occurs when the oxygen bonds with a fuel that is solid or liquid. This type of combustion, unlike the homogenous, can occur under any quantity of burning matter. In this case the speed of combustion depends on the quantity of oxygen, i.e. the faster the oxygen is supplied, the faster the combustion will be.

As it was already mentioned, combustion is a chemical reaction accompanied by flame, during which heat and smoke are released. Burning cannot happen unless the following three elements are present:

a) fuel
b) oxydator (O2 – oxygen)
c) heat / heat source

Analyzing these three elements, Obsborn concluded that all three are equally important for the process of combustion, i.e. that combustion will stop in case any of them is eliminated (Drawing 1)



Drawing 1: Fire/ Obsborn triangle

a) Fuel

The matter created, naturally or artificially, that can ignite and burn is called fuel. Fuel can be: solid, liquid or gas.

Coal, wood, plastic, rubber, textile products, etc. are considered solid fuel.

Solid fuel has a compound process of combustion. Namely, the speed of combustion does not depend entirely on the supply of oxygen but also on the speed of oxygen combining with the specific surface of the fuel.

The material constituted from tiny dust particles, so called explosive dust, is also considered to be solid fuel. Such material is; zinc, aluminium, magnesium, coal, sulphur, sugar, flour, sawdust etc. This kind of solid fuel under certain circumstances can create an explosive mixture. An explosion can occur, if the air contains enough quantity of such dust with certain size of the particles, in touch with a heat source.

It was already stated that fuel can also be liquid. What is typical for this type of fuel is that it does not burn when in liquid form. Under the heat source, some of the liquid fuel evaporates and the evaporated material burns in combination with the air. This means that combustion of liquid fuels happens on its surface when the evaporated gases mix with the air (oxygen).

Combustion of gas fuels is the simplest form of combustion – homogenous combustion. It requires the presence of gas fuel in a certain mixture with the air and contact with a heat source for the combustion process to begin.

Explosive combustion can occur when the whole quantity of gas is in the certain mixture with the oxygen.

b) Oxygen (O2) – oxydator

Oxygen is one of the three elements necessary for the process of combustion to begin. Combustion is a process in which oxygen unites with the fuel.

Oxygen is a free gas, which represents 20.95% of the atmosphere, but it is also present in nature as bonded with other elements (in water, vegetation and many other matters). The bonding is by far more intensive if the process happens at higher temperature, especially during combustion. **All this means that if the supply of oxygen is increased, combustion will become more and more intensive due to the increased release of energy-heat.** This has been known to people long ago and it has been used in blacksmith's to enkindle burning coal in order to reach higher temperature. **On the other hand, if the supply of oxygen in the combustion area is reduced, the intensity of combustion will decrease.** If the quantity of oxygen in the combustion area is reduced to 16% or below, combustion will stop i.e. we say the fire extinguished. For instance, if a burning candle is placed under a glass bell (or other hermetically closed container) it will burn until the oxygen inside the container is reduced to 16% or below and will then extinguish.

c) Heat source

For the process of combustion to begin, not only the presence of oxygen and fuel, but also the presence of a heat source is required. The heat source can have different origin, such as natural occurrences (thunder strike, volcano eruption, chemical reaction - self-combustion, etc.), but it can also be a result of human activity.

Electrical discharging in the atmosphere (thunder strike) as a

reason for fire accounts for 1% of the total number of fires in the Balkan region.

Self-combustion, resulting from strong sunrays and the biochemical reaction in the fuel is rarely a reason for forest fires. It is almost never the reason which causes forest fires. The possibility of self-combustion is by far higher in agriculture where hay and straw or in the wood industry where sawdust or other easy flammable fuel are stored.

Various human activities are the main or basic cause (directly or indirectly) of fire in open areas.

1.1 WAYS OF TRANSFERRING HEAT

In cases where all three elements necessary for combustion (oxygen, fuel and heat source) are present, combustion will not begin unless heat is transferred to the fuel. Heat can be transferred to the fuel in a number of ways: radiation, conduction, convection, friction (mechanical) and through a biochemical reaction.

Heat energy is transferred by **radiation** when the heat source and the fuel are not in contact, i.e. are placed at certain distance. The radiation strength will depend on the degree to which the body that radiates is heated, its size and shape, the material from which it is made, etc.

Transferring heat by **conduction (conductivity)** is a feature of solid (bodies) objects. Namely, heat is transferred from one end of the object to the other and in case it is in contact with another body, it passes the heat onto this body. Objects are divided into good and bad heat conductors. For example, if we hold a wooden

and a metal rod and simultaneously place one end of each in fire the following will happen. We could be holding the wooden rod, although it has caught fire, until the fire gets too close to the hand with which we are holding, whereas we would soon drop the metal rod because of the quick spread of the heat from one to the other end of the rod; from the fire to our hand.

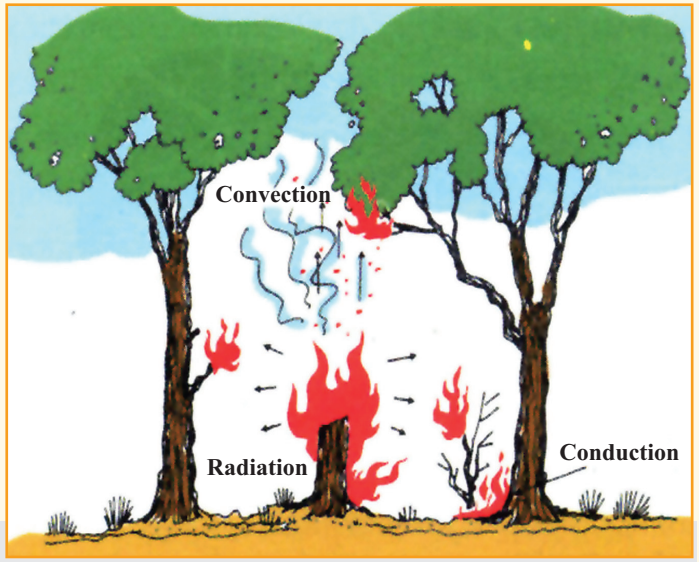
This example demonstrates that metals are good conductors of heat, while wood is a weak conductor. Air and materials that are easily spread (hay) are also bad heat conductors.

Transferring heat by **convection** or flow is a feature of liquid or gas matters. First of all, the layers which are closest to the heat source heat up, and then heat is transferred from hotter to colder layers. For instance, the ground layer of air is heated from the surface of the land, it then becomes lighter and rises upwards, and the colder and heavier air falls down from the upper layers, which leads to air masses flow. Another example can be that of a glass container filled with water placed on a heat source (stove). In a short while you will notice the flow of water from the bottom of the container towards the water surface (the hot and lighter water moves upwards), whereas the water from the upper layers moves downwards (the cold and specifically heavier water moves downwards).

Transfer i.e. creation of heat by **friction** occurs when two bodies rub against each other at a certain speed. Human beings have known this even in prehistoric times and in fact this is how they lit fire.

As a result of certain internal biochemical reactions within the fuel itself, there is a release of heat which heats the material to the point of self-conduction. This kind of combustion occurs with types of fuel that are easily spread (hay, sawdust, coal etc.)

The level/temperature of self-conduction is different for different materials.



Drawing 2:
Transferring heat

2. REASONS FOR THE OCCURRENCE OF FOREST FIRES

Our knowledge and experience so far indicates that in 99% of cases, man is the cause of forest fire (directly or indirectly). Thunder strikes and self-ignition as causes of forest fire account for only 1%. People cause forest fires due to recklessness, ignorance, cupidity, diversion, sickness-pyromania and other.

Under the category of fires caused by recklessness and ignorance come fires caused:

- By employees conducting certain agricultural and forest operations in the fields or forests. Such fires usually occur in early spring (working in the fields, afforestation) when grass vegetation from previous year is dry and new vegetation has not sprouted yet. Setting the stubble on fire is the most common case of fire caused by recklessness and such a method of cleaning the crops is forbidden by law in Macedonia.
- The collectors of forest fruits and herbs, hunters and fishermen, stockbreeders and tourists.
- Fires caused by technical objects in the forest (railway and road public transport, high voltage transmission lines, etc). The number of fires in open areas is large due to the absence of timely preventive measures (cleaning the surrounding area, verges by the side of roads and similar) around the objects mentioned.

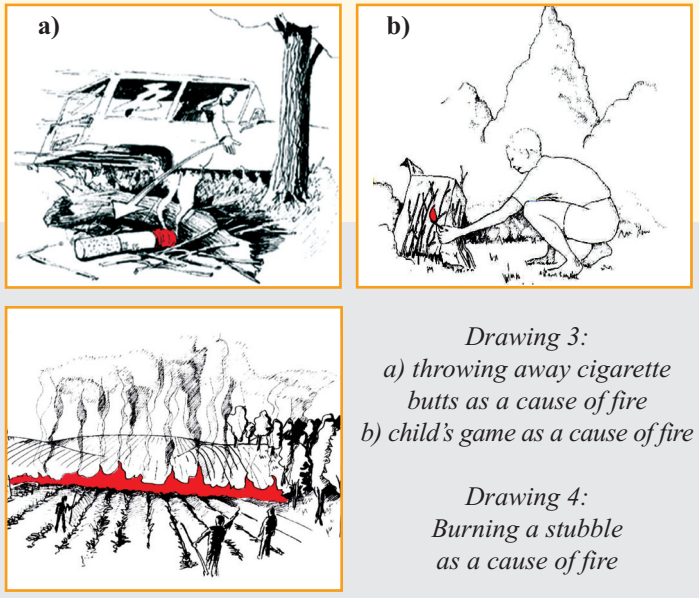
In the category of fires caused by cupidity and diversion are forest fires caused intentionally (arson) with a certain aim:

- In order to increase the agricultural lands or pastures, man burns forests without taking into consideration the consequences of such an action.
- In certain suitable weather conditions, some people intentionally set the vegetation on fire, as revenge on the foresters.
- Forests can also be intentionally set on fire for political reasons i.e. to make the country unstable with the large number of fires in open areas.

The category of fires caused by lack of awareness and pyromania encompasses:

- Fires caused by children's games with fire (children are unaware that such games can cause fire and be fatal for them)
- Fires caused by sick people "pyromaniacs" to whom setting objects or forests on fire and watching them burn presents a great pleasure.

Fires occurring during wartime are considered to be a separate category. These fires are not classified under any of the above listed categories.



Drawing 3:
a) throwing away cigarette butts as a cause of fire
b) child's game as a cause of fire

Drawing 4:
Burning a stubble as a cause of fire

3. CLASSIFICATION OF FOREST FIRES

There are several classifications of forest vegetation fires, but the most frequent one is the **classification according to the zone of active combustion:**

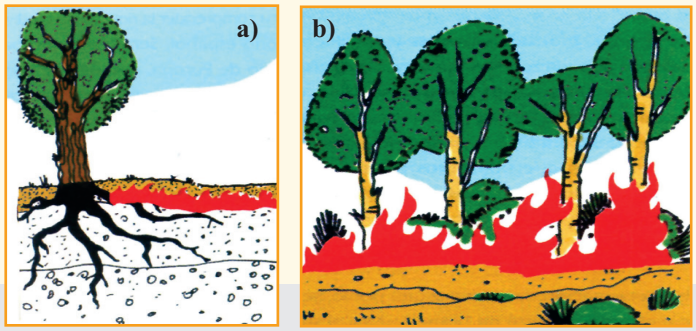
a) under surface fire
b) ground or surface fire
c) fire in the tree crowns and
d) total or combined fire.

a) Under surface fire

Under surface fire is very rear in our country. **In case of this kind of fire, combustion occurs under thick layers** of moss, peat, **undecayed leave, etc. i.e. combustion is in a kind of "glowing".** The fire spreads gradually and the smoke released fills the spaces between the fuels and unnoticeably comes to the surface. An exception to this is when it moves by the roots of some stump which acts as a chimney and the smoke comes out to the surface more intensively. **Noticing such fires is difficult. As a result such fires often remain undetected, but are noted by the fact that the entire vegetation above them dries out.**

b) Ground or surface fire

Ground or surface fire is considered a fire during which there is active combustion on the land's surface i.e. ground vegetation burns or the leaves with small fallen down branches, cones, etc. This is one of the most frequent fires and causes other types of fire (combined or fire in the tree crowns). **Depending on the field configuration and fuel distribution, this type of fire spreads very quickly. It is a serious problem when it comes to localizing and extinguishing.** Based on the above mentioned conditions and the presence or absence of wind, the flames in this type of fire can reach a height of up to 1.5m and more. In plains the intensive combustion usually happens at the fire edges, whereas in the mountainous areas it happens at the head of the fire. The speed with which this fire spreads (without strong wind) can reach up to 2.5 km/h.



Drawing 5:
a) under surface fire *b) ground or surface fire*

c) Fire in the tree crowns

Fire in the tree tops is a kind of fire in which there is combustion only in the tree tops. In most cases, the fire is in the individual trunks, but there are also cases when a larger area is on fire. Fire, sometimes, on marsh land or in case of very strong winds, simply "flies" through the tree crowns without coming down to the ground. **In such cases, due to the high speed, all that burns are the leaves, whereas branches remain only "half burnt".** This kind of fire can also occur as a phase of a combined fire when only the tree crowns burn. Because of the fact that the

combustion intensity is in the braches rich in leaves, and consequently humidity is higher, there is more smoke and flames. The spreading speed is high and occurs as explosive jumps – longer flames.

Drawing 6: Total or combined fire

e) Total or combined fire

Fires during which the surface fuel and the tree crowns both simultaneously burn are called combined or total fires. Because of this feature they are most difficult to localize and extinguish.

The spreading speed of such fires, depending on the field configuration, the type and distribution (vertical and horizontal) of fuel, as well as the wind speed can reach up to 20 km/h.

The spreading itself has three phases: **preparatory phase, fire jump and calming phase.**

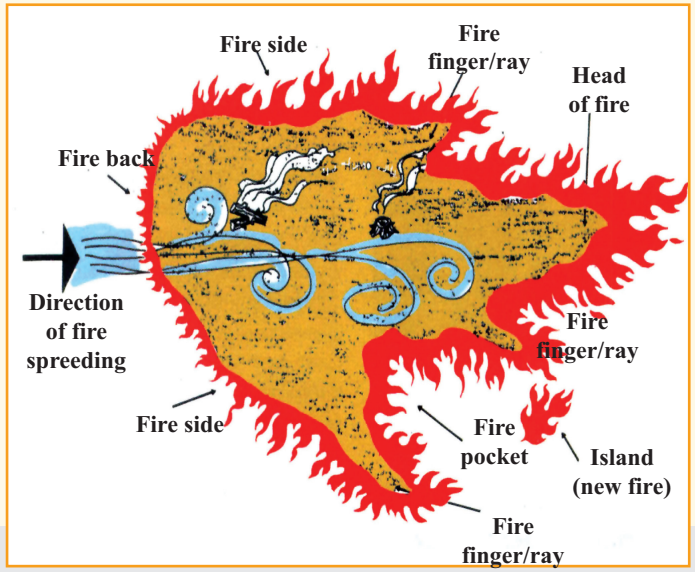
The preparatory phase is when the fire has reached the tree crowns and dries and burns the leaves. During this combustion the heat released is accumulated in the tree crowns and forms a heat pillar above the tree crowns. This pillar consists of hot air, smoke and other particles (partially burned wood particles, sparks, small pieces of leaves, etc.) This heat accumulated in the tree crowns and the convection pillars radiates and thus warms and dries the tree crowns in the area before the head of fire. When sufficient quantity of evaporated combustible gases is accumulated in the tree crowns in the area before the head of fire, at a certain point in case of intensive burning in the head of the fire, the gases in the tree crowns ignite in the area before the head of fire. This ignition can occur at different distances from the head of fire and is called the **fire jump.** That is the second phase of the fire spread and the jump can happen even at several hundred meters before the head of fire. This causes another fire in the area before the main head of fire. Then follows a **calming phase,** i.e. the "main" fire moves towards the new fire which comes down from the **tree crowns** to the ground, too. At these moments we get an impression that the fire has subsided, but in fact it is the first preparatory phase of a new fire jump occurs here.

The fire fighters should be familiar with this kind of fire spreading so much so as to avoid the danger of being caught between the two fires when there is a fire jump and putting their lives in danger.

Although it is not considered to be a separate type of fire and is basically a combined fire, we will also describe the oak shrub **"prnar"** (Quercus coccifera L) fire, which is most frequent in our country and has an explosive combustion because of the oils present in the leaves. During this fire there is a release of high temperatures which makes extinguishing very difficult. Extinguishing this kind of fire is difficult because the trees grow very densely and the area is inaccessible. This kind of vegetation is typical for the south and south-east part of Macedonia (Gevgelija, Valandovo, Demirkapija, etc).

Consequently combined or total fire is typical for this region.

In case of ground or combined fires, the following parts can be distinguished at the fire site: fire back, fire sides, fire fingers of rays, fire pockets, head of fire and islands (new fires).



Drawing 7:
Parts of a fire site.

Fire back is the place of the fire where burning is of lowest intensity and slowest spreading speed.

Fire side is the line of burning which is of stronger intensity and higher spreading speed compared to the fire back, but is not the main direction in which the fire is spreading.

Fire fingers or rays are parts of the head of fire. They are formed as a result of the fact that the head of fire reached areas where there is no fuel or the fuel burns with a lower intensity. The rays can later unite with the head of fire forming one line or they can continue in another direction creating new heads of front.

Areas between the fire rays are called fire pockets. They are extremely dangerous if the fire fighters or some other people are caught in them, without being aware that the fire has surrounded them.

The head of fire is the line of most intensive burning. It is the fire's main direction.

The island or new fire is a new hot spot in the area before the head of fire. It can be created by a fire jump, burning cone, burning leaf, etc.

4. PROTECTIVE MEASURES AGAINST FOREST FIRES

All measures taken as protection against forest fires, according to the time they are taken and their aim are divided into:

- **preventive measures**
- **preparatory measures**
- **suppressive or repressive measures**

4.1 PREVENTIVE MEASURES

These measures for protection of forest against fires are taken continuously throughout the whole year. These measures are directed entirely towards people as they account for 99% of the forest fires caused. **Their ultimate goal is to prevent the occurrence – cause of forest fires i.e. reduce the number of fires.** Based on this, they are the most effective measures for protection of forests against fires and according to their character and application they can be divided into:

Legal measures
Educational measures
Informative-propaganda measures

Legal measures

The State of Macedonia addresses these issues in the Constitution and other laws and by-laws. Under the law, protection of crops, grasslands and forests against fires is the responsibility of the owners or those managing the areas. Since forests are a national treasure, all citizens are responsible for the protection against fires. Thus, the Parliament passes normative acts which are further defined in by-laws. Owners and managers apply this in practice in pursuance of decisions, rulebooks, etc. This implies that the basic protection of forests against fires is primarily a responsibility of the owners of those who manage the forest. The legislation determines the measures and activities that need to be taken by the responsible subjects, for protection of forests against fires as well as the penalties for any failure to act accordingly.

Educational measures

TThese are measures which include educating people. They can be applied with all age groups; nevertheless they are most successful and useful for young people. These measures aim to point out the dangers that are brought about by fires, but also the benefits from their proper use. These measures are most effective with preschool children and primary school students.

These measures can be implemented in a number of ways. Various lectures on protection of forests against fire are one of the ways. The printed and electronic media can also be used (magazines, TV, radio, etc.) through suitable articles and shows. For this purpose specialized school magazines with rich contents can be published. Picture books or illustrated games which include contents dealing with protection against forest fires are effective with preschool children.

Their ultimate goal is to familiarize children with this area and to induce love for the forests and nature and in particular familiarize them with the consequences and damage of forest fires. All this helps them develop the right attitude towards the forest as a national treasure, love and a sense of responsibility towards the forest, that they preserve all their lives.

The above are permanent measures, i.e. are taken throughout the whole year and not only in the period of forest fires.

Informative-propaganda measures

CThese measures aim to warn or inform people (forest visitors, employees, etc.) about the dangers of forest fires, how to behave in forests and instruct them about the immediate measures in case of fire.

These measures can be implemented in a number of ways:

- Posting signs at visible places (main and side roads) in regards to forbidding fires in open areas, marking places in forests where fires are allowed, and signs forbidding movement in the forest.
- Organizing meetings and informative conversations with different groups of people (livestock herders, farmers, collectors of forest fruits, etc).
- These measures also include making mascots, badges, flyers, posters, public debates, etc. in order to inform about protection of forests against fires.

In order to achieve greater success, the informative – propaganda measures can be combined with the educational measures.

Drawing 8: Conversation with stockbreeders for information

4.2 PREPARATORY MEASURES

Bearing in mind the fact that the preventive measures can never completely prevent the occurrence of forest fires, other measures, the so called pre-suppressive / preparatory measures are also needed. **Preventive measures aim at preventing or reducing the number of forest fires whereas the pre-suppressive preparatory measures enable us to deal with a forest fire in an organized way.** These measures are taken throughout the whole year and they include:

- ***early fire detection***
- ***conveying the information***
- ***organizing transportation for the fire fighters***
- ***procurement of appropriate tools and equipment***
- ***recruitment and training of fire fighters***
- ***building fire fighting cuts, etc***
- ***Building fuel breaks***
- ***Fuel mapping and fuel reduction***
- ***Fire danger rating***
- ***Forest fire operational plan***

4.2.1 Early fire detection

Early fire detection is extremely important for its fast localization and extinguishing.

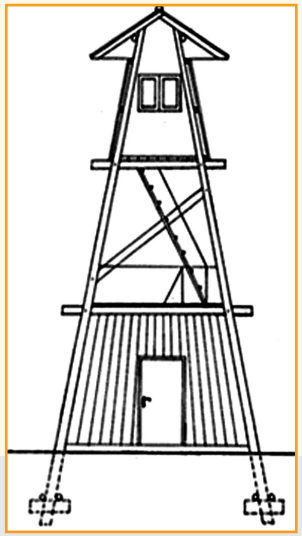
Early fire detection warrants the organization of a watch unit due to the fact that mountainous areas are frequently difficult to monitor and cover vast areas especially during the so called “critical period” of the year when the number of forest fires is highest.

. The watch can be performed in a number of ways:

a) field watch from the watch-towers
b) ground patrol
c) air watch
d) automatic and electronic watch

a) field watch from the watch-tower

Field watch from one or several points is performed by people (watchmen) from the already built watch-towers or from the existing constructions. The watchman should be equipped with a field map, instrument for determining angles (compass) binoculars, radio or signalizing instrument, handy tools for manual extinguishing (shovel, mattock, iron broom, water bags, etc.).



Drawing 9: Watch-tower

b) Ground patrol

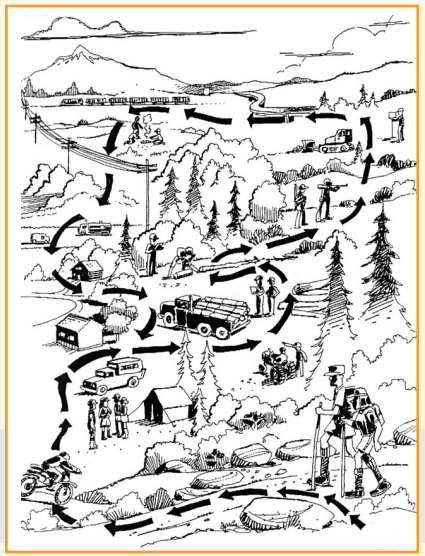
Following certain routes through the forest, on foot, animals' backs or in vehicles is called patrolling. Patrolling can be organized separately, or it can be just a part of some other activity performed by the same person (for example forester, forest worker, forest engineer, etc.). The person or people patrolling should have a radio so as to timely report an occurrence of fire.

c) air watch

More developed countries or countries possessing large forest areas employ aircrafts (airplanes, helicopters, etc.) for early fire detection. A special air-unit can be formed or sports and passenger flights can be used. The planes which are part of the special units can carry water and immediately commence extinguishing the fire.

d) automatic and electronic watch

This kind of watch is a more recent way to discover fires and is used primarily for the inaccessible areas and large areas of forests. These are specially equipped stations (with cameras and other electronic equipment) which automatically and independently (without human presence) watch the field, and in the event of fire, send information to the relevant centre. Besides their numerous advantages, there are also disadvantages, such as giving false alarm caused by a flock of birds or insects which are registered by the station as fire smoke.



Drawing 10: Walking patrol for early detection of fires

4.2.2 Conveying the information

Early fire detection without conveying that information fast would not have the desired effect. The most appropriate way to convey the information is the use of a radio. A high quality network of transmitters and relays which will enable high quality coverage over the entire territory and suitable equipment for the watchmen (radios, mobile telephones) is required.

4.2.3. Organizing transportation for the fire fighters

Organizing transportation for the fire fighters to the fire itself is also of great importance. Provided that we have detected the fire early and conveyed the information fast, the organized transportation of the fire fighters to the fire itself will enable them to arrive at the fire site and localize and extinguish it. Fire fighters and their equipment can be transported with the use of animals, off-road vehicles, helicopters, etc. This depends on the access to the site and the economic strength of the county. The routes and the time needed for transportation are planned ahead of time, which reduces the intervention time when a fire occurs.

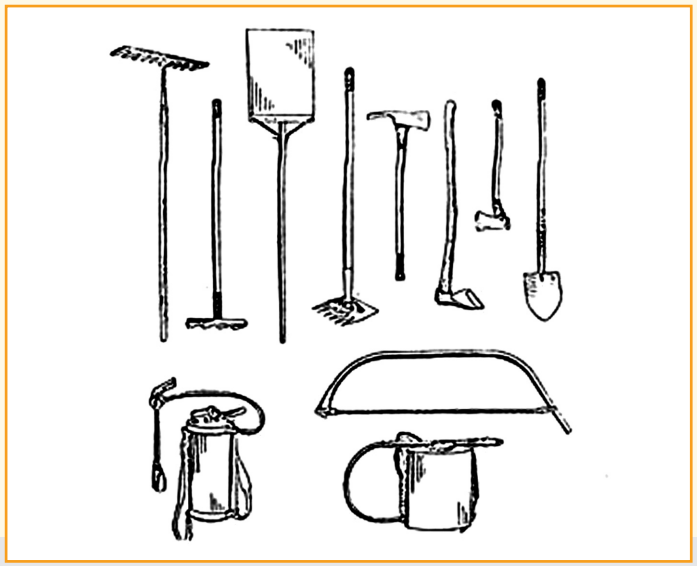
4.2.4 Procurement of appropriate tools and equipment

Apart from the sufficient number of well trained fire fighters, the procurement of suitable tools and equipment for localizing and extinguishing fires is also of great importance. This implies that the procurement of tools and equipment for localizing and extinguishing fires should not be always the same i.e. it depends on the type of fuel, field configuration, training of fire fighters, etc. For example, for an area dominated by grass vegetation, there is a need of steel brooms, shovels, mattocks, back bag pumps, etc., whereas for an area with tall forest, in addition to the above

listed tools, there is a need of motor saws, axes and heavier machinery (bulldozer, tractor, etc.). The tools should always be in operational state (sharpened, solid handles, etc.) and kept in special places for that purpose. The heavy machinery, otherwise used in every day work, can be mobilized during forest fires and should be in a proper working order.

Conditions that need to be fulfilled by the tools and equipment:
- they should have better efficiency and productivity
- they should be more universal
- they should be easily transportable
- they should be durable i.e. made of high quality material
- they should be simple to use

According to the kind of work performed with the tools and equipment, they can be divided into:
- equipment and tools for cutting and pulling down trunks
- equipment and tools for raking, pushing and hitting
- equipment and tools for digging and building firebreak
- equipment for water
- equipment for starting a counter fire
- equipment for lighting when extinguishing fires at night
- equipment and tools for mining.



Drawing 11:
Tools for localizing and extinguishing fires

4.2.5 Recruiting and training the fire fighters

Localizing and extinguishing forest fires is an extremely difficult physical and psychological activity. In most cases the field conditions are severe (high temperature, inaccessible and steep areas, high smoke concentration, etc.). **The fire fighters selected should be healthy, both mentally and physically, and well trained.** They should be familiar with localizing and extinguishing tactics as well as with the tools and equipment for those purposes.

4.2.6 Building of fuel breaks

In order to localize and extinguish bigger forest fires, fire fighters should have a defensive secure position or a fuel break from where they would extinguish the fire. Because of the high heat and spreading speed, these positions are created at a certain distance in the area before the head of the fire. Fuel should be removed from the area in front of the head of the fire. In order to gain more time, fuel is removed prior to the occurrence of the forest fire creating the fuel break. Fuel breaks are places permanently cleaned of fuel. **They are created during regular forest activities and are clean areas without any fuel.** Sometimes plants that do not burn easily can grow in the fuel breaks. The width of the fuel breaks varies depending on the trunks' height, the field steepness, etc. but on average they are between 6m and 50m wide. Fuel breaks can also serve as fire fighting paths for quick intervention.

4.2.7 Fuel mapping and fuel reduction

As it was already stated, apart from other factors, the possibility of a fire break and the fire behaviour are predicated upon by the type of fuel and its characteristics. The knowledge of the fuel characteristics and its field distribution determine the measures, such as the choice of suitable tools and forest fire extinguishing equipment, the choice of suppression tactics under certain circumstances (weather, terrain configuration), etc. Because of this importance of the fuel, and in order to get a clear picture of the field situation, the fuel is **mapped** and classified in classes of fuel. This data serves to better organize protection against fires as part of the other pre suppressive measures.

Fuel reduction measures are taken on sites where it is estimated

that the quantity of fuel is high and of such characteristics that it poses a threat of fire occurrence. This can be performed in a number of ways depending on the type of vegetation, equipment and people available, legislation, etc:

- grass mowing
- treatment with herbicides
- prescribed / controlled burning, etc.

Using fire (prescribed / controlled burning) is a very effective way of fuel reduction, but its use requires appropriate knowledge. In our country, this way of fuel reduction is most often used for eliminating the remains after harvest cut, especially sanitary cut, and is also used in general for fuel reduction during regular forest activities. Appropriate training of people, combined with legislation, would significantly contribute to the reduction in the number of fires.

4.2.8 Fire danger rating

The primary aim of this measure is to determine the danger of a fire break in space and time as precisely as possible. This means answering the question: are there conditions for the fuel to start burning and where? There are several methods of varying precision, mostly based on the weather conditions and the characteristics of the fuel. This estimation can be long-term and short-term.

The long-term method is based on past statistical data, climate characteristics of the region, type of vegetation, human factor, etc. It is with lower precision and refers to a longer period of time.

The short-term method of fire danger rating, i.e. the daily forecast, is more important. It is based on the weather conditions during the day and the state of the fuel (mostly on the percentage

of humidity in it); in fact it gives the probability of a fire break within a 24 hour period. This enables the relevant institutions and the rest of the citizens to take measures aimed at stopping the fire outbreak (prescribed for each degree of danger) or to increase the degree of readiness of the fire fighting forces on a timely bases.

4.2.9 Forest fire operational plan

The organizations which manage forests and forest lands are required by law to prepare annual operational plans for protection against forest fires. These plans consist of three parts.

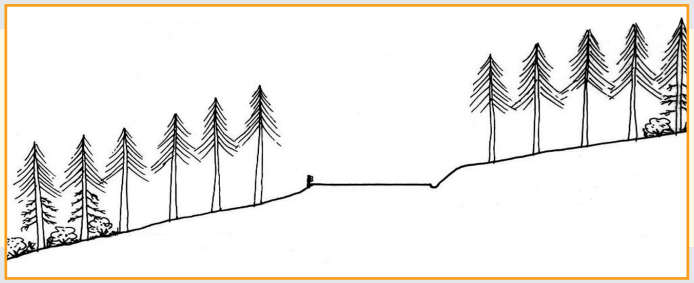
In the first part, a review and analysis of the situation with the forest fires in the past in that region is prepared, taking into consideration all the aspects (number of fires, causes, burnt area, fire extinguishing equipment and tools used, tactics, number of people included, the weather conditions, hour of the day when the fire started, locations, etc.).

After the detailed analysis in the first part, based on that data, in the second part the preventive and pres suppressive measures for the following year are planned.

The third part consists of a detailed list of people who will implement those measures with precise dates and deadlines included. For the purposes of the planned watch during the critical period of the year for fire breaks, a detailed list of people, equipment and vehicles divided into teams with the watch time is also prepared.

The procedures to be followed in certain situations and various maps (maps of fuel, roads, water reservoirs, etc.) are included as an annex to this plan.

Drawing 12: a) clean fuel break



Drawing 12: b) a road as a fuel break

The above stated clearly points out the importance of the preparatory measures. They are of great importance. The efficiency of the suppressive measures depends on them.

4.3 DIRECT OR SUPPRESSIVE MEASURES

Wild fires will occur regardless of the best preventive measures. This creates a need for suppressive measures. These are measures taken during the fire and their purpose is to localize and extinguish the fire.

In order to localize or extinguish a fire, it is necessary to remove one of the elements from the so-called Obsborn triangle, i.e. the material burning, the heat source or the oxygen. Depending on the material used for that purpose, the extinguishing methods are divided into:

a extinguishing a fire with soil (soil method)
b) extinguishing a fire with water (water method)
c) extinguishing a fire with fire (fire method)
d) extinguishing a fire with chemicals (chemical method)
e) extinguishing a fire with explosive (explosive method)
f) extinguishing a fire by plane (air-bombing)

Drawing 13: Removing some of the elements of the fire triangle

a) extinguishing a fire with soil (soil method)

Apart from the water method, the soil method is the oldest fire extinguishing method. Soil or sand is used in this method. **Depending on the extinguishing tactics used, soil is thrown directly onto the flame of in front of it.** The soil acts as an insulator i.e.

removes the oxygen from the fuel (by covering the fuel burning with soil, the air cannot get in contact with it and burning stops). The soil acts as a heat insulator too i.e. the heat energy needed for the tree to burn cannot get to it because of the layer of soil over the fuel. Therefore, the fuel cannot ignite or at least it does not ignite easily.

b) extinguishing a fire with water (water method)

As it was already stated, the water method is the oldest form of extinguishing fire. **Water has a multi fold influence on the combustion process.**

First of all, water on either the fuel burning or the fuel in the area before the head of fire, wastes the heat energy on the evaporation process, thus reducing the temperature below the ignition point. As a result, the fire dies down.

Second, because of water evaporating, the presence of steam in the air increases. The steam and smoke released from the fire reduce the percentage of oxygen in the air which reduces the intensity of the fire or sometimes extinguishes the fire (depending on the thickness of the steam and smoke).

There are numerous tactics and various equipments for this method (from manual to mechanical equipment). It is a highly successful method but the problem is that there is not always water near the fire and it has to be transported to the fire site. Transportation is a serious problem because of the inaccessible mountainous areas which makes employing this method more difficult and diminishes its efficiency.

c) extinguishing a fire with fire (fire method)

In this method, fire is used to extinguish a fire. This method clears the field from fuel, which extinguishes the fire. In fact,

depending on the localizing and extinguishing tactics used, at a certain distance from the fire a "controlled" fire (which can be moved in the same or opposite direction of the main fire) which burns the fuel in the area before the head of fire is lit. **When the fire reaches the area where the "controlled" fire was, there is nothing left there to burn so it extinguishes.**

It is worth mentioning that this is a highly effective but risky method. **This method is employed only by experts and experienced people** (fire fighters) by completely securing the "controlled" fire i.e. securing that it does not get out of control and lead to unwanted consequences.

d) extinguishing a fire with chemicals (chemical method)

In this extinguishing method different chemicals are used. Basically, this is a water method, due to the fact that all the chemicals, with almost no exception, are dissolved into water and improve its characteristics. Up to 70% of the water used in extinguishing forest fires is wasted. **That is the reason why different chemicals are added to improve the extinguishing effect.**

Besides its many advantages, the biggest drawback of the chemical method is the chemicals' price (some are really expensive), some harm the environment i.e. pollute the environment or are even toxic. Recently a lot of attention has been paid to the environmental aspect of the chemicals and almost all of them have the environmentally friendly sign.

e) extinguishing a fire with explosive (explosive method)

Under certain circumstances, explosive can be used to localize and extinguish forest fires. Depending on the need, the explosive

can be used as an addition in other methods (pulling down trunks, digging canals, making firebreaks, etc) or directly for extinguishing.

When used directly for extinguishing, the explosive works in two ways. When explosive set in the ground explodes a huge "dust cloud" is created, which reduces the percentage of oxygen in the air, thus reducing the fire intensity or completely extinguishing the fire. This explosion also removes the fuel so there is nothing left to burn.

The second way involves an explosion caused at the moment when the head of fire is above the set explosive. Apart form the above stated, in this case the air stretches rapidly (an explosion) as a result of which the fire is left without any air i.e. oxygen, so it dies down.

This is a highly effective method which can replace a lot of fire fighters, but at the same time it is extremely dangerous and risky, unless it is correctly and timely applied. **Due to all this, explosive should be used very carefully by experts and people trained for this purpose.**

f) extinguishing a fire by plane (air-bombing)

Basically, this is a water method (sometimes even chemical), but because it is very specific, it is classified as a separate method. Apart form planes, helicopters are also used for this method nowadays. There are specialized types of planes for this purpose, but other planes for different purposes are also used.

This is a very appropriate method because of the speed of planes and helicopters, their coverage (they can cover vast territories), their access to the inaccessible terrains (especially mountainous), the quantities of water they can carry, etc.

Localizing or extinguishing can be done individually or in combination with ground fire fighters.

The methods for localizing forest fires were described in the previous chapter, but whether they will be applied separately or in a certain combination depends on a number of factors, primarily on the type of forest. Based on this, the forest fires extinguishing tactics are generally divided into:

- tactic for localizing and extinguishing an ***under surface fire***
- tactic for localizing and extinguishing a ***ground/surface fire***
- tactic for localizing and extinguishing a ***total or combined fire***

5.1 TACTIC FOR LOCALIZING AND EXTINGUISHING AN UNDER SURFACE FIRE

This tactic is used for localizing and extinguishing under surface fires. Under surface fires are specific forest fires which appear under the surface of the fuel (usually these are deep layers of peat, leaves, etc.). What is typical for them is that the combustion occurs beneath the surface without any flame and small quantity of smoke. These fires are very difficult to detect, localize and extinguish.

The localizing and extinguishing tactic employed is that of digging insulation canals in front of the head of fire. In fact, detecting the fire edge is the most difficult thing. In order to detect the fire edge, trial canals up to the hard soil deep are being dug. After the fire edge is determined, at a certain distance in front of it, but parallel to it, an insulation canal is dug. This canal is 50cm wide and deep up to the hard soil or as deep as possible. This is a difficult procedure because of the type of fuel – peat (undecayed organic matter), the terrain, tree roots, etc. While digging the insulation canal, the material that is being dug out is thrown on the

surface of the fire site. In case the canal comes across trunk roots already caught in the fire, the whole trunk is considered as taken by the fire and is rounded by the canal. Once the whole fire is surrounded with an insulation canal, if there is water in the vicinity, it is best to fill it with water.

As it was already pointed out, this type of fire is very specific and difficult to extinguish, therefore people have to watch it for a certain time to make sure that it is completely extinguished and has not spread.

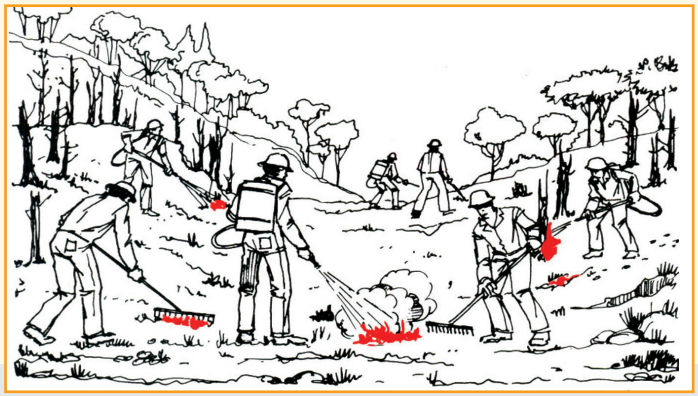
5.2 TACTIC FOR LOCALIZING AND EXTINGUISHING A GROUND/SURFACE FIRE

During ground/surface fires, the fuel burns on the surface with flames reaching usually up to 1.5m in height. There are various methods of localizing and extinguishing ground/surface fires depending on a number of factors, but generally they are divided into two basic groups: direct and indirect.

The direct method of localizing and extinguishing a fire is employed when the fire allows the fire fighters to get closer to the head of fire (the speed is low max. 500m/h, the flames height is approximately 0.5m, etc.). Under such circumstances, fire fighters can directly spray water onto the material burning at the fire front, throw soil, hit the flames with the so-called "iron brooms" or combine simultaneously some of the above mentioned methods.

Apart from these methods, there is also the method of "two feet", which is in fact a combination of the direct and indirect way of localizing and extinguishing a ground/surface fire. At a certain distance away from the fire (as close as possible) the fuel

is cleaned in such way that a 60 cm wide rail is formed, and soil is dug and thrown directly onto the fire. In this way the fuel is removed from the terrain and a clear surface approximately 60cm wide is created. At the same, time throwing the soil directly onto the flames suffocates and extinguishes the fire.



Drawing 14: Application of direct and indirect methods

Drawing 15: Method of two feet

When the fire moves at a higher speed (above 500m/h, sometimes even 2.5km/h), and the height of the flames is up to about 1.5m, some of the above mentioned ways cannot be employed. The so-called indirect methods are used for localizing and extinguishing.

The **parallel method** is one of the indirect methods. When this way of extinguishing is employed, the fire method, i.e. fire is used. Depending on the speed and strength of the fire, the terrain configuration, the number and skills of the fire fighters, another controlled fire is lit at a certain distance from the fire. The controlled fire is parallel to the main fire i.e. they move in the same direction. **After the controlled fire burns down an area of about 4-8m wide before the fire head, it is extinguished by the fire fighters who control it by applying some of the direct methods.** When the fire reaches the burned down surface it will die down because of the paucity of fuel.

There is another way in which fire is used when extinguishing a ground/surface fire, the so-called **counter fire.** In this case, depending on the fire spreading speed and the terrain configuration, a controlled fire is lit in the area before the head of fire. The difference compared to the previous case is that the controlled fire moves in the opposite direction i.e. is moving towards the main fire. When the two fires get in contact, there is intensive burning first and then the fire dies down because there is no fuel left.

In both cases, when the fire method is used, there is a danger of the controlled fire spinning out of control. Because of all this, we should be very careful when employing these two ways of extinguishing fires, and they should be employed only under command of experts and experienced people.

Another indirect way of localizing and extinguishing ground/surface fires is making a **fire break.** Depending on the

fire spreading speed, the terrain configuration, the number of fire fighters and their equipment, at a certain distance from the head fire a fire break is made. **This means that all the fuel from the terrain is removed forming a 2-4m wide line.** The leaves and fallen branches, one-year old plants, bushes and low trunks are removed. The older trunks with thick bark (such as oak, pine, etc.) are not removed but their lower branches up to 2-2.5m high are cut. When making the fire break, the existing firebreaks such as rocks, springs, areas without vegetation, roads etc. should be used. These breaks are used as parts of the fire break which makes things easier and increases the efficiency. **After the fire break has been cleaned, a canal about 0.5m wide is dug in the middle down to the mineral layer depth.** The soil that is dug out is thrown on the side where the fire is burning. When the fire reaches the fire break it encounters a cleared surface with no fuel and as a result it dies down. The fire fighters wait on the other side of the fire break ready to react in case there is a possibility of the fire crossing over the fire break. In such a case, the fire is extinguished with some of the direct methods. This method is very effective but it requires a sufficient number of fire fighters, sometimes machinery and above all good organization.

5.3 TACTIC FOR LOCALIZING AND EXTINGUISHING A TOTAL OR COMBINED FIRE

Localizing and extinguishing total or combined fires is one of the most difficult task in the area of forest fire protection. During these fires all the fuel on the ground and the trunks burns, and the central burning point is located in the tree crowns , which is why

these fires are also called high fires. The fire spreading speed and the quantity of energy released i.e. the temperature makes their localization and extinguishing more difficult. The spreading speed varies from 2-6 km/h, but there are also fires that spread at over 20mk/h (for example, hurricane fire, wild fires, etc.). The temperature released during combined fires is over 1000 C. All this, combined with the inaccessible mountainous terrains, makes extinguishing these fires extremely difficult or even impossible. Localizing or extinguishing these kinds of fires can last for a couple of days or even a couple of weeks. As a result, only indirect ways of localizing and extinguishing are used for combined fires. The best known are:

a) wide firebreak
b) Counter fire
c) Air-bombing
d) Mining – using explosive

In almost all of the above mentioned ways of localizing and extinguishing combined fires, the main aim is to lower the central burning point, which is located on the tree crowns, down on the ground and extinguish it there. They can be employed separately, or they can be combined depending on the terrain configuration, the size of the head of fire and its characteristics (spreading speed, intensity of burning, etc.), the available equipment, the number and training of the fire fighters, etc.

a) Wide firebreak

The wide firebreak is made during the fire. **The fuel is cleaned at a certain distance from the head of fire and a wide firebreak is made** (depending on the spreading speed and the terrain

configuration). First, the direction of the firebreak is determined. It is best to use an existing road, an area without vegetation, a spring, a river or some other barrier that already exists. In cases of developed relief, the best position for a firebreak is the mountain or hill slope. Once the firebreak route is determined, it is marked or one person goes in the front determining the direction, while the others follow him/her with chain saws or other tools cutting the trunks that enter the firebreak. The firebreak width can vary, but the smallest one should be at least twice as wide as the highest trunks near the firebreak. For example, if the highest trunks are 20m, the firebreak width should be at least 40m or more if it is deemed necessary. The trunks are cut so as to fall with the tops towards the fire, and with their other side towards the area we are protecting. Next, the branches are cut and cleaned together with all the combustible material on the ground within the borders of the firebreak (leaves, fallen down brunches, grass vegetation, bushes, etc.). The collected combustible material on the half towards the fire is thrown on the fire side. In this way, a clean area, couple of meters wide, without any fuel is made in the middle of the firebreak. In this area following an imaginary line in the middle of the firebreak a canal 0.5-1m wide is dug down up to hard material depth. The soil that is dug out is thrown on the side of the fire. The fire fighters with their equipment are distributed behind this firebreak. When the fire reaches the firebreak, it first gets to the tree crowns of the pulled down trunks and they start to burn intensively . This lowers the central burning point closer to the ground. After the crowns burn down, the fuel pilled up when cleaning the firebreak and the logs from the cut trunks start to burn which lowers the central burning point even closer to the ground. The fire intensity weakens. Eventually, the

surface fire reaches the dug canal – trench and dies down there.

During all this time the fire fighters make sure the fire does not cross over the firebreak at any point and extinguish it in case it does. If possible, it is recommended to water the fuel placed on the half of the firebreak towards the forest we are protecting. The most critical moment is when the fire reaches the firebreak so the pulled down crowns start to burn. The most care should be taken at that moment.

Making a wide fire fighting firebreak is a wide-scope task that needs to be completed as fast as possible. A larger number of fire fighters with appropriate equipment are needed. Heavy machinery (bulldozer) is also recommended as it would make things happen faster and better.

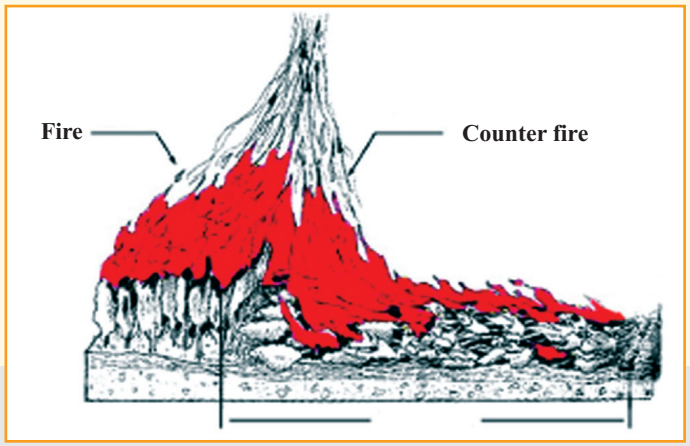
b) Counter fire

The fire method is used in this way of extinguishing. **At a certain distance away from the head of the main fire a controlled fire directed towards the "main" fire is lit,** which is why this method is called counter fire.

First of all, at a certain distance form the head of fire, depending on the fire spreading speed and the terrain configuration, the line where a counter fire will be lit is determined. Then, this line, a couple of meters wide, is cleared of the fuel, i.e. the standing trunks are cut, the leaves, fallen down branches and the grass vegetation, etc. are collected. The fuel is thrown in the direction of the fire. At a certain moment, when favourable conditions are created, the pilled up fuel ignites. Favourable conditions for starting a counter fire are when the fire moves in a direction opposite of the main fire direction. When there is wind that blows opposite the main fire, the counter fire gets the desired direction. This wind can be a natural shift in the wind direction or can result from the fire itself which creates air masses which move opposite the fire. This situation is used mostly when the fire is lit on flat terrains.

In case of steep terrains, the counter fire makes use of the steepness and moves upwards. This is used when the counter fire is lit on one side of the mountain or hill slope where as the main fire is on the other side so the two fires meet on the top.

When the two fires collide, there is intensive burning first, which later on abates and dies down completely. **The fire dies down as a result of the fact that the counter fire burned down the fuel in the area in front of the head of fire so there is nothing left to burn.**



Drawing 16: Counter fire

This is a very effective way of localizing and extinguishing combined fires, but it is also very dangerous as a new fire can appear if the controlled fire escapes our control. Roads, fuel breaks (constructions already existing in the forest), etc. can also be used when causing a counter fire. When the counter fire is lit it has to be secured by fire fighters who would prevent the fire from getting out of control. They also carefully watch the moment when the two fires, the main and counter fire, collide which creates intensive burning. The risk of the fire spreading-jumping over the defence line is highest at this point. In such a case, the fire fighters intervene and extinguish the fire.

All the above stated implies that this way of localizing and extinguishing combined fires is not only very effective but also very dangerous and requires know-how and field experience on the part of the people responsible and the fire fighters.

c) Air-bombing

When this way of localizing and extinguishing combined fires is employed, planes and helicopters are used and the extinguishing method is usually water or chemical. **The aircrafts can be used in two ways: when they extinguish the fire alone (without the fire fighters on the ground participating) and when they localize and extinguish in cooperation with fire fighters on the ground.**

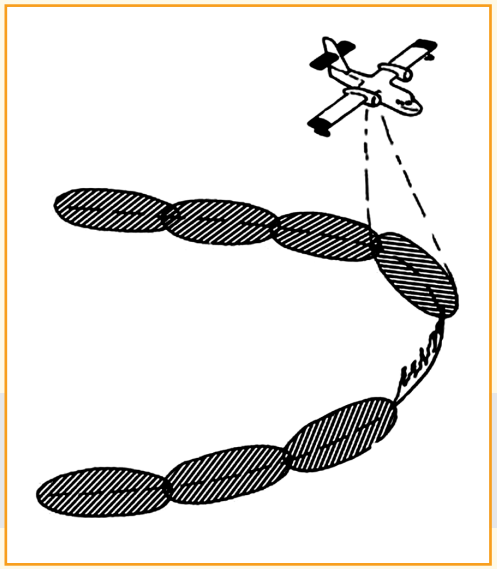
In the first case, the fires are in the initial phase i.e. at the very beginning, or are small scale fires. This is used very rarely with combined fires only in cases of inaccessible terrain.

In the latter case, aircrafts are used in combination with fire fighters from the ground. The planes and helicopters release the water or chemical on the head of fire or at a certain distance before it. When the water or chemical is released over the fire, extinguishing and lowering the central burning point from the tree crowns onto the ground happen simultaneously. **Immediately after the water is thrown on the fire, the fire fighters on the ground approach and start to extinguish the fire, which at this point is a ground/surface fire. This is possible when the fire is not of great speed and intensity, which allows the aircrafts to get very close to or just over the fire.**

In case of a fast and intensive fire, the aircrafts cannot fly close to the fire or above it, at the required height, so they release the water or chemical in the area before the head of fire. This wets the fuel in the areas before the head of fire. When the fire reaches the wet fuel its heat-energy is wasted on water or chemical evaporation. As a result, the fire subsides i.e. the central burning point is lowered from the crowns onto the ground. At his moment the fire fighters approach to extinguish the fire.

There are different ways in which the water or chemical can be released (at once or in several phases) and this can be done from different heights. The tactics vary also in the number of available aircrafts i.e. whether they will extinguish the fire in a series one after the other or each aircraft will extinguish a different part of the fire.

Employing aircrafts is the most modern way of localizing and extinguishing forest fires but it is also very expensive because of the price of aircrafts, their maintenance and flying expenses. Apart form this, the pilots and fire fighters on the ground need to be well-trained in order to have a synchronized and effective extinguishing.



Drawing 17: Employing air method

d) Mining – using explosive

Although very effective, this manner of localizing fires is used very rarely, almost never, in our country due to the danger coming from the explosive. Explosive can be used for making canals, wide firebreak, pulling down trunks, i.e. clearing –removing the fuel in the area before the head of fire. This is the indirect way in which explosive can be used.

In case of combined fires, the following way of extinguishing can be very effective. At a certain distance from the head of fire a line is determined and along this line, wholes are dug or drilled in the ground where the explosive is placed. Depending on the length of the line, a number of various pieces of explosive is placed. The pieces are wired together so that they will explode simultaneously. When the head of fire reaches the line where the explosive is placed, the explosive is activated from a safe distance. The explosion creates a canal without any fuel. At the same time, a large quantity of soil and dust goes up in the air which suffocates the fire (reduces the presence of oxygen in the air). Moreover, soil and stone particles fall on the head of fire burying the fuel (soil method). When this method is employed, another phenomenon can influence the fire. Because of the explosion, the air expands suddenly, which leaves less concentrated air at the explosion site which reduces the quantity of oxygen at the head of fire. This happens extremely fast but is enough to suffocate the fire.

This can completely extinguish the fire or transform it into a weak, ground/surface fire which can be easily extinguished.

It was already stated that this both a dangerous, but also an effective method. **If we choose this method, we need experts – miners, explosive and secure terrain.** This means setting guards who would prevent movement of people in the secured are in order to avoid accidents.

All these methods of localizing and extinguishing forest fires (direct and indirect) can be employed separately or in combination. This depends on the head of fire (sometimes the head of fire can be tens of kilometres long), the terrain configuration, type of fuel, weather conditions, number and training of the fire fighters, equipment, etc.

2. Positioning the fire fighters along the line of defence position (head of fire)

Apart from being familiar with the methods and tactics of localizing and extinguishing open area fires, organizing and positioning the fire fighters is also of great importance. Practice proves that even when the fire fighters are well trained and well equipped, there will be no success unless they are properly positioned. This leads to disorganization, poor synchronization or even panic. All this additionally complicates the localizing and extinguishing of open area fires. To avoid this, **fire fighters can be positioned along the line of defence position in one of the following ways:**

a) separate
b) group
c) progressive

a) Separate positioning of fire fighters

When this way is used, the fire fighters are positioned at a certain distance from each other and each of them has a section of the defence position where he/she extinguishes the fire. The defence position is usually 10-15m wide, depending on the fire. The fire fighters are positioned in this way in cases of ground fires and in cases when some of the direct extinguishing methods are used. For example, when the steel brooms, water bags, rakes, shovels, etc. are used.

This positioning can also be used with the method of two-feet or when digging canals, when every fire fighter has his/her own part and together they create a whole.

b) Group positioning of fire fighters

When this way is used, the fire fighters are positioned in groups of 5-10, equipped with different tools. One of them besides extinguishing also has the role of the group leader. This person coordinates the other group members and contacts the other groups and the headquarters. Each group gets a section of the defence position that needs to be protected. The width of each section varies according to the scope of work. This positioning is used when making a wide firebreak, creating a counter fire or fire break.

It is important to know that when the fire fighters are positioned in this way, every fire fighter has his/her own task within the group, but they as a group create a whole.

c) Progressive positioning of fire fighters

When progressive positioning is used, the work that needs to be done is also divided into phases. Each phase is completed by an individual fire fighter or a group of fire fighters. For example, when making a wide firebreak, an individual or a group of fire fighters mark the firebreak route first. The next group cuts the trunks. The group behind them clears the braches from the pulled down trunks and the last group clears the fuel. When the last group of fire fighters finish their, work a complete firebreak is left behind them.

Drawing 18: Progressive positioning of fire fighters

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