CTIF – Fire prevention commission

Document: Dangers concerning the production of carbon monoxide by generators and other internal combustion engines

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1. Scope of the document

The purpose of this document is to provide an overview of the carbon monoxide related risks related to firefighter operations. The procedures discussed within include how to operate with firefighter's equipment powered by internal combustion engines.

2. Carbon monoxide related risks

Carbon monoxide can be produced in burning carbon-containing material. It can arise in dwellings when stoves burning charcoal, wood, oil, petroleum or gas (methane) are used. It can also be produced in internal combustion engines. Increased concentrations of CO can be found in private garages and in underground car-parks even during the usual operation of vehicles.

The values of CO produced in stoves, water heaters and vehicles can therefore exceed the values specified in standards concerning the safety of users. Carbon monoxide can burn itself. The lower explosion level is 12,5 vol % or 125.000 ppm. This level is very high; it can occur exceptionally during a fire if air supply is limited. At this level CO can begin to burn. The phenomenon linked to CO produced during a fire and instantly igniting when fresh air enters the room is called backdraft.

Carbon monoxide is produced in incomplete flaming combustion as well as in smouldering. The quantity of CO produced in flaming combustion is several times smaller than the quantity produced in smouldering. It means that much more CO is produced in well loaded stoves where doors for fresh air are closed to slow-down the combustion than in cases where more air can enter the stove.

The reason for a smaller quantity of carbon monoxide being produced is primarily the fact that carbon monoxide burns with flames if there is enough air present. In this case carbon dioxide that is less dangerous to humans is produced.

The combustion becomes incomplete when there is not enough fresh air (i.e. air with 21 vol. % oxygen) in the room due to bad ventilation. The problem with fresh air supply occurs when old windows are replaced by new ones that are better sealed.

The excessive concentrations of CO in a room occur mainly as a result of:

- bad smoke extraction (poorly cleaned chimneys),
- badly constructed or damaged flues (flues are cracked or they are leaking smoke due to faults in construction or during maintenance),
- inadequate ventilation or supply of fresh air in a room where a stove burning charcoal, wood, oil, petroleum or gas is placed (air supply of heating appliances). Inadequate ventilation can occur due to mistakes in planning or execution of ventilation or due to later interventions in the room (replacement of windows by better sealing ones),
- the use of machines and appliances driven by internal combustion engines (motor-driven pumps, motor-driven saws, generators etc.) in a closed room.

3. Carbon monoxide effects on humans

The production of CO in the use of generators and other appliances driven by internal combustion engines.

Storms and tempests with strong wind, landslides, floods, sleet etc. can damage power supply. One of the temporary measures in this case is the use of portable generators driven by petrol or diesel engines of various powers. These are internal combustion engines that can be used to drive pumps, saws and the like. Firefighters can use them when they intervene in accidents.

Picture 1: Petrol generator in a room

When a generator is operating, petrol or diesel fuel is burning and carbon monoxide is produced. Carbon monoxide, CO, is a colourless, odourless, and tasteless, but highly toxic and combustible gas.

Data of the Institute for Public Health of the Republic of Slovenia reveal that CO poisoning is the most frequent unintentional deadly poisoning; in Slovenia about 10 people die of such poisoning every year.

Inhaling CO does not irritate mucous membranes, so we are not able to feel it and get out of the toxic area in time. In the lungs CO enters the blood system and is distributed to every part of the body. It binds to proteins that contain iron and copper. The most important proteins that CO binds to are hemoglobin, myoglobin and mytochondrial cytochrome oxidase. It has a 240 times greater affinity to haemoglobin than oxygen and it combines with haemoglobin to produce carboxyhemoglobin, which usurps the space in haemoglobin that normally carries oxygen and in this way reduces the capacity of haemoglobin to deliver oxygen to bodily tissues. Moreover, it slows down cellular respiration because it suppresses the function of cytochrome oxidase. Due to lack of oxygen and slower cellular respiration, significant damage is caused to the central nervous system, especially to the brain. The most common symptoms of carbon monoxide poisoning may resemble other types of poisonings and infections, including symptoms like headache, nausea, vomiting, dizziness, fatigue, seizures, sleepiness, ending in a loss of consciousness.

Until recently, the CO poisoning assessment was based on determining the level of carboxyhemoglobin in a blood sample by a gas analyser with CO-oximeter in hospital labs. Nowadays, pulse CO-oximeters are also available in Slovenia (picture 2). They enable fast and non-invasive determination of CO poisoning that does not require blood samples. Pulse CO-oximeters estimate carboxyhemoglobin levels with a non-invasive finger clip similar to a pulse oximeter. These devices function by passing various wavelengths of light through the fingertip and measuring the light absorption of the different types of hemoglobin in the capillaries. By using pulse CO-oximeters, a fast and non-invasive measurement of carboxyhemoglobin levels is possible even in emergency centres and on location, something we could not do till now. Pulse CO-oximeters are already being used by firefighters who are exposed to gasses when fighting a fire.

Picture 2: Pulse CO-oximeter

People poisoned by CO have to be treated with 100 % oxygen as soon as possible by using a non-rebreathe mask (picture 3). They should be taken to a hospital.

Picture 3: Treatment with 100 % oxygen via non-rebreathe mask with reservoir (NRB mask)

During the operation of an appliance driven by an internal combustion engine in a closed or partly closed room the level of CO can increase very quickly and symptoms of CO poisoning can occur in persons present. The speed and gravity of such poisoning depends on the concentration of CO in the air as well as the time of exposure and the physical activity of a poisoned person: the higher the concentration, the longer the exposure and the more intense the physical activity (firefighting for instance), the more serious the poisoning. Table 1 presents how the effect of CO on humans depends on the concentration of CO in the air and on the duration of exposure.

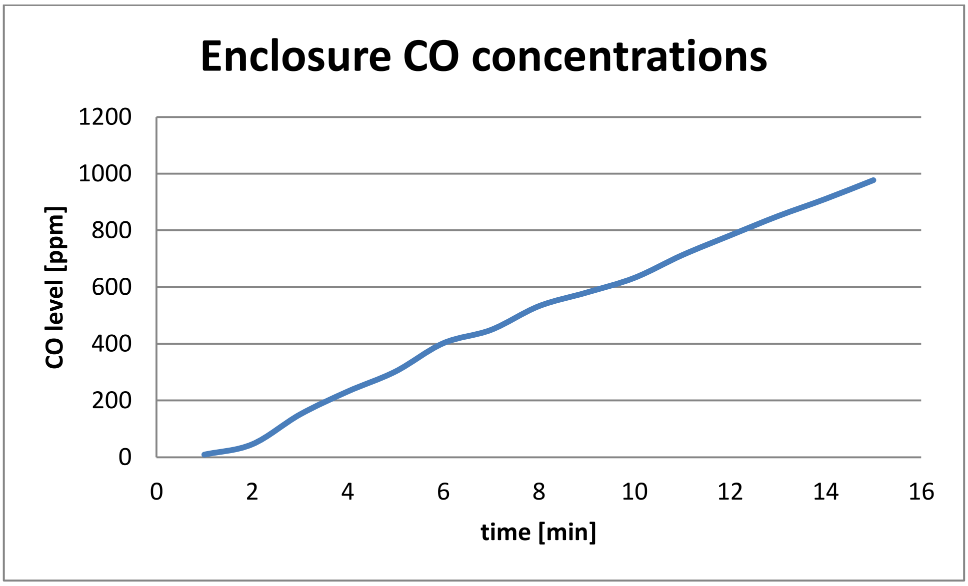
Table 1: The acute effects produced by carbon monoxide in relation to ambient concentration in parts per million

Concentration	Symptoms
35 ppm (0.0035%)	Headache and dizziness within six to eight hours of constant exposure
100 ppm (0.01%)	Slight headache in three hours

200 ppm (0.02%)	Slight headache within two to three hours; loss of judgment
400 ppm (0.04%)	Frontal headache within one to two hours
800 ppm (0.08%)	Dizziness, nausea, and convulsions within 45 min; insensible within 2 hours
1,600 ppm (0.16%)	Headache, tachycardia, dizziness, and nausea within 20 min; death in less than 2 hours
3,200 ppm (0.32%)	Headache, dizziness and nausea in five to ten minutes. Death within 30 minutes.
6,400 ppm (0.64%)	Headache and dizziness in one to two minutes. Convulsions, respiratory arrest, and death in less than 20 minutes.
12,800 ppm (1.28%)	Unconsciousness after 2–3 breaths. Death in less than three minutes.

4. Carbon monoxide formation

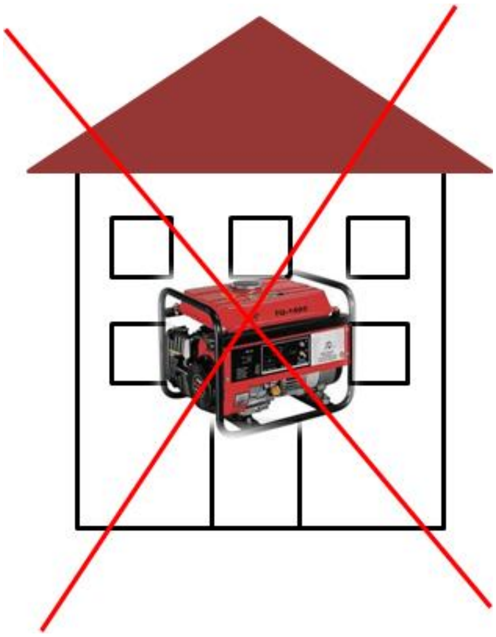
The graph in picture 4 shows the level of CO in a room of 27 m^3 in relation to time when a 750 W generator is operating there. Doors and windows of the room are closed. The graph shows that the level of CO rises very quickly, the deadly dose of 400 ppm is reached in 6 minutes. With a window slightly open this concentration would be reached in 10 minutes.



Picture 4: Level of CO in a close room in relation to time

Deadly or harmful concentrations in buildings can occur when appliances driven by internal combustion engines are placed too close to the building.

Appliances driven by internal combustion engines should not be used in rooms! Open windows and doors do not prevent the presence of high concentrations of CO in a room. It is fatal!

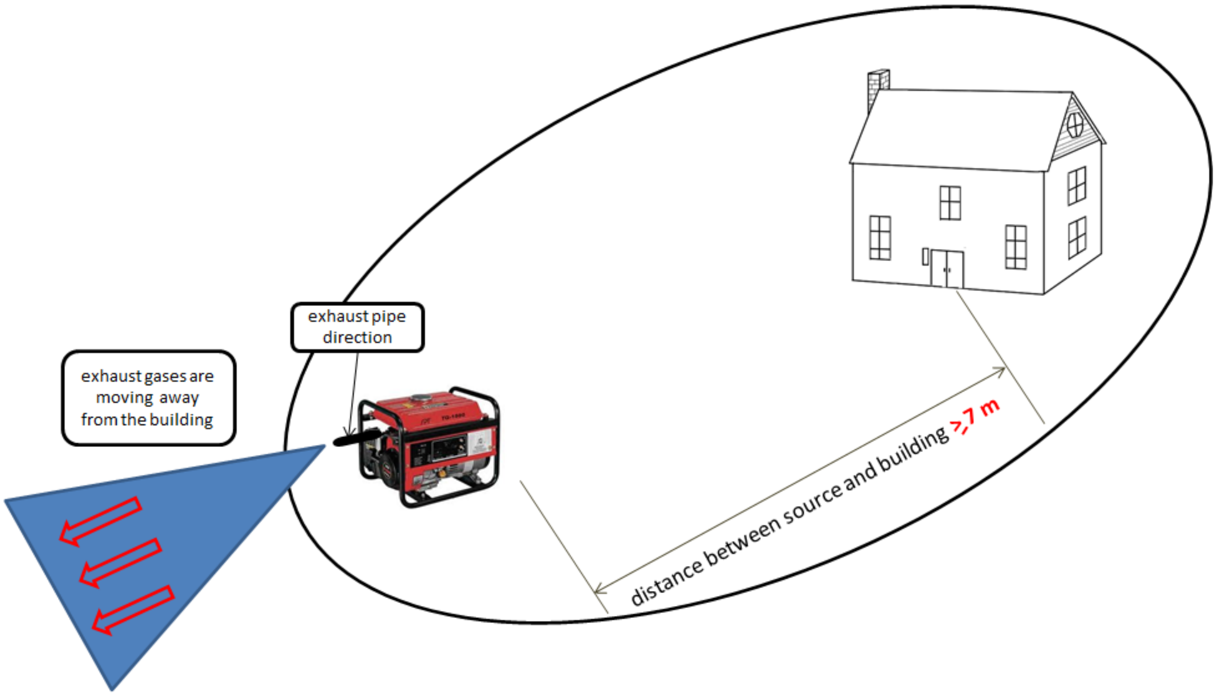


Picture 5: Appliances driven by internal combustion engines should not be used in buildings

In three days after the Hurricane Sandy hit the eastern part of the United States at the end of October, at least 9 people died of CO poisoning because electrical generators were used inappropriately.

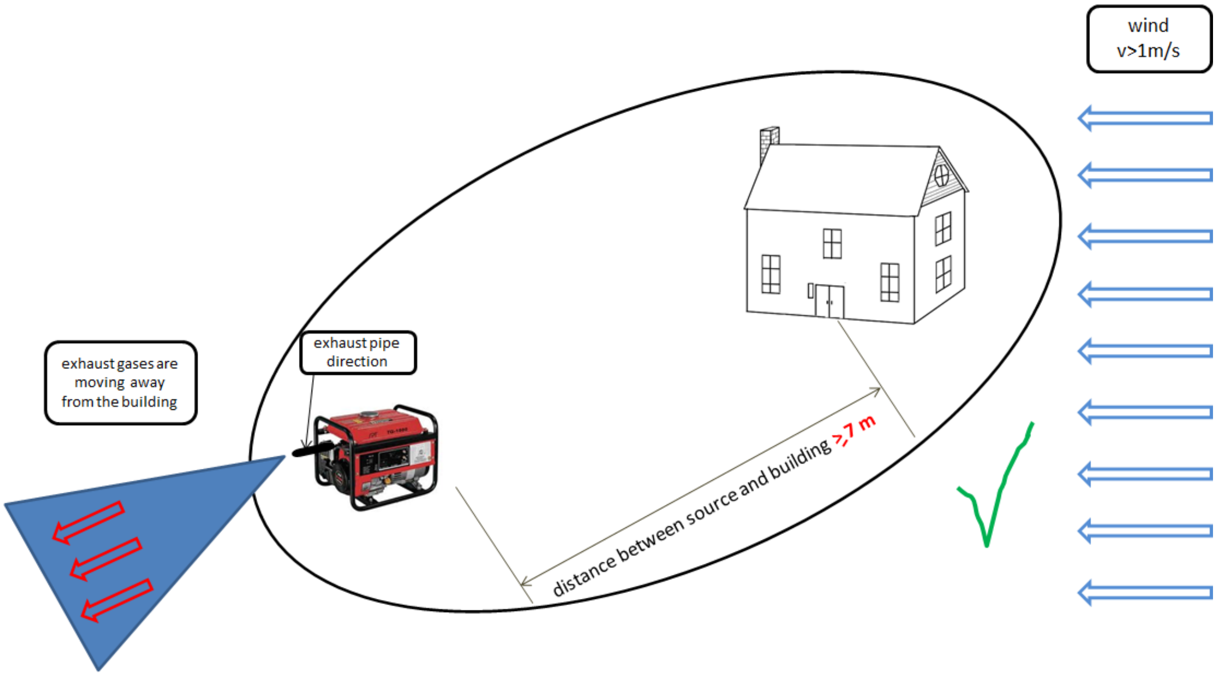
People usually think that CO is lighter than air, but this is not entirely true. The molar mass of CO is 28 g/mol. The molar mass of air is slightly higher, 29 g/mol. Since 79 % of air is nitrogen with a molar mass of 28 g/mol, the molar masses of CO and air are almost equal. This means that the movement of CO in an environment depends on two factors: the engine that produces CO and atmospheric conditions. The factors by which the generator effects the movement of CO include the speed and the temperature of exhaust gases at the end of the exhaust pipe. Since the speed at the end of the exhaust pipe is about 7 m/s, the engine itself pushes exhaust gases (including CO) in a given direction. The temperature of exhaust gases at the end of the exhaust pipe (about 200 ^{o}C) also effects the movement of exhaust gases. The difference between the temperature of exhaust gases and the temperature of the environment causes the gases to rise into the air. Wind has an important influence on the movement of these gases (CO included).

Researches and measurements of CO movement in the open are scarce. A series of calculations and computer simulations can be found in literature. Measurements and calculations performed at the Faculty of Chemistry and Chemical Technology, University of Ljubljana, and some other institutions abroad show that an appliance driven by an internal combustion engine should be placed at least 7 m away from a building. Such a distance of the appliance from a building ensures that the CO concentration which reaches the building is decreased to a level that does not endanger human life. The CO concentration at the building also depends on the direction of the exhaust pipe; it must be directed away from the building (picture 6).



Picture 6: Adequate distance and setting of an appliance (direction of the exhaust pipe) driven by an internal combustion engine

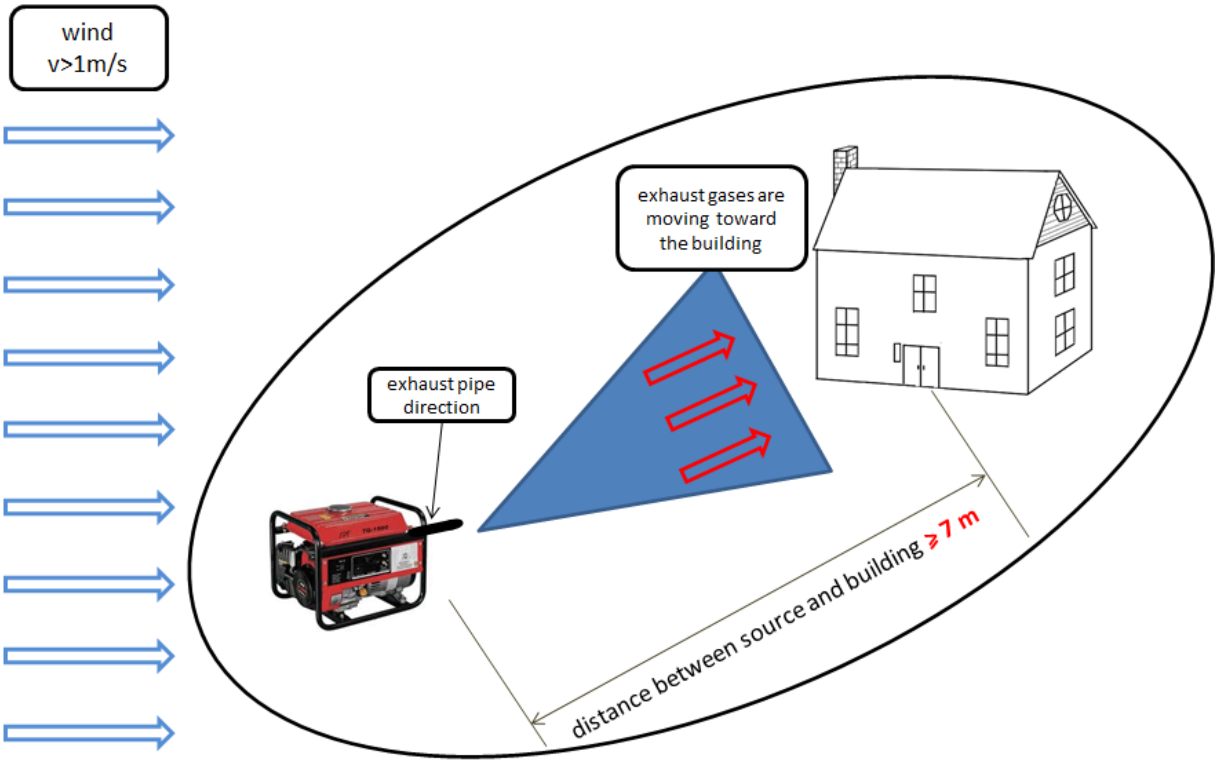
The appliance is also properly placed if the wind blows exhaust gases away from the building. When using the advantages of the wind, the direction of the wind should be monitored and the setting of the appliance adjusted to the direction of the wind.



Picture 7: Adequate distance and setting of an appliance driven by an internal combustion engine (using the direction of the wind)

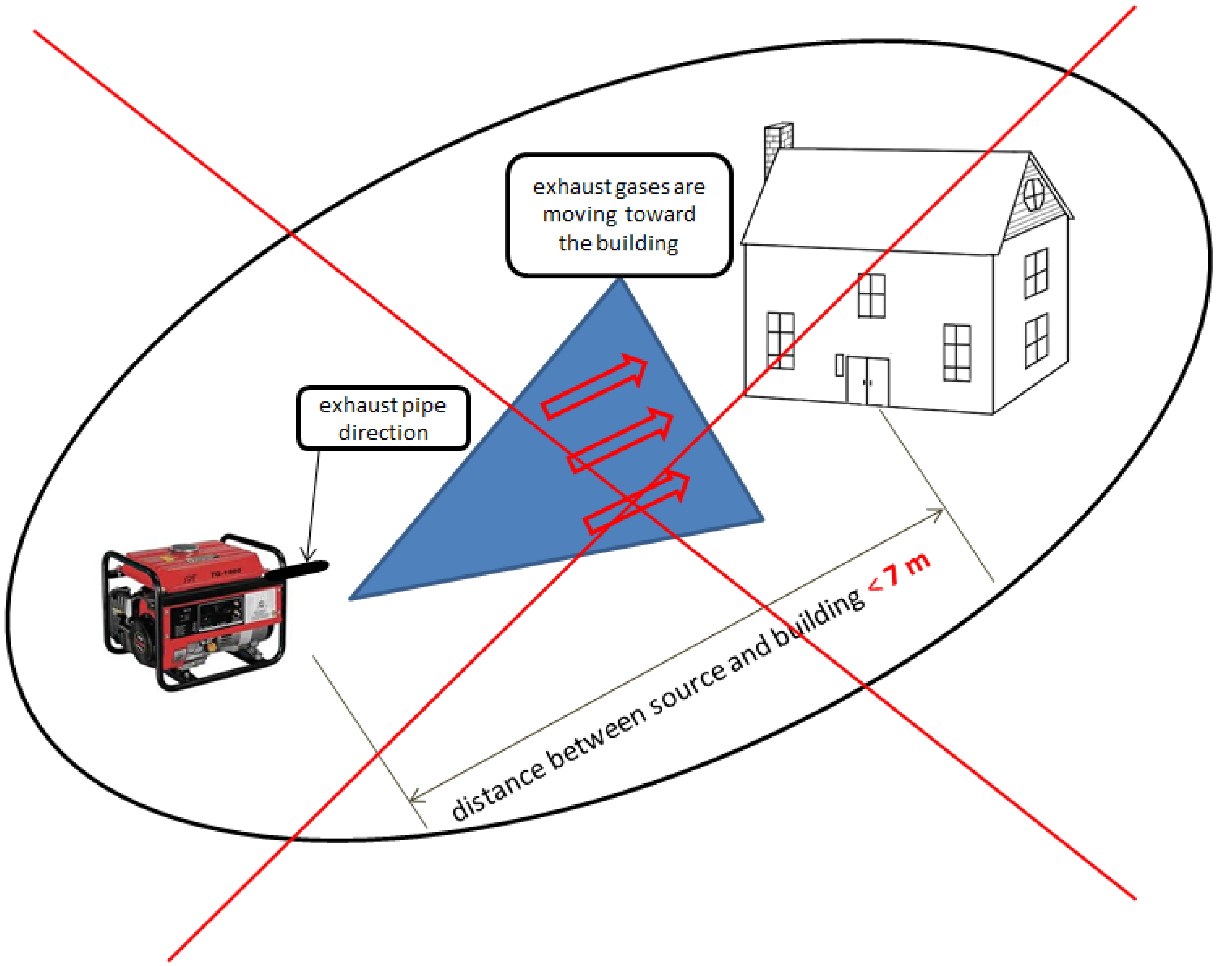
The placement of such an appliance closer than 7 m from a building is not safe even when the wind blows from a building towards the appliance. Namely the air whirls when close to a building and it can cause CO to dwell at or in the building.

The situation regarding the setting of the appliance driven by an internal combustion engine, and consequently the exposure of people at or in the building, changes if the wind blows faster than 1 m/s in the direction from the appliance to the building (picture 8) because in this case a dangerous CO concentration can be reached at the building (and inside it if windows and doors are open) even when the distance is more than 7 m. In such cases, the people at or in the building should be carefully monitored and the operation of such an appliance or work on the site should be interrupted from time to time. At any sign of faintness, those affected should leave the room.



Picture 8: Setting of an appliance driven by an internal combustion engine when the wind pushes exhaust gases toward the building

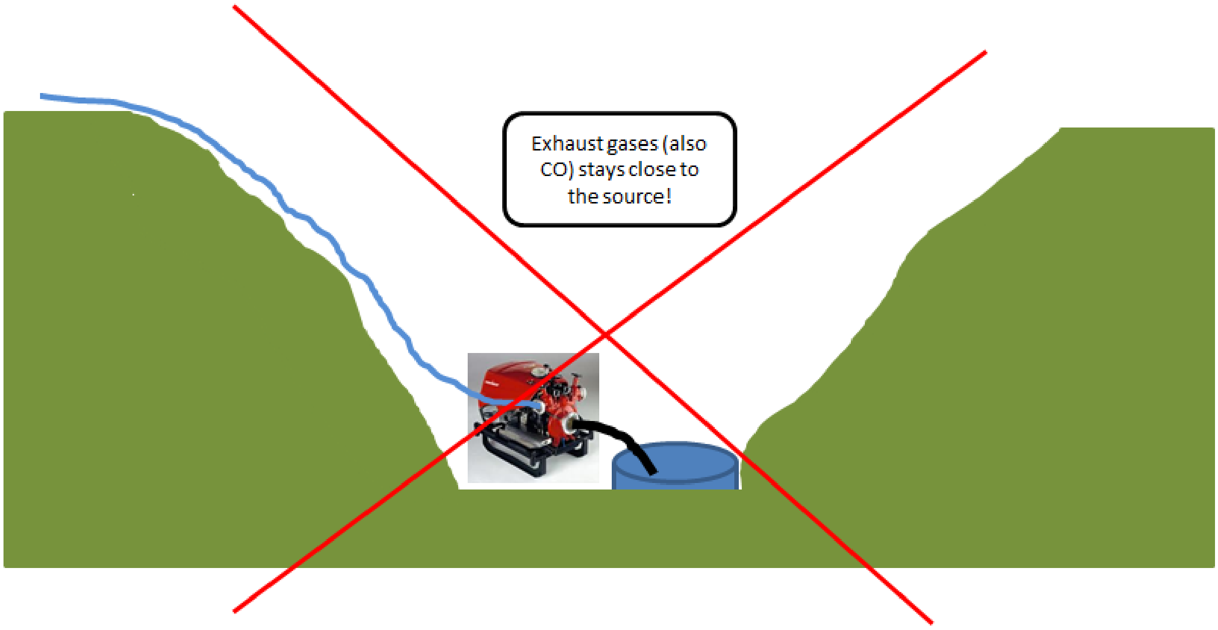
An appliance driven by an internal combustion engine is also incorrectly set if it is placed at a distance less than 7 m from a building or if its exhaust pipe is directed toward a building (picture 9)



Picture 9: Incorrect setting of an appliance driven by an internal combustion engine

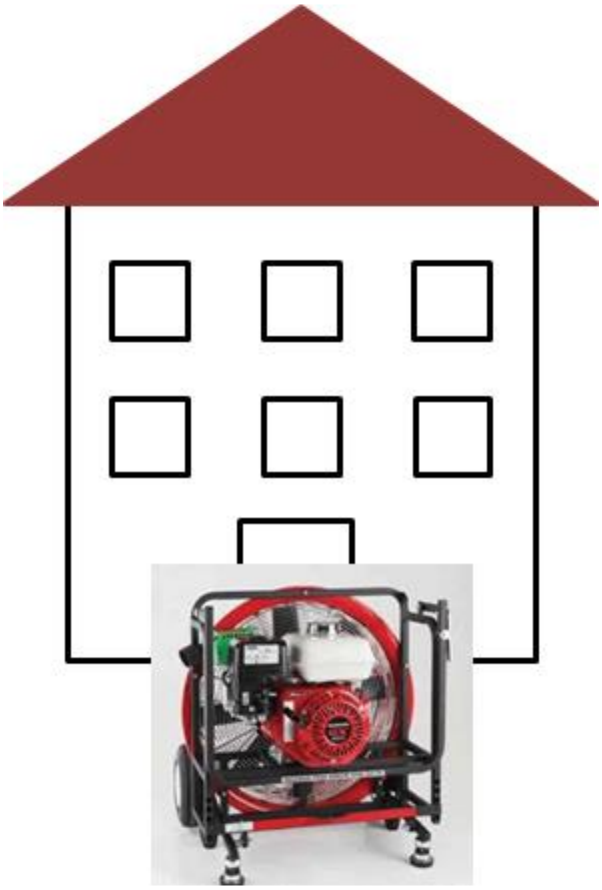
A special case is the use of appliances driven by internal combustion engines in shafts, sinkholes, wells, deepened parts of buidings, etc. (picture 10). The previously described properties of CO (almost equal molar mass of CO and nitrogen N_2) cause CO during the operation of the appliance to uniformly fill the deepened space and spread in a similar way as in closed rooms.

The use of appliances driven by internal combustion engines in deepenings (shafts, sinkholes, wells, deepened parts of buildings) is life threatening. When the use of such appliances cannot be avoided, all activities in their vicinity should be performed using a self-contained breathing apparatus. Persons working in such an environment should be constantly monitored.



Picture 10: Such a use of an internal combustion driven pump is life threatening

CO is also produced by positive pressure ventilation driven by an internal combustion engine (e.g. Tempest), which affects the movement of air. When buildings are ventilated by positive pressure ventilation, a larger amount of exhaust gases including CO can enter the building. In a prolonged use of such ventilation (longer than 15 minutes), the building should be additionally ventilated and people entering the building should be warned against the dangers of CO.



Picture 11: Positive pressure ventilation can also produce higher levels of CO

5. Summary

1. In the use of any appliance driven by an internal combustion engine, CO is produced and it can be dangerous to humans even in low concentrations. We cannot depend on our senses to detect CO because it is colourless, odourless, and tasteless. When appliances driven by internal combustion engines are operating in a room, even a candle flame is not a proper indicator. The level of oxygen changes negligibly while the level of CO increases quickly.

2. Never use appliances driven by internal combustion engines in rooms (open doors and windows do not guarantee proper ventilation). Deadly concentrations of CO can occur after a few minutes of their operation. High concentrations of CO stay in a room a long time after the appliance is switched off.

3. Never use appliances driven by internal combustion engines in deepening (shafts, sinkholes, wells, deepened parts of buildings). The effect of CO spreading is similar to the one occurring in the use of appliances driven by internal combustion engines in rooms. When the use of such an appliance

cannot be avoided, all activities in its vicinity should be performed using a self-contained breathing apparatus. Persons working in such an environment (using a self-contained breathing apparatus) should be constantly monitored.

4. When appliances driven by internal combustion engines operate in the open, safe distances should be respected. Appliances should be placed at least 7 m from the building and exhaust pipes should be directed away from the building.

5. It is recommended to install CO detectors labeled with a sign of European standard EN 50291 and equipped with a loud audible warning device.

6. Fire brigades that intervene in an environment where CO is to be expected should be equipped with personal dosimeters (picture 12) for timely detection of the presence of CO.

Picture 12: Personal dosimeter for the detection of carbon monoxide (CO)

7. In case we have symptoms of CO poisoning, we have to leave the toxic area as fast as we can and call number 112 for help. Treatment with 100 % oxygen by using a non-rebreathe mask must start on the spot or in the ambulance during the transport to a hospital.

8. CO poisoning requires rest and avoiding physical strain such as longer walks.

9. If we suspect CO poisoning we should warn the physician about it.