Bundesinstitut für Risikobewertung

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Dry ice: carbon dioxide poisoning is possible

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Alongside its long-lasting cooling properties, which are utilised for the storage, shipping and transportation of fresh and frozen goods, commercially available dry ice is also used to create fog effects at events such as private parties or concerts. The German Federal Institute for Risk Assessment (BfR) is publishing this Opinion on the health risks of dry ice to consumers.

Cases of poisoning with dry ice occur worldwide, and have been reported in countries such as Germany, Japan, Thailand, Switzerland and the United States. Accidents involving the handling of dry ice also include cases of frostbite or damage caused by the explosion of freight containers. This BfR Opinion focuses on the risk of poisoning.

The term ‘dry ice’ refers to solid carbon dioxide (CO_2) cooled to at least −78.5 °C. At room temperature, dry ice turns into gaseous CO_2 by sublimation. This is accompanied by a strong increase in pressure with a risk of explosion in airtight containers. The gaseous CO_2 released by dry ice can cause suffocation. This is because the CO_2 displaces the oxygen in the air, such as in rooms with inadequate ventilation or during transport in vehicles. As a result, the oxygen content of inhaled air is reduced. At the same time, the uptake of oxygen into red blood cells is also reduced in the lungs. High concentrations of CO_2 in inhaled air can lead to an insufficient supply of oxygen in the brain or bodily tissue. From simple headaches, symptoms at levels exceeding about 2 percent CO_2 can include perspiration, shortness of breath, palpitations, respiratory distress, fainting, visual disturbances, tremors and impaired consciousness. At concentrations above 5 percent in inhaled air, CO_2 has a narcotic effect. Once the level of CO_2 exceeds about 8–10 percent, unconsciousness and death by suffocation can occur in a matter of minutes.

The risk of dry ice poisoning increases in proportion to the quantity of dry ice used, the size of the room and ventilation. As a general rule, dry ice should be stored and transported only in appropriate, well-insulated containers. These containers must not be airtight (danger of explosion). In enclosed spaces and vehicles, adequate ventilation must always be ensured during transportation, storage and use.

BfR risk profile:
Dry ice: carbon dioxide poisoning is possible
(Opinion no. 047/2020)

A	Affected persons	General population				
B	Probability of an impairment to health from handling dry ice	Practically impossible	Unlikely	**Possible**	Likely	Certain
C	Severity of the impairment to health from handling dry ice	No impairment	**Mild impairment**		**Moderate impairment**	**Severe impairment (irreversible)**
D	Validity of available data	**High: The most important data are available and are internally consistent**		Medium: Some important data are missing or inconsistent		Low: A large volume of important data is missing or inconsistent
E	Controllability by the consumer [1]	Control not necessary	**Controllable with precautionary measures**		**Controllable by avoidance**	Not controllable

Fields with a dark blue background indicate the properties of the risk assessed in this opinion
(for more details, see the text of Opinion no. 047/2020 from the BfR dated 7 October 2020).

Explanations

The risk profile is intended to visualise the risk outlined in the BfR Opinion. The profile is not intended to be used to compare risks. The risk profile should only be read in conjunction with the corresponding Opinion.

[1] – Row E – Controllability by the consumer
Details given in the row 'Controllability by the consumer' are merely descriptive and not to be understood as a recommendation by the BfR.

GERMAN FEDERAL INSTITUTE FOR RISK ASSESSMENT (BfR)

1 Subject of the assessment

The German Federal Institute for Risk Assessment (BfR) is issuing this Opinion on poisoning in the context of the use of dry ice from the perspective of consumer health protection. Health risks associated with the handling of dry ice include carbon dioxide poisoning, frostbite or damage caused by the explosion of the packaging used to hold the dry ice. This BfR Opinion focuses on the risk of carbon dioxide poisoning that arises when consumers are involved in handling dry ice.

A case involving at least three deaths and other casualties in connection with a birthday party held in a Moscow steam sauna has been reported on recently in the media. At this event, 25 kg of dry ice was added to a pool containing warm water in order to create bubble and fog effects. Carbon dioxide gas was rapidly released, leading to symptoms of suffocation and the deaths of several guests.

A search of the published scientific literature and other publications available online revealed only a few known cases of poisoning with dry ice for the period from 2013 to 2019.

In general, incidents involving (short-term) exposure to dry ice can be assigned to one of three groups:

(1) Acute poisoning by inhalation, including death resulting from suffocation by inhaling very high concentrations of CO_2 in inadequately ventilated spaces or motor vehicles. Reports here include work-related accidents and accidents suffered by private consumers.

(2) Frostbite (corrosive tissue damage) affecting the skin and mucous membranes of the upper digestive tract, resulting from direct dermal or (more rarely) oral contact with dry ice. Reports here include work-related accidents, accidents suffered by private consumers and cases of misuse.

(3) Injuries suffered from fragments of bursting containers, resulting from the explosion of gas-tight vessels used to hold dry ice ('dry ice bombs'). Reports here include work-related accidents, cases of misuse, accidents suffered by private consumers and criminal activities.

Possible sources of danger

The use of dry ice can lead to cases of poisoning from carbon dioxide (CO_2), since dry ice sublimes to gaseous CO_2. Known fatalities caused by CO_2 typically result from an acute toxic effect by inhalation in enclosed spaces. The BfR is not aware of any incidents of fatal injuries caused by 'dry ice bombs' or frostbite caused by the chilling effects of dry ice.

Long-term (chronic) exposure to elevated concentrations of CO_2 from the use of dry ice can have effects on bone metabolism [1]; such effects include the accumulation of carbonate in the bone matrix [2-4]. Potential risks to health caused by chronic exposure to elevated levels of CO_2 resulting from consumer use of dry ice are considered less relevant because of the assumption that consumers do not handle dry ice on a daily basis.

The following potential sources of accidents when handling dry ice constitute the primary risks for dry ice poisoning (after [5]):

1. Storage of large quantities
2. Storing and using dry ice in small, unventilated spaces
3. Transporting dry ice in passenger compartments
4. Storing dry ice in gas-tight containers (danger of explosion)
5. Failing to wear appropriate personal protective equipment

From reports in the press and research articles, it is clear that cases of poisoning involving dry ice and carbon dioxide occur worldwide. Alongside Germany, cases have also been reported in Japan, Thailand, Switzerland and the United States. For the USA, for example, the number of fatalities caused by carbon dioxide poisoning (this figure also includes fatalities caused by dry ice) is reported as a constant figure of roughly 90 cases (accidents at work) annually for the period from the 1980s to 2015 [6].

Table 1: Fatalities following the inhalation of elevated concentrations of CO_2 in conjunction with the use of dry ice. Results from open-access literature and an online search (illustrative, not representative).

Period	No. of fatalities
2013 to 2019	5 deaths associated with dry ice in Germany [7-9]
2013 to 2019	4 deaths associated with dry ice (Switzerland, USA) [10-13]
2000 to 2011	21 deaths associated with CO_2 (USA), with specific circumstances for each individual case [14].
1994 to 2012	9 deaths associated with dry ice in other countries [5, 10, 15-20]

Reports of non-fatal cases of poisoning have also been published, as well as accidents involving 'dry ice bombs' and cases of frostbite.

For the period 2013 to 2019, two cases were reported to the BfR concerning dry ice in accordance with section 16e of the German Chemicals Act:
• Case 1: 2017; professional use; 1 adult; dry ice vapours in an aircraft; mild symptoms: reddening of eyes, dry cough, retrosternal burning sensation, clinical examination was unremarkable
• Case 2: 2018; professional use; 1 adult; transportation of dry ice in a car; mild symptoms: dizziness, clinical and medical equipment based examination was unremarkable (incl. blood gas analysis and X-ray examination of thorax)

In 2019, a request made to the German Poisons Information Service yielded 53 case reports involving a total of 61 persons for the period from 2013 to 2019. In 31 of these 53 cases, the usage was by private citizens. In these cases involving non-professional exposure, one fatal case, one serious case and two moderately serious cases (but partly with mixed intoxication (e.g. by party drugs) were documented. All other cases in the consumer segment involved mild symptoms or an asymptomatic case history.

2 Hazard characterisation

Accidents involving dry ice can be harmful to health and can also be fatal in extreme cases. The corresponding fatal cases have been caused by the sublimation of dry ice into gaseous CO_2 [5, 6, 10, 15, 21, 22]. Fatal incidents caused by dry ice must be viewed in the context of the toxicity by inhalation of gaseous CO_2.

The gaseous CO_2 released by dry ice displaces oxygen and therefore decreases the partial pressure of oxygen in inhaled air. In addition, CO2 acts as a respiratory poison or agent of suffocation: As the concentration of gaseous CO_2 in inhaled air rises, it becomes harder to exhale the CO_2 produced in the body via the lungs, while the uptake of oxygen into the red blood cells is simultaneously reduced. As a result, an elevated level of CO_2 in inhaled air results in less oxygen being carried by red blood cells and can therefore cause suffocation even if the partial pressure of oxygen in inhaled air is indeed adequate.

Depending on the concentration of CO_2 in inhaled air and the duration of exposure, the consequences of acute CO_2 poisoning range from mild symptoms to a loss of consciousness or even death (see also Table 3). At less than 2 percent, no acute symptoms of poisoning other than a headache are to be expected. As the concentration of CO_2 in air increases, CO_2 levels rise in the blood: a resulting respiratory acidosis then leads to an activation of the respiratory centre, an increase in breathing frequency (tachypnea) and a rapid pulse. As CO_2 levels in

inhaled air continue to rise, symptoms such as dizziness, nausea, perceptual disorders, tinnitus, etc. are the first signs of a reduced oxygen supply the brain. At 5 percent, CO_2 has a narcotic effect and seizures or ECG changes can occur. From about 8–10 percent, CO_2 causes unconsciousness and can already be lethal. From about 20–30 percent, death can result in just a few minutes.

The severity of symptoms depends on CO_2 concentration and exposure time, while the individual's age and constitution will also determine the effects of CO_2 on a case-by-case basis [23]. These individual differences should be accounted for when assessing the poisoning risk and in relation to drawing conclusions about the handling of dry ice. The recovery of one individual after a severe case of CO_2 poisoning involving the virtually complete saturation of room air with CO_2 has been reported (accident at work with liquid CO_2 [21]). One should note, however, that the lack of oxygen can trigger the occurrence of brain damage that may prove to be permanent.

For private consumers, temporary exposure to high concentrations of CO_2 from ≥10 percent by volume in inadequately ventilated spaces—such as vehicle interiors, basements or storage areas—is considered to be a potential cause of death. For accident-related deaths, short exposure times (of a few minutes) are presumed. An associated risk frequently arises in relation to the incorrect handling of dry ice together with a lack of information about safety or proper use. In the accident-related circumstances mentioned above, private consumers are at risk of suffocation when handling dry ice.

Exposure

The two tables below present the known effects on health from elevated concentrations of CO_2 in inhaled air as well as the standard values, guidance values and exposure limit values for CO_2 in inhaled air and in indoor air.

Table 2: Standard values, guidance values, exposure limit values and values for the acute toxicity of CO_2 by inhalation. Dose-dependent and time-based effects of elevated CO_2 concentrations in humans.

Standard values, guidance values and exposure limit values for CO_2		
CO_2 conc. in inhaled air [% vol.]	**Exposure time**	**Effect/result**
0.04	---	• Standard value for inhaled air [6, 7]
0.1	---	• Upper limit value for indoor air, accounts for elevated CO_2 concentration with simultaneous lower/decreasing concentration of O_2 in indoor air [4]
0.14	---	• Value used to classify indoor air as having a low air quality (DIN 2007-09) [1]
0.5	8 h twa	• Maximal admissible concentration (MAK value), does not apply to artificially ventilated rooms [4]

twa = time-weighted average, MAK = maximal admissible concentration

Table 3: Dose-dependent and duration-related effects of elevated CO_2 concentrations in humans.

Dose-dependent and duration-related effects of elevated CO_2 concentrations in humans		
CO_2 conc. in inhaled air [% vol.]	**Exposure time**	**Effect/result**
≥0.1	n.d.	• Tension in head, headache [2]
≤2	n.d.	• No effects [10]
2.5	n.d.	• Impairments to perception [1]
2–6	n.d.	• Tachypnea[10]
≥3	n.d.	• Hypercapnia/respiratory acidosis [2, 3], resp. distress [2]
3–5	n.d.	• Stimulates the respiratory centre via chemoreceptors [2, 3]
4–7 (approx.)	n.d.	• Stimulus of respiratory centre, elevated pulse, disturbed blood circulation in the brain, giddiness, nausea, buzzing in the ears [24]
>5	n.d.	• Narcosis [2, 3]
6	6–8 min	• Changes in ECG (older persons (aged approx. 60) more affected than younger individuals (aged 23)) [4]
8–10 (approx.)	n.d.	• Symptoms worsen at approx. 4–7 % vol. (see above), convulsions, unconsciousness with death following soon after [24]
10	n.d.	• Unconsciousness [23] • Potentially fatal [23] • Weakness, tinnitus, increased sensitivity to pain [2]
>10	n.d.	• Headache, sweating • Fatal consequences [3] • Rapidly leads to death [24]
	10–20 min	• Loss of consciousness [4]
10–30	n.d.	• Weakening of visual perception, sensitivity to light, nystagmus, weakening of auditory perception, vomiting [10]
>17	20–52 sec	• Unconsciousness, dizziness, blurred vision, irritation to the throat [4]
>20	1 min	• Unconsciousness, convulsions [4]
≥20	A few minutes	• Death is likely [10]
25	n.d.	• Palpitations, convulsions [2]
≥30	Immediate	• Unconsciousness and rapid death [10]
Continuous and permanent exposure to elevated levels of CO_2	Several days	• Declined blood levels of calcium and inorganic phosphate [4] • Accumulation of carbonate in bone tissue/matrix [2-4].
0.7 to 1.2	26 days	• Significant drop in performance when testing visual motor skills [22]

n.d. = no data

3 The legal situation

German occupational safety legislation defines an occupational exposure limit of 5000 ml/m^3 (ppm) or 9100 mg/m^3 (TRGS 900 [25]). This is equivalent to a permitted concentration of CO_2 in the workplace of 0.5 percent. This concentration is roughly 12.5x the level of CO_2 found in normal inhaled air (0.04%).

The European Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR) contains provisions that specify regulations for the classification, packaging, labelling and documentation of dangerous goods, for their handling during this conveyance and for the vehicles used to carry these goods. For dry ice (UN1845), the special provisions in ADR 5.5.3 are to be applied [26]. These provisions include requirements for instructing the employees involved, for the consignments (packaging, labelling), and for the documentation and vehicle markings. Since 2017, an identification requirement has also applied to all types of conveyance utilised for dry ice in road traffic, regardless of whether this material is carried as a coolant or

conditioning agent or as a consignment (to be labelled as 'CARBON DIOXIDE, SOLID', possibly with the suffix 'AS COOLANT'). Alongside this requirement to label individual shipments, a special warning notice must also be affixed to vehicles and containers without adequate ventilation.

Since 1 January 1999, private citizens have been exempt from dangerous goods legislation applying to road traffic. Accordingly, private citizens may convey dangerous goods if these are "packaged as appropriate for retail sale, and are intended for personal or household use, or for sport and leisure activities".

Carbon dioxide is listed in Annex IV of Regulation (EU) No 1907/2006 (REACH). In accordance with point (a) of Article 2(7) of the REACH Regulation, substances listed in Annex IV are exempted from Titles II (registration), V (downstream users) and VI (evaluation), "as sufficient information is known about these substances that they are considered to cause minimum risk because of their intrinsic properties".

The acute toxicity of dry ice or CO_2 is low in comparison with many other substances. According to Regulation (EU) No 1272/2008 (CLP), carbon dioxide is not classified as acute toxic, and shall only be labelled when it is marketed as a pressurised gas.

4 Risk characterisation

Cases of poisoning from the CO_2 released by dry ice occur both in a professional and private context. Cases of severe or fatal poisonings are rare, however. The cases described in the literature occurred due to incorrect storage, transportation or use, or are the result of suicidal intent.

Related risks frequently arise in relation to the incorrect handling of dry ice together with a lack of information about safety or proper use. In the accident-related circumstances as described, a general risk of suffocation when handling dry ice is present for private consumers.

The specific risk of suffocation from the release of gaseous carbon dioxide by sublimation from dry ice can be defined on a case-by-case basis. To obtain a quantitative estimate of the risk, a number of factors must be considered:

- Quantity of dry ice: the larger the quantity, the larger the volume of CO_2 that can be released
- Size of room, ventilation: the smaller and less well-ventilated the room (e.g. bathroom, vehicle (and space taken up by cargo in vehicle)), the greater the concentration of CO_2 in the air
- Sublimation rate: high temperatures and good heat dissipation increase the rate of sublimation, resulting in the faster release of CO_2—e.g. as a result of direct contact with warm water (fog effects in swimming pool)
- Conditions of the room, as well as individuals' physical size and posture: since CO_2 is heavier than air, CO_2 concentrations are higher near to the ground (basement, swimming pool, sitting/lying on the ground)
- Activity and number of individuals, initial concentration of CO_2 in the room
- Packaging: type, gas permeability, insulation

Accordingly, consumers should only use dry ice in smaller quantities—such as for the cooling of perishable goods, for example. Adequate ventilation of the storage facility and/or means of

transport (passenger vehicle) should be ensured, as well as good heat insulation, gas permeability for the freight container (danger of explosion) and insulated gloves/clothing while handling.

Further information on the subject of poisoning from the BfR website:

https://www.bfr.bund.de/en/poisonings-10142.html

BfR 'Opinions app'

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About the BfR

The German Federal Institute for Risk Assessment (BfR) is a scientifically independent institution within the portfolio of the Federal Ministry of Food and Agriculture (BMEL) in Germany. It advises the German federal government and German federal states (“Laender”) on questions of food, chemical and product safety. The BfR conducts its own research on topics that are closely linked to its assessment tasks.

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