CHAPTER 17

Fumigants

Packaging and formulation of fumigants are complex. Those that are gases at room temperature (methyl bromide, ethylene oxide, sulfur dioxide, sulfuryl fluoride) are provided in compressed gas cylinders. Liquids are marketed in cans or drums. Solids that sublime, such as naphthalene, must be packaged so as to prevent significant contact with air before they are used. Sodium cyanide is only available in an encapsulated form so that when wild canids attack livestock their bite releases the poison.

Mixtures of fumigants are sometimes used. For instance, chloropicrin, which has a strong odor and irritant effect, is often added as a "warning agent" to other liquid fumigants. It is important to be aware of the possibility of such mixtures.

Liquid halocarbons and carbon disulfide evaporate into the air while naphthalene sublimes. Paraformaldehyde slowly depolymerizes to formaldehyde. Aluminum phosphide slowly reacts with water vapor in the air to liberate phosphine, an extremely toxic gas.

Fumigants have remarkable capacities for diffusion (a property essential to their function). Some readily penetrate rubber and neoprene personal protective gear, as well as human skin. They are rapidly absorbed across the pulmonary membranes, gastrointestinal tract and skin. Special adsorbents are required in respirator canisters to protect exposed workers from airborne fumigant gases. Even these may not provide complete protection when air concentrations of fumigants are high.

NAPHTHALENE

Toxicology

Naphthalene is a solid white hydrocarbon long used in ball, flake or cake form as a moth repellent. It sublimes slowly. The vapor has a sharp, pungent odor that is irritating to the eyes and upper respiratory tract. Inhalation of high concentrations causes headache, dizziness, nausea and vomiting. Intensive, prolonged inhalation exposure, ingestion or dermal exposure (from contact with heavily treated fabric) may cause hemolysis, particularly in persons afflicted with glucose-6-phosphate dehydrogenase deficiency.[1] The metabolites of naphthalene actually are responsible for the hemolysis.[2] Secondary renal tubular damage may ensue from the naphthol and from the products of hemolysis. Convulsions and coma may occur, particularly in children. In infants, high levels of methemoglobin and bilirubin in the plasma may lead to encephalopathy. Kernicterus has been specifically described as a complication of exposure to naphthalene with severe hemolysis and resulting hyperbilirubinemia.[3] Some individuals exhibit dermal sensitivity to naphthalene.

HALOCARBONS

Toxicology

The halocarbons as a group are most commonly encountered as solvent agents. They have been associated with a wide variety of toxicities, including central nervous system, liver and renal toxicity, reproductive toxicity and carcinogenicity. However, not all are equipotent, nor do any of them routinely express this wide variety of effects.[4]

HIGHLIGHTS

Easily absorbed in lung, gut, skin

SIGNS & SYMPTOMS

Highly variable among agents

Many are irritants

Carbon disulfide, chloroform, ethylene dichloride, hydrogen cyanide, methyl bromide may have serious CNS effects

Methyl bromide, ethylene dibromide, ethylene oxide, aluminum phosphide (phosphine gas) can cause pulmonary edema

Chloroform, carbon tetrachloride, ethylene dichloride, ethylene dibromide, formaldehyde, carbon disulfide may have liver and/or kidney impacts

Hydrogen cyanide causes severe hypoxia without cyanosis in early stages

TREATMENT

Skin, eye decontamination

Ensure breathing, pulse

Control seizures

Consider GI decontamination

Specific measures needed for various agents

CONTRAINDICATED

Catecholamine-releasing agents in carbon disulfide poisoning

Ipecac in cyanide poisoning

COMMERCIAL PRODUCTS

Hydrocarbon: naphthalene

Halocarbons: methylene chloride,* methyl bromide, methyl iodide, chloroform,* carbon tetrachloride,* chloropicrin, ethylene dichloride, ethylene dibromide,* 1,3-dichloropropene, 1,2-dichloropropane,* dibromochloropropane, paradichlorobenzene

Oxides and Aldehydes: ethylene oxide, propylene oxide,* formaldehyde and paraformaldehyde, acrolein

Sulfur Compounds: sulfur dioxide, sulfuryl fluoride, carbon disulfide*

Phosphorus Compounds: phosphine

Nitrogen Compounds: sodium/hydrogen cyanide, acrylonitrile*

Methyl Isothiocyanate Generators: Metam sodium, metam potassium, dazomet

** Discontinued in the U.S.*

The individual characteristics of each registered or previously registered as pesticides will be discussed.

Methylene chloride is one of the less toxic halocarbons. It is absorbed by inhalation and to a limited extent across the skin. Exposure to high concentrations may cause central nervous system depression, manifesting as fatigue, weakness and drowsiness. A case has been described of severe optic atrophy after high level exposure to this agent.[5] Some absorbed methylene chloride is degraded to carbon monoxide in humans, yielding increased blood concentrations of carboxyhemoglobin.[6] However, concentrations are rarely high enough to cause symptoms of carbon monoxide poisoning. Ingestion has caused death from gastrointestinal hemorrhage, severe liver damage, coma, shock, metabolic acidosis and renal injury. In laboratory animals, extraordinary dosage has caused irritability, tremor and narcosis, leading to death. When heated to the point of decomposition, one of the products is the highly toxic phosgene gas that has caused significant, acute pneumonitis.[7]

The methyl halides (methyl bromide and **methyl iodide)** are similar in their toxicity and metabolic fate.[8] They are colorless and nearly odorless to moderately pungent (methyl iodide), but are severely irritating to the lower respiratory tract, sometimes inducing pulmonary edema, hemorrhage or a confluent pneumonia. The onset of respiratory distress may be delayed 4-12 hours after exposure. The methyl halides are central nervous system depressants but may also cause convulsions. Early symptoms of acute poisoning include headache, dizziness, nausea, vomiting, tremor, slurred speech and ataxia. The more severe cases of poisoning exhibit myoclonic and generalized tonic-clonic seizures, which are sometimes refractory to initial therapy. Residual neurological deficits including myoclonic seizures, ataxia, muscle weakness, tremors, behavioral disturbances and diminished reflexes may persist in more severely poisoned patients.[8,9,10] If liquid methyl halides contact the skin, severe burning, itching and blistering occurs. Skin necrosis may be deep and extensive.[11]

Chloroform has an agreeable, sweet odor and is only slightly irritating to the respiratory tract. It is well absorbed from the lungs and is also absorbed from the skin and gastrointestinal tract. It is a powerful central nervous system depressant (in fact, it has been used as an anesthetic).[12] Inhalation of toxic concentrations in air leads to dizziness, loss of sensation and motor power, and then unconsciousness. Inhalation of large amounts causes cardiac arrhythmias, sometimes progressing to ventricular fibrillation.[13] Large absorbed doses damage the functional cells of the liver and kidney. Ingestion is more likely to cause serious liver and kidney injury than is inhalation of the vapor.

Carbon tetrachloride is less toxic than chloroform as a central nervous system depressant but is much more severely hepatotoxic, particularly following ingestion. Liver cell damage is apparently due to free radicals generated in the process of initial dechlorination.[14] Sporadic arrhythmias, progressing to fibrillation, may follow inhalation of high concentrations of carbon tetrachloride or ingestion of the liquid. Kidney injury also occurs sometimes with minimal hepatic toxicity. The kidney injury may be manifested by acute tubular necrosis or by azotemia and general renal failure. Even topical exposure has resulted in acute renal toxicity.[15]

Chloropicrin is severely irritating to the upper respiratory tract, eyes and skin. Inhalation of an irritant concentration sometimes leads to vomiting. Ingestion could be expected to cause a corrosive gastroenteritis.[16,17]

1,2-dichloroethane (ethylene dichloride) is moderately irritating to the eyes and respiratory tract. Respiratory symptoms may have a delayed onset. It depresses the central nervous system, induces cardiac arrhythmias and damages the liver. Additional manifestations of poisoning include headache, nausea, vomiting, dizziness, diarrhea, hypotension, cyanosis and unconsciousness.[18]

Ethylene dibromide is a severe irritant to skin, eyes and respiratory tract. The liquid causes blistering and erosion of skin and is corrosive to the eyes. Once absorbed, it may cause pulmonary edema and central nervous system depression. Damage to testicular tissue has occurred in animals.[19] Its chemical similarity to DBCP (dibromochlorpropane) suggests this compound may have some damaging effect on testicular tissue with long-term exposure.[20] Persons poisoned by ingestion have suffered chemical gastroenteritis, liver necrosis and renal tubular damage. Death is usually due to respiratory or circulatory failure.[21] A powerful disagreeable odor is advantageous in warning occupationally exposed workers of the presence of this gas.

Dichloropropene and **dichloropropane** are strongly irritating to the skin, eyes and respiratory tract. Bronchospasm may result from inhalation of high concentrations. Liver, kidney and cardiac toxicity are seen in animals, but there are limited data for humans.[22] It appears that the risk of such toxicity is relatively low for humans except in large exposures, especially by ingestion.

Paradichlorobenzene is solid at room temperature. It is now widely used as a moth repellent, air freshener and deodorizer in homes and in public facilities. The vapor is only mildly irritating to the nose and eyes. Liver injury may occur following ingestion of large amounts. Although accidental ingestions, especially by children, have been fairly common, symptomatic human poisonings have been rare. The last report in the peer-reviewed literature of acute poisoning was in 1959.[23] Chronic intentional exposure has led to severe encephalopathy and serious withdrawal symptoms.[24]

OXIDES AND ALDEHYDES

Ethylene oxide and **propylene oxide** are irritants to all tissues they contact. Aqueous solutions of ethylene oxide can cause blistering and erosion of the affected skin. The area of skin may thereafter be sensitized to the fumigant. Inhalation of high concentrations is likely to cause pulmonary edema and cardiac arrhythmias. Headache, nausea, vomiting, weakness and a persistent cough are common early manifestations of acute poisoning.[25] Coughing of bloody, frothy sputum is characteristic of pulmonary edema.

Airborne **formaldehyde** is irritating to the eyes and to membranes of the upper respiratory tract. In some individuals, it is a potent sensitizer, causing allergic dermatitis. In addition, it has been associated with asthma-like symptoms, though there remains some controversy as to whether these represent true allergic asthma caused by formaldehyde.[26,27,28] High air concentrations may cause laryngeal edema, asthma or tracheobronchitis, but apparently not pulmonary edema. Aqueous solutions in contact with the skin cause hardening and roughness due to superficial coagulation of the keratin layer. Ingested formaldehyde attacks the lining membrane of the stomach and intestine, causing necrosis and ulceration. Absorbed formaldehyde is rapidly converted to formic acid. The latter is partly responsible for the metabolic acidosis that is characteristic of formaldehyde poisoning. Circulatory collapse and renal failure may follow the devastating effects of ingested formaldehyde on the gut, leading to death.[29] **Paraformaldehyde** is a polymer that slowly releases formaldehyde into the air. Toxicity is somewhat less than that of formaldehyde because of the slow evolution of gas.

Acrolein (acrylaldehyde) is an extremely irritating gas used as a fumigant and an aquatic herbicide. The vapor causes lacrimation and upper respiratory tract irritation, which may lead to laryngeal edema, bronchospasm and delayed pulmonary edema. The consequences of ingestion are essentially the same as those that follow ingestion of formaldehyde. Contact with the skin may cause blistering.[30]

SULFUR COMPOUNDS

Sulfur dioxide is a highly irritating gas, so disagreeable that persons inhaling it are usually prompted to seek uncontaminated air as soon as possible. However, laryngospasm and pulmonary edema have occurred, occasionally leading to severe respiratory distress and death. It is sometimes a cause of reactive airways disease in occupationally exposed persons.[31]

Sulfuryl fluoride has been used extensively for structural fumigation. Generally, use experience has been good, but some fatalities have occurred when fumigated buildings have been prematurely reentered by unprotected individuals.[32] Since this material is heavier than air, fatal hypoxia may follow early reentry. Manifestations of poisoning have been nose, eye and throat irritation, weakness, nausea, vomiting, dyspnea, cough, restlessness, muscle twitching and seizures.[33,34]

Carbon disulfide vapor is only moderately irritating to upper respiratory membranes. It has an offensive "rotten cabbage" odor. Acute toxicity is due chiefly to effects on the central nervous system. Inhalation of high concentrations for short periods has caused headache, dizziness, nausea, hallucinations, delirium, progressive paralysis and death from respiratory failure.[35] More prolonged exposure to lesser amounts has led to blindness, deafness, paresthesia, painful neuropathy and paralysis.[36] Carbon disulfide is a potent skin irritant, often causing severe burns. Long-term occupational exposures have been shown to accelerate atherosclerosis, leading to ischemic myocardiopathy, polyneuropathy and gastrointestinal dysfunction.[37] Toxic damage to the liver and kidneys may result in severe functional deficits of these organs.[38] Reproductive failure has been noted.

PHOSPHORUS COMPOUNDS

Phosphine gas is extremely irritating to the respiratory tract. It also produces severe systemic toxicity. It is used as a fumigant by placing solid aluminum phosphide (phostoxin) near produce or in other storage spaces. By way of hydrolysis, phosphine gas is slowly released. Most severe acute exposures have involved ingestion of the solid aluminum phosphide, which is rapidly converted to phosphine by acid hydrolysis in the stomach. Poisoning due to ingestion carries a high mortality rate (50% to 90%).[39,40] The complex chemistry and toxic mechanisms of phosphine were recently reviewed. Three interdependent mechanisms contribute to phosphine toxicity: disruption of the sympathetic nervous system, suppressed energy metabolism and oxidative damage to the cells.[41] Extracellular magnesium levels have been found to be slightly elevated, suggesting a depletion of intracellular magnesium from myocardial damage.[42]

Poisonings had become quite frequent during the late 1980s and early 1990s in some parts of India.[39,40] The principal manifestations of poisoning are fatigue, nausea, headache, dizziness, thirst, cough, shortness of breath, tachycardia, chest tightness, paresthesia and jaundice. Cardiogenic shock is present in more severe cases. Pulmonary edema is a common cause of death. In other fatalities, ventricular arrhythmias, conduction disturbances and asystole developed.[39,43] The odor of phosphine is said to resemble that of decaying fish.

NITROGEN COMPOUNDS

Sodium cyanide/hydrogen cyanide gas causes poisoning by inactivating cytochrome oxidase, the final enzyme essential to mammalian cellular respiration. The patient will have signs of severe hypoxia, but in some cases may not appear cyanotic. This is due to the failure of hemoglobin reduction in the face of loss of cellular respiration. This

will result in a pink or red color to the skin and arteriolization of retinal veins. In addition to the suggestive physical findings, one may also find an unusually high pO_2 on a venous blood gas.[44] Cyanosis is a late sign and indicates circulatory collapse.

The cells of the brain appear to be the most vulnerable to cyanide action. Presenting signs are nonspecific and can be found with many poisonings. Unconsciousness and death may occur immediately following inhalation of a high cyanide concentration, respiratory failure being the principal mechanism. Metabolic acidosis is another common presenting sign. Low-dose exposures cause a constriction and numbness in the throat, stiffness of the jaw, salivation, nausea, vomiting, lightheadedness and apprehension. Worsening of the poisoning manifests as violent tonic or clonic convulsions. Fixed, dilated pupils, bradycardia and irregular gasping respiration (or apnea) are typical of profound poisoning. The heart often continues to beat after breathing has stopped.[44,45] A bitter almond odor to the breath or vomitus may be a clue to poisoning, but not all individuals are able to detect this odor.[44]

Acrylonitrile is biotransformed in the body to hydrogen cyanide. Toxicity and mechanisms of poisoning are essentially the same as have been described for cyanide, except that acrylonitrile is irritating to the eyes and the upper respiratory tract.

METHYL ISOTHIOCYANATE GENERATORS

Metam sodium, metam potassium and **dazomet**, when used as fumigants, all rely on conversion to methyl isothiocyanate.[46] There is very limited literature on the effects of these agents when used as fumigants, but the toxicity appears to be related to exposure to methyl isothiocyanate. This is discussed in more detail in **Chapter 16, *Fungicides***, in the subsection, *Thiocarbamates*.

Confirmation of Poisoning

Naphthalene is converted mainly to alpha naphthol in the body and promptly excreted in conjugated form in the urine. Alpha naphthol can be measured by gas chromatography. Many halocarbons can be measured in blood by gas chromatographic methods. Some can be measured in the expired air as well.

Methylene chloride is converted to carbon monoxide in the body, generating carboxyhemoglobin, which can be measured by clinical laboratories.

Paradichlorobenzene is metabolized mainly to 2,5-dichlorophenol, which is conjugated and excreted in the urine. This product can be measured chromatographically.

Methyl bromide yields inorganic bromide in the body. Methyl bromide itself has a short half-life and is usually not detectable after 24 hours. The bromide anion is slowly excreted in the urine (half-life about 10 days) and is the preferred method of serum measurement.[10] The serum from persons having no exceptional exposure to bromide usually contains less than 1 mg bromide ion per 100 mL. The possible contributions of medicinal bromides to elevated blood content and urinary excretion must be considered, but if methyl bromide is the exclusive source, serum bromide exceeding 6 mg per 100 mL probably means some absorption, and 15 mg per 100 mL is consistent with symptoms of acute poisoning. Inorganic bromide is considerably less toxic than methyl bromide; serum concentrations in excess of 150 mg per 100 mL occur commonly in persons taking inorganic bromide medications. In some European countries, blood bromide concentrations are monitored routinely in workers exposed to methyl bromide. Blood levels over 3 mg per 100 mL are considered a warning that personal protective measures must be improved. A bromide concentration over 5 mg per 100 mL requires that the worker be removed from the fumigant-contaminated environment until blood concentrations decline to less than 3 mg per 100 mL.[47]

Carbon disulfide can be measured in urine by gas chromatography, but the test is not generally available.

Cyanide ion from cyanide itself or **acrylonitrile** can be measured in whole blood and urine by an ion-specific electrode or by colorimetry. Symptoms of toxicity may appear at blood levels above 0.10 mg per liter.[45] Urine cyanide is usually less than 0.30 mg per liter in nonsmokers, but as much as 0.80 mg per liter in smokers. Thiocyanate, the metabolite of cyanide, can also be measured in blood and urine. It is considered elevated at blood levels exceeding 12 mg per liter.[45] Urine thiocyanate is usually less than 4 mg per liter in nonsmokers, but may be as high as 17 mg per liter in smokers.

Serum fluoride concentrations have been measured in fatalities from **sulfuryl fluoride** fumigation. Ante-mortem concentrations have ranged from as low as 0.5 mg/liter in one chronic exposure case to the range of ~20 mg/liter in acute poisoning deaths.[34]

There are no practical tests for absorbed alkyl oxides, aldehydes or phosphine that would be helpful in diagnosis of poisoning.

Large industrial plants sometimes monitor human absorption of halocarbons by analysis of expired air. Similar technology is available in some departments of anesthesiology. These analyses are rarely needed to identify the offending toxicant because this is known from the exposure history. In managing difficult cases of poisoning, however, it may be helpful to monitor breath concentrations of toxic gas to evaluate disposition of the fumigant. Protein and red cells levels in the urine may indicate renal injury. Free hemoglobin in urine most likely reflects hemolysis, as from naphthalene. Elevations of alkaline phosphatase, lactate dehydrogenase (LDH), serum GGT, ALT, AST and certain other enzymes are sensitive indices of insult to liver cells. More severe damage increases plasma concentrations of bilirubin. A chest X-ray may be used to confirm the occurrence of pulmonary edema. Electromyography may be useful in evaluating peripheral nerve injury. Sperm counts may be appropriate for workers exposed to **dibromochloropropane** and **ethylene dibromide**.

Some occupational health agencies now urge periodic neurologic and neuropsychological testing of workers heavily exposed to fumigants and solvents to detect injury to the nervous system as early as possible. This would be particularly desirable in the case of exposures to such agents as methyl bromide and carbon disulfide that have well documented chronic neurotoxic effects.

Treatment of Fumigant Toxicosis

1. Flush contaminating fumigants from the skin and eyes with copious amounts of water or saline for at least 15 minutes. Some fumigants are corrosive to the cornea and may cause blindness. Specialized medical treatment should be obtained promptly following flushing. Skin contamination may cause blistering and deep chemical burns. Absorption of some fumigants across the skin may be sufficient to cause systemic poisoning in the absence of fumigant inhalation. For all these reasons, decontamination of eyes and skin must be immediate and thorough.

2. Remove victims of fumigant inhalation to fresh air immediately. Even though initial symptoms and signs are mild, keep the victim quiet, in a semi-reclining position. Minimal physical activity limits the likelihood of pulmonary edema.

3. If victim is not breathing, clear the airway of secretions and resuscitate with positive pressure oxygen apparatus. If this is not available, use chest compression to sustain respiration. If victim is pulseless, employ cardiac resuscitation.

4. Manage patients with signs and symptoms of severe poisoning, including pulmonary edema, respiratory failure, shock, renal failure and seizures in an intensive care unit.

5. Control convulsions. Seizures are most likely to occur in poisonings by methyl bromide, hydrogen cyanide, acrylonitrile, phosphine and carbon disulfide. See **Chapter 3, *General Principles*** for seizure management. In some cases of methyl bromide poisoning, seizures have been refractory to benzodiazepines and diphenylhydantoin, so consider resorting to anesthesia using thiopental.[10]

6. If a fumigant liquid or solid has been ingested less than an hour prior to treatment, consider gastric emptying, followed by activated charcoal, as suggested in **Chapter 3**.

7. Monitor fluid balance and check urine sediment regularly for indications of tubular injury. Measure serum alkaline phosphatase, LDH, ALT, AST and bilirubin to assess liver injury.

Specific Treatment Measures for Particular Fumigants

Specific additional measures recommended in poisonings by particular fumigants follow.

Naphthalene

1. If naphthalene toxicosis is caused by vapor inhalation, this can usually be managed simply by removing the individual to fresh air.

2. Decontaminate skin promptly by washing with soap and water. Remove eye contamination by flushing with copious amounts of clean water. Eye irritation may be severe, and if it persists, should receive ophthalmologic attention. See **Chapter 3, *General Principles*** for more information on decontamination.

3. Examine the plasma for evidence of hemolysis: a reddish-brown tinge. Examine the blood smear for "ghosts" and Heinz bodies. If present, monitor red blood cell count and hematocrit for anemia and urine for protein and cells. Measure direct- and indirect-reacting bilirubin in the plasma. Monitor fluid balance and blood electrolytes. If possible, monitor urinary excretion of naphthol to assess severity of poisoning and clinical progress.

4. If hemolysis is clinically significant, administer intravenous fluids to accelerate urinary excretion of the naphthol metabolite and protect the kidney from products of hemolysis. Use Ringer's lactate or sodium bicarbonate to keep urine pH above 7.5.

5. Consider the use of mannitol or furosemide to promote diuresis. If urine flow declines, intravenous infusions must be stopped to prevent fluid overload and hemodialysis should be considered.[2]

6. If anemia is severe, blood transfusions may be needed.

Carbon Tetrachloride

For carbon tetrachloride poisoning, several treatment measures have been suggested to limit the severity of hepatic necrosis. The limited experience is outlined below.

1. Consider using hyperbaric oxygen, which has been used with some success.[14]
2. Administer n-acetyl cysteine (Mucomyst) orally as a means of reducing free radical injury.[48]

Dosage of Mucomyst

- ***Dilute the proprietary 20% product 1:4 in a carbonated beverage, and give about 140 mg/kg body weight of the diluted solution as a loading dose. Then give 70 mg/kg every 4 hours after the loading dose for a total of 17 doses (this dosage schedule is used for acetaminophen poisonings).***

Administration via duodenal tube may be necessary in patients who cannot tolerate Mucomyst.[49] Intravenous administration of n-acetyl cysteine may be used; more information is available through the poison control centers.

Carbon Disulfide

Mild poisonings by carbon disulfide inhalation may be managed best by no more than careful observation, even though sensory hallucinations, delirium and behavioral aberrations can be alarming. Severe poisonings may require specific measures.

1. If manic behavior threatens the safety of the victim, administer diazepam as a tranquilizer.

Dosage of Diazepam

- ***Adults: 5-10 mg administered slowly, intravenously***
- ***Children: 0.2-0.4 mg/kg, administered slowly, intravenously***

Give as much as is necessary to achieve sedation.

2. Do not give catecholamine-releasing agents, such as reserpine or amphetamines.

Phosphine Gas

Experience in India suggests that therapy with magnesium sulfate may decrease the likelihood of a fatal outcome.[39,43,50] The mechanism is unclear, but may possibly be due to the membrane stabilization properties of magnesium in protecting the heart from fatal arrhythmias. In one series of 90 patients, magnesium sulfate was found to decrease the mortality from 90% to 52%.[39] Two controlled studies have been done, one of which showed a reduction in mortality from 52% to 22%.[50] The other study found no effect on mortality.[51]

Dosage for Magnesium Sulfate

- ***3 grams during the first 3 hours as a continuous infusion, followed by 6 grams per 24 hours for the next 3 to 5 days.***[39]

Hydrogen Cyanide and Acrylonitrile

Poisonings by hydrogen cyanide and acrylonitrile gases or liquids are treated essentially the same as poisoning by cyanide salts.

1. Because cyanide is so promptly absorbed following ingestion, commence treatment with prompt administration of oxygen and antidotes. The three antidotes − amyl nitrite, sodium nitrite and sodium thiosulfate − are available in cyanide antidote kits, available from various sources. Read and follow the package insert.[52] The nitrates are intended to produce methemoglobin, which binds cyanide, which is then released and metabolized by rhodanese with the help of thiosulfate.

2. Hydroxycobalamin has been known from animal studies to be an effective antidote for cyanide poisoning.[53,54] Hydroxycobalamin has a higher affinity for cyanide than do tissue cytochromes, thereby competitively binding and inactivating both free and cytochrome-bound cyanide. The cyanocobalamin formed is readily excreted by the kidney. The product became commercially available in 2007 in the United States (Cyanokit, Merck).[55]

3. Administer oxygen continuously. Hyperbaric oxygen has been evaluated as effective in this condition.[56] If respiration fails, maintain pulmonary ventilation mechanically.

4. Measure hemoglobin and methemoglobin in blood. If more than 50% of total hemoglobin has been converted to methemoglobin, consider blood transfusion or exchange transfusion, because conversion back to normal hemoglobin proceeds slowly.

Although various cobalt salts, chelators and organic combinations have shown some promise as antidotes to cyanide, they are not generally available in the United States. None has been shown to surpass the effectiveness of the nitrite-thiosulfate regimen.

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