**Chapter 36
Chemical properties of hazardous materials**

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**Introduction**

Hazardous materials can be classified as chemical, radiological, or biological agents that can cause human illness when contacted. The basic physical and chemical properties of a hazardous material determine the manner in which victims/patients are exposed, the degree of morbidity and mortality associated with a given “hazmat” event, the type of decontamination necessary, and the type of personal protective equipment (PPE) required in the response.

Each hazardous material has a unique set of chemical properties. Here we will discuss the chemical properties of a hazardous material that can be used to place it into a group allowing assessment of the potential for contamination, the extent of exposure, the decontamination process, and type of PPE required.

One of the best examples of how the chemical properties of a substance can affect a hazmat response can be seen in the “sarin gas” attacks which occurred in Japan. On June 27, 1994 in Matsumoto, a Japanese terrorist released sarin gas, producing symptoms consistent with a cholinergic syndrome in approximately 600 individuals over a few hours. Over that time period, eight of the 53 prehospital responders developed symptoms of sarin exposure [1] and one of those responders required hospitalization for treatment [2]. Similarly, 11 of the 18 physicians caring for these patients in one emergency department developed symptoms, six of whom required treatment after exposure to contaminated patients alone [3].

In Tokyo, Japan, on March 20, 1995, a terrorist released sarin into five subway cars on three separate rail lines. As a result, 11 commuters were killed and over 5,000 patients required emergency medical evaluation. Again, victims quickly developed symptoms of cholinergic agent exposure and 640 victims arrived at the closest hospital (St Luke’s International Hospital) over just a few hours. Although unable to fully decontaminate all who arrived, simple measures taken (removal of clothing, optimization of ventilation in patient waiting areas, and frequent rotation of staff through waiting areas) resulted in limited exposure of medical staff. No staff required treatment for toxic exposures [4]. Of note, several other hospitals reported staff members who required treatment for exposure to sarin (25 of 39 prehospital providers required treatment at one facility) [5].

**Types of contamination**

In order to understand the effect of chemical properties on hazardous materials response, we must first differentiate between *exposure* and *contamination*and discuss the types of contamination that can occur.

When an object or individual is exposed to or comes into contact with a hazardous material, that object or individual may or may not become contaminated with the substance. Contamination occurs when the hazardous substance is physically transferred from the source to an object or individual.

*Primary contamination* occurs when an object or individual comes into direct contact with a hazardous material in such a manner that the material is transferred from the source and is physically on the object or individual. This type of contamination is most common in victims at the hazmat site, as well as first responders including police, fire, and EMS personnel [6].

*Secondary contamination* occurs when an object or individual comes into contact with a contaminated object. The hazardous material on the object may then be transferred to the clean object or individual, resulting in secondary contamination. Secondary contamination is the most common manner in which health care workers, such as emergency department staff receiving patients from the field, become contaminated after the release of a hazardous material [6,7].

Contamination may be best understood through the example of a child with dirty hands. A child gets out of the bath and is clean (non-contaminated). The child goes out to play in the yard, finding a mud puddle (the contaminant). After playing in the mud, the child has mud all over his hands (primary contamination). The child then goes inside and pets the dog, leaving dirty handprints on the dog (secondary contamination). The child washes his hands (decontamination) and no longer has any evidence of playing in the dirt. The child's father later arrives home and gives his perfect child a hug. He pets the dog and notes dirt on his hands (secondary contamination). The father looks at his dog and asks, “Have you been rolling in the mud again?”

Both primary and secondary contamination may occur in an overt or covert manner.

*Overt exposure* occurs when something is obviously contaminated or exposure is known. Overt exposures may become obvious when a material causes rapid onset of symptoms, or the material is a large liquid or solid that can easily be identified. Both of the examples above (the release of sarin and the child with muddy hands) illustrate overt exposures. The release of sarin “gas” (actually a liquid vapor) may be too small to detect visually but the rapid onset of symptoms allows for early identification of contamination. The dirt on the child’s hands illustrates a material that can be visually identified despite the distance in both time and space from the scene.

*Covert exposure* occurs when an object or individual does not have obvious contamination or does not immediately know that he or she has been contaminated. Covert exposure may occur when the hazardous material is associated with delayed onset of symptoms or a hazardous material is too small to see. Biological agents are commonly associated with covert exposure. As illustrated in the example below, biological agents not only are too small to see but also have an incubation period in which exposed individuals are not aware that they have been exposed.

In the fall of 2001, envelopes filled with spores of *Bacillus anthracis* were mailed via the United States postal services to multiple locations. Individuals inhaled these microscopic spores when they were released from the envelopes during the mail sorting processing, delivery of the envelopes, or opening of the envelopes. Initially, ten patients became ill with symptoms of inhalational anthrax and four died. None of these individuals were aware that they had been exposed [8]. As awareness of the anthrax attacks spread, early recognition, aggressive medical management, and prophylactic treatment resulted in only six deaths in the 22 individuals known to have become ill [9].

An understanding of the types of contamination allows first responders to be aware of the potential for contamination and protect themselves and others. Only with vigilance can we control or mitigate secondary contamination. Mitigation is critical and can prevent a small incident from becoming a mass causality incident or true disaster.

**General categories of hazardous materials**

One common method used to group hazardous material incidents is by the category of material involved: chemical, biological, radiological, and nuclear (CBRN – note that E for Explosives is sometimes added to this acronym in the context of weapons of mass destruction). Each category has unique characteristics and requires a different approach to decontamination. Knowledge of the categories will aid in understanding the expected patient presentation and type of decontamination required.

**Chemical**

Exposure to a chemical hazard is generally overt; patients are immediately aware of their contamination. Most who are contaminated by chemicals will require formal decontamination. The morbidity associated with the event will depend on the physical properties of the chemical encountered.

**Biological**

Biological agents include bacteria, viruses, and biological toxins. Biological events are unique in that the release of biological hazards is almost always covert. Because of this, contaminated patients will likely have already performed decontamination at home without knowledge that contamination has occurred, having returned home, changed clothes, and showered as part of their normal daily routine. For most exposures this will be sufficient, and no further decontamination is necessary.

There have been instances in which exposure to a suspected biological agent has occurred in an overt fashion, such as the anthrax scare events that occurred in the wake of the 2001 anthrax attack. When exposure to a biological agent is suspected, exposed and/or contaminated individuals may be instructed to wash their hands and face in a bathroom, return home, change and wash clothes, shower, and then wash surfaces they have contacted since the time of the exposure. Biological hazmat incidents are unique in that responders must consider prophylactic treatment of the biological exposure based on the agent involved [10]. Consultation with the local or state health department should occur when considering such measures.

### Radiation/nuclear

Ionizing radiation is an energized particle (alpha particle, beta particle) or wave (x-ray, gamma ray) released from a nuclear or radioactive material, capable of breaking covalent bonds. Ionizing radiation can cause illness when the covalent bonds of DNA and other molecules vital to cellular function are damaged. Through this mechanism, ionizing radiation can cause an acute radiation syndrome or local tissue damage at the site of exposure. Each type of radioactive material will produce a specific particle or wave. These particles or waves have unique physical properties that affect the ability of the particles to travel through material and cause tissue injury. The type of ionizing radiation encountered will not only determine the injury and illness encountered but also affect the type of PPE required to protect responders.

Nuclear and radiation incidents are frequently separated as the distinction helps to highlight the difference between management of the two types of events. Exposure to radiation alone does not result in contamination but can cause significant tissue damage. Nuclear events, however, can result in the release of radiation as well as the release of radioactive and nuclear particles with the potential to cause contamination and radiation-related injury. Therefore, decontamination and PPE are not necessary when caring for patients who have simply been exposed to radiation. On the other hand, radioactive or nuclear material can cause contamination and will require decontamination.

Finally, contamination with radioactive material does not represent an acute medical emergency. Exposure to radiation can cause both acute radiation sickness as well as local tissue damage but the onset to symptoms is delayed. Therefore, although it is important to remove the nuclear material as soon as possible, *stabilizing medical care, including surgical procedures for repair of traumatic injury, should not be delayed for complete decontamination.* See Volume 2, [Chapter 37](https://jigsaw.vitalsource.com/books/9781118990827/epub/OPS/Vol2/c37.xhtml) for additional detail on this topic.

## Basic properties of hazardous materials

### Physical properties of hazardous materials

The physical properties of a hazardous material will affect the type of contamination (primary/secondary), exposure (overt/covert), degree of morbidity associated with an incident, and decontamination procedures/PPE necessary in the response to an incident. The most important chemical property of any substance is its state of matter (solid, liquid, or gas) at ambient temperature. Solids in general will be the least likely to cause widespread contamination and require less complicated decontamination procedures and a lower level of PPE, while vapors and gases will have the greatest potential to cause increased morbidity and require the higher levels of PPE.

*Solids* occupy a fixed volume and shape. Large solids are less likely to cause contamination as they are easy to detect and more difficult to move. However, small solids such as dust particles may be easily transferred from a single source to another object or individual and result in both primary and secondary contamination in an overt or covert manner.

The explosion of a “dirty bomb” illustrates contamination with a solid hazardous material. Detonation of a device constructed with TNT and a small amount of radioactive U234, a radioactive solid, could result in blast injuries from the explosion and contamination with U234. Small particles can cause primary contamination of anyone in the immediate vicinity of the explosion, and could be transferred to first responders, resulting in secondary contamination. Decontamination should therefore be aimed at removing the solid particles (picking or wiping them off).

When responders encounter a solid hazardous material, they may make several assumptions based on this physical state. In general, Level D PPE with a simple particulate face mask is sufficient to protect responders from secondary contamination. Decontamination requires only removal of the solid. Washing with soap and water may be required to remove very small particles of a solid contaminant. It should be noted that solid aerosols (such as the anthrax spores that aerosolized when the contaminated envelopes were opened in the 2001 anthrax attacks), although solids, will not follow these general rules. The most important physical property of a solid is its melting point or the temperature at which the solid becomes a liquid.

*Liquids* occupy a fixed volume but not a fixed shape. Because of this, liquids can flow, are more likely to cause contamination, and may be more difficult to detect and contain. The volume of liquid will affect the ease with which it can cause primary and secondary contamination. Large volumes of liquids are easier to detect but harder to avoid, while small volumes of liquids will be harder to detect and more likely to be aerosolized (as in the sarin example above).

When responders encounter a liquid hazardous material, they may make several assumptions based on this physical state. In general, Level C PPE is sufficient to protect responders from secondary contamination with liquid hazardous materials. Level C PPE includes a splash-resistant suit that will protect against most liquids. Decontamination of victims/patients exposed to a liquid will likely require washing with soap and water. The amount of washing will depend in large part on the water solubility of the material as well as the corrosive properties of the material. Liquid hazardous materials can be absorbed through the skin or mucous membranes, making decontamination critical. It should be noted that liquid aerosols, although liquids, will not follow these general rules. The most important physical property of a liquid is its boiling point, or the temperature at which the liquid becomes a gas.

*Gases* do not occupy a fixed volume or a fixed shape. Because of this, they are difficult to both detect and contain. However, in general, a gas will not cause contamination but rather only result in symptoms of exposure to the gas. The exception to this general rule is the absorption of a gas by a liquid or porous material (clothing). That material may then become contaminated and result in secondary exposure when that material “off-gases” or releases the gas. Off-gassing will occur when the contaminated material moves to an area in which the concentration of the gas is lower than the initial environment. Because gases do not occupy a fixed volume or space and can be easily compressed, what may appear to be a small release may quickly become a widespread event, impossible to contain.

Carbon monoxide (CO) is one of the most commonly encountered hazardous gasses. When decontaminating a patient exposed to CO, responders must only remove the patient from the area of contamination. No further decontamination is necessary. Clothing may absorb CO and off-gassing will occur; however, the amount of CO released will be quickly reduced to a non-toxic concentration in open air.

When responders encounter a gaseous hazardous material, they may make several assumptions based on this physical state. In general, Level A or B PPE is required to protect responders from exposure to the hazardous material. Decontamination of victims/patients exposed to a gas generally requires only removal of the victim from the source followed by removal of any material that may result in off-gassing (taking their clothes off). Further decontamination using soap and water or other decontamination material is generally not necessary. Gaseous hazardous materials are inhaled and may be absorbed through the skin or mucous membranes. As such, even after appropriate decontamination, the victim/patient may continue to be exposed to the hazardous material and experience adverse effects of the material in a delayed manner. The most important physical property of a gas is its density relative to ambient air. This will determine its tendency to either disperse or settle in low-lying areas.

*Aerosols* are very small solid or liquid particles which when released into the air remain suspended for a period of time, and thus behave like a gas. The amount of time these particles remain in the air is dependent on the mass of the material. Larger particles such as droplets may only stay suspended for seconds, while smaller particles can stay suspended for hours. Aerosols are extremely common and the ability of a solid or liquid to aerosolize makes that material much more dangerous. When aerosolized, toxicants are harder to contain, more difficult to detect, and have an increased potential to reach a human mucosal surface (eyes, mouth, lungs, etc.) that would not otherwise contact the material. Several examples of aerosolized solids and liquids are illustrated below.

Smoke is a classic example of an aerosolized solid. One might assume that smoke is a cloud of gas. However, the majority of the material visible is a solid aerosol of particles (soot). This soot or partially combusted solid is black in color and due to its small mass, easily becomes aerosolized and may stay suspended for days.

 Water is the most commonly encountered aerosolized liquid. Everyone has encountered mist, fog, or clouds which are common names given to aerosolized water. Any liquid can become aerosolized, resulting in a “cloud” of toxic material, which is impossible to contain, with increased potential to contaminate and cause illness. One of the most devastating examples of aerosolization of a liquid used in a terrorist attack was illustrated in the Japan sarin incident.

When responders encounter an aerosol, they may make several assumptions based on this physical state. In general, these types of hazmat events are the most dangerous and have the greatest potential to result in morbidity. As such, responders should assume that Level A PPE is required to protect them from exposure. If the solid or liquid is not absorbed through the skin, Level B or C PPE with a “clean” air supply may be sufficient. Decontamination of aerosolized liquids or solids will likely require removal of the victim from the source and full decontamination using soap and water or other decontamination materials.

### General chemical properties of hazardous materials

The solubility and the acid/base characteristics of a hazardous material are chemical properties that will determine, to a large extent, the degree of morbidity associated with an incident, as well as the type of decontamination necessary and the type of personal protective equipment (PPE) required in the response.

#### Solubility

The solubility of a hazardous material is the ability of that substance (the solute) to dissolve in another (the solvent). The solubility of any material is determined by the molecular polarity of the solute relative to the polarity of the solvent. A *polar molecule* is one that has a negatively charged end and a positively charged end. A *non-polar molecule* is one that has no relative charge associated with the molecule. A particular material is soluble in another substance when both substances are either polar or non-polar. Simply stated, “Like dissolves like.” In most cases we are concerned with the ability of the hazardous material to dissolve in water (water soluble) or lipid (non-water soluble).

The solubility of hazardous materials will determine both the ability of material to be absorbed through the skin and the type of decontamination procedures necessary for an individual material. Because skin is made of cell walls with a lipid bilayer, water-soluble molecules are less likely and lipid-soluble molecules are more likely to be absorbed through the skin. Indeed, skin breakdown is required for polar hazardous materials to cause systemic illness when absorbed through the skin. As a result, polar hazardous materials are associated with a decreased risk of significant exposure when skin contamination occurs. It should be noted that the opposite is true of the mucous membranes. Due to the high water content in these regions, water-soluble materials will be easily absorbed through mucous membranes and appropriate precautions must be taken. Alternatively, absorption of a lipid-soluble material across the skin may occur quickly without any evidence of skin breakdown and result in significant systemic illness despite a seemingly mild exposure.

Because water is the most common solvent used in the decontamination process, the water solubility of a substance is critical to determine the type of decontamination required for an individual hazardous material. Water, a polar molecule, will dissolve any other polar molecule or water-soluble molecule. Because of this, when performing decontamination of those contaminated with an isolated polar molecule, use of water alone may be sufficient. Water alone, however, will be unable to dissolve a non-polar or non-water-soluble hazardous material. These molecules will require an emulsificant to be used in the decontamination process. The most commonly used emulsificant is soap. Soap has a polar head and non-polar or uncharged tail. The non-polar tails of soap surround the non-polar (non-water-soluble) molecule such that the only exposed part of the solute is the charged heads of the soap molecule. Water can then bind to the polar end of the soap molecules, making the non-water-soluble molecules water soluble. These complexes are referred to as micelles.

#### Acids and bases

Caustic substances (acids or bases) are commonly encountered hazardous materials. These chemicals are discussed in detail in Volume 1, [Chapter 46](https://jigsaw.vitalsource.com/books/9781118990827/epub/OPS/c46.xhtml). However, it should be noted that the pH of an individual material might help in its early identification. Acids and bases also cause rapid onset of symptoms and therefore exposure is more likely to be detected early. Finally, if a hazardous material acts as an acid or base, that characteristic will determine the end point of decontamination as victims should be washed with copious amounts of water until their skin pH is again neutral.

## Identifying basic properties of hazardous materials

Several resources are available to assist responders in the identification of the chemical properties of hazardous materials. Toxicologists, clinical pharmacists, and poison information specialists are available for consultation through the US poison control center system. Poison Control can be accessed 24 hours a day, 7 days a week by calling 1-800-222-1222. Additional resources are available in hard copy, electronic copy, and as mobile applications for multiple operations systems. These resources can be found at the web addresses listed below.

* “Orange Book” or Emergency Response Guide: [www.phmsa.dot.gov/prepare-respond](http://www.phmsa.dot.gov/prepare-respond)
* Wiser: [http://wiser.nlm.nih.gov](http://wiser.nlm.nih.gov/)
* CHEMM: [http://chemm.nlm.nih.gov](http://chemm.nlm.nih.gov/)
* REMM: [www.remm.nlm.gov](http://www.remm.nlm.gov/)

## Conclusion

Hazardous materials may be solids, liquids, or gases. The state of the hazardous material will affect both the ease with which the material can be spread and the measures necessary to remove it. Both solids and liquids can be aerosolized. Aerosolized materials are more difficult to contain than their non-aerosolized counterparts and may result in widespread contamination. When performing decontamination, responders must consider not only the state of the hazardous material but also its water solubility. Water may be used to decontaminate water-soluble toxins, while soap and water may be necessary to decontaminate those exposed to non-water-soluble materials.

Providers should maintain a high level of situational awareness and consider the potential for hazardous materials exposure when responding to any incident. Through a basic knowledge of the chemical properties of a hazardous material, and their effect on contamination and exposure, providers will be better able to make an initial assessment of the risk of secondary contamination, the minimum level of PPE necessary, and the decontamination procedures required. However, responders should also remember that each hazardous material will behave in a unique manner based on its individual chemical characteristics. Because of the wide variety of substances encountered and the potential for injury or loss of life, responders should consider consultation with a qualified clinical toxicologist, hazmat response expert, or others with advanced training to ensure a safe and successful response.

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