6. POTENTIAL FOR HUMAN EXPOSURE

6.1 OVERVIEW

Sulfur mustard has been identified in at least 3 of the 1,636 hazardous waste sites that have been proposed for inclusion on the EPA National Priorities List (NPL) (HazDat 2003). However, the number of sites evaluated for sulfur mustard is not known. The frequency of these sites can be seen in Figure 6-1. Of these sites, all are located within the United States.

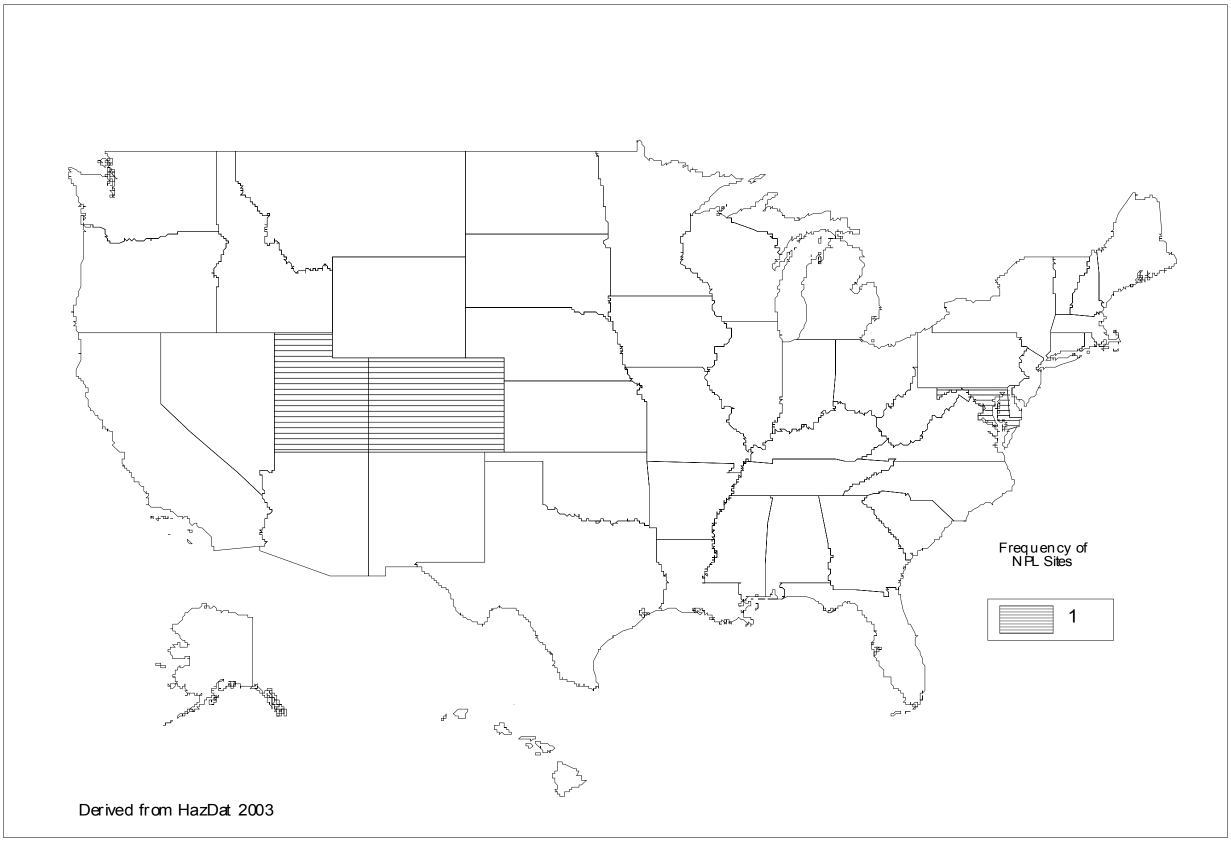
Sulfur mustard is not a naturally occurring compound and its primary application is in chemical warfare. The United States has not produced it since 1968. Chemical agents, such as sulfur mustard, are extremely hazardous materials, which is why they were used as weapons. The hazard is increased when the agent is contained in explosively configured munitions, an inherent feature of chemical weapons. Since chemical weapons no longer have any value as a military deterrent, Congress has mandated that all chemical agents and munitions be destroyed by the end of the year 2004 (NRC 1994). However, the destruction of all chemical agents and munitions in the United States containing sulfur mustard is likely to continue for some unspecified time beyond this date. Sulfur mustard is known to be stored at seven Army bases (see Section 5.1) across the continental United States, some of which may also be at NPL sites (DOA 1988). Persons working at or living near Army bases where this material is stored or destroyed are at a greater risk of exposure.

Information about other mustard agents (e.g., nitrogen mustard or HN, thickened mustard or HT, and lewisite), although related to sulfur mustard, is not included in this document (see Chapter 4).

6.2 RELEASES TO THE ENVIRONMENT

During World War I with its use as a chemical warfare agent, sulfur mustard was released directly to the atmosphere in countries outside the United States. From World War I until the 1970s, disposal of chemical weapons, such as sulfur mustard, at sea was accepted practice. Consequently, sulfur mustard is found in ocean waters at several sites around the world. It does not occur naturally, and is no longer produced in the United States. Sulfur mustard that was produced for military applications is now being

Figure 6-1. Frequency of NPL Sites with Sulfur Mustard Contamination



Derived from HazDat 2003

stored in military depots and storage facilities across the United States (see Section 5.1). Both sulfur mustard agent and munitions are currently or will be destroyed on site at these Army facilities. All chemical agents maintained in the Army stockpile are now at least 30 years old and some are more than 50 years old; none were manufactured after 1968 (NRC 1994). There have been almost 1,500 "leaking" munitions identified in the stockpile since 1982, some of which are leaking sulfur mustard (NRC 1994). In September 1993, a 100-gallon spill from a 1-ton container of sulfur mustard was discovered at Tooele Army Depot, Utah (NRC 1994). Other leaks of sulfur mustard have been identified from chemical munitions (e.g., 155-mm projectiles) as recently as October 16, 2002 (DOA 2003). Thus, environmental releases of sulfur mustard may potentially occur near Army bases where this material is stored and destroyed. However, because of the Army's efforts to mitigate exposure of the general population to sulfur mustard (as well as to other stockpile chemical agents), no releases of sulfur mustard have been reported beyond the confines of these storage locations.

6.2.1 Air

Sulfur mustard may be released to air at stockpile and non-stockpile sites across the United States where sulfur mustard is known to be located. However, because of the Army's efforts to mitigate exposure of the general population to sulfur mustard (as well as to other stockpile chemical agents), no releases of sulfur mustard to air have been reported beyond the confinement of these facilities. No known releases of sulfur mustard to the atmosphere have been reported with the destruction of sulfur mustard by incineration (MacNaughton 2001).

Sulfur mustard has not been identified in air at any of the three NPL hazardous waste sites where it was detected in some environmental media (HazDat 2003).

6.2.2 Water

From World War I until the 1970s, disposal of sulfur mustard at sea was standard practice. However, limited information about this practice is available before the mid-1940s. In 1943, sulfur mustard was released into the waters of Bari Harbor, Italy with the sinking of the American freighter, S.S. John Harvey (SIPRI 1971). Since the end of World War II, ocean dumping has occurred in many areas, such as the Baltic Sea (Mazurek et al. 2001); the coastal waters around Japan (Kurata 1980); the Adriatic Sea near

Bari, Italy; and the coastal waters of the United States (Brankowitz 1987). Some of the known ocean dumping sites off the continental United States are summarized in Table 6-1.

Sulfur mustard has not been identified in groundwater or surface water at the three NPL hazardous waste sites where it was detected in some environmental media (HazDat 2003).

6.2.3 Soil

No releases of sulfur mustard to soil have been reported in the literature. However, sulfur mustard is currently stored at several sites around the United States and its territories in stockpile and non-stockpile quantities (see Figure 5-1). Non-stockpile locations include known sites containing significant quantities of buried chemical weapons and wastes. Sulfur mustard is the most frequently identified material at these sites (NRC 2000).

Sulfur mustard has been identified in soil at one site of the three NPL hazardous waste sites where it was detected in some environmental media (HazDat 2003).

6.3 ENVIRONMENTAL FATE

6.3.1 Transport and Partitioning

On the basis of its use during warfare and its physical/chemical properties, sulfur mustard should partition to and be transported in the atmosphere following release. The vapor pressure of sulfur mustard is moderate (0.11 mm Hg at 25 °C), but is high enough for sulfur mustard to be in air in the immediate vicinity of liquid droplets (DOA 1996).

On surface soil, Small (1984) reported that volatilization would be the main route of sulfur mustard loss. However, on moist surface soil, hydrolysis would be the main loss pathway. At 25 °C, sulfur mustard deposited on a surface soil will evaporate within 30–50 hours (Munro et al. 1999). Meteorologic conditions such as temperature and wind will greatly affect the persistence of sulfur mustard on soil; with warmer temperatures and stronger winds, persistence of sulfur mustard decreases (Franke 1967). For example, sulfur mustard will vaporize 2–3 times faster at 20 °C than at 5 °C (Franke 1967). The freezing

Table 6-1. Location of Historical Dumping Areas for Sulfur Mustard (H) in Coastal Waters of the United States

Location of munitions loading	Destination	Date	Munition	Quantity
Attu and Adak, Alaska	12 miles off Chichagoff	1947	Bulk agent	Unknown
Charleston, South Carolina	Site “Baker”	August—October 1946	Bombs, projectiles, mines, bulk	Over 7 tons
Colts Neck Naval Pier, Earle, New Jersey	39˚ 39’ N, 70˚ 57’ W	June 15, 1967	Rockets, Bulk	3,890 tons
Colts Neck Naval Pier, Earle, New Jersey	39˚ 33’ N, 71˚ 02’ W	August 7, 1968	Contaminated water	2,975 tons
Edgewood Arsenal, Maryland	38˚ 30’ N, 72˚ 10’ W	June 18, 1962	Projectiles, Bulk	3 tons
Edgewood Arsenal, Maryland	38˚ 30’ N, 71˚ 06’ W	August 6–7, 1964	Bulk, Projectiles	65 tons
Naval Mine Depot, Yorktown, Virginia	Site “Baker”	March 21–25, 1946	Projectiles	13 tons
New Orleans Port of Entry, Braithwaite, Louisiana	Gulf of Mexico	March 1–7, 1946	Projectiles	207 tons
NWS Concord, California	37˚ 40’ N, 125˚ 0’ W	April 8–19, 1958	Bulk	9,030 tons
Theodore Naval Magazine, Mobile, Alabama	Gulf of Mexico	July 13, 1946	Bombs (German)	7 tons

Source: Brankowitz 1987

point of sulfur mustard is between 13 and 15 °C. In temperate regions, sulfur mustard should be a solid for half of the year (Munro et al. 1999). Solidified sulfur mustard is less volatile, of lower water solubility, and is less reactive than liquified sulfur mustard. A study of persistence under winter conditions found that sulfur mustard could be detected after 2 weeks, but was below detection limits (not stated) at 4 weeks (Franke 1967). When snowfall covered samples, high recoveries were demonstrated even after 4 weeks. This study also showed that persistence was affected by the size of droplets. Larger droplets of sulfur mustard increased both stability and recovery (Johnsen and Blanch 1984). Other factors that influence vaporization include pH, moisture content, porosity of the surface, and physical constituents of the soils (Rosenblatt et al. 1975). Because of its low solubility in water (920 mg/L) and ease of hydrolysis once dissolved (see Section 6.3.2.2), sulfur mustard is not transported through soil into groundwater (Munro et al. 1999).

In water, sulfur mustard will volatilize to air, hydrolyze, or remain unchanged. Without turbulence and at low temperatures, large quantities of sulfur mustard will persist under water for long periods of time (Munro et al. 1999). For example, sulfur mustard disposed of in sea water at several locations around the world continues to be brought to the surface where it has injured unsuspecting fisherman (Jorgensen et al. 1985; Kurata 1980; Mazurek et al. 2001). Volatilization of sulfur mustard from water surfaces is expected to be moderate based upon a Henry's law constant of 2.1×10^{-5} atm·m^3/mol (DOA 1996). Using this Henry's law constant and an estimation method (Lyman et al. 1990), volatilization half-lives of sulfur mustard for a model river and model lake are 36 hours and 503 days, respectively. Hydrolysis of sulfur mustard may be slow because of its limited solubility and the fact that sulfur mustard freezes at 14 °C (see Section 6.3.2.2). Sulfur mustard is expected to sink to the bottom of the water column because it is denser than water (1.27 g/cm^3 at 20 °C; see Table 4-1).

Sulfur mustard does not bioconcentrate or biomagnify due to its reactivity. It is also unlikely that it is transported through the vascular systems of plants since it would almost surely undergo hydrolysis in the process (Rosenblatt et al. 1975).

6.3.2 Transformation and Degradation

6.3.2.1 Air

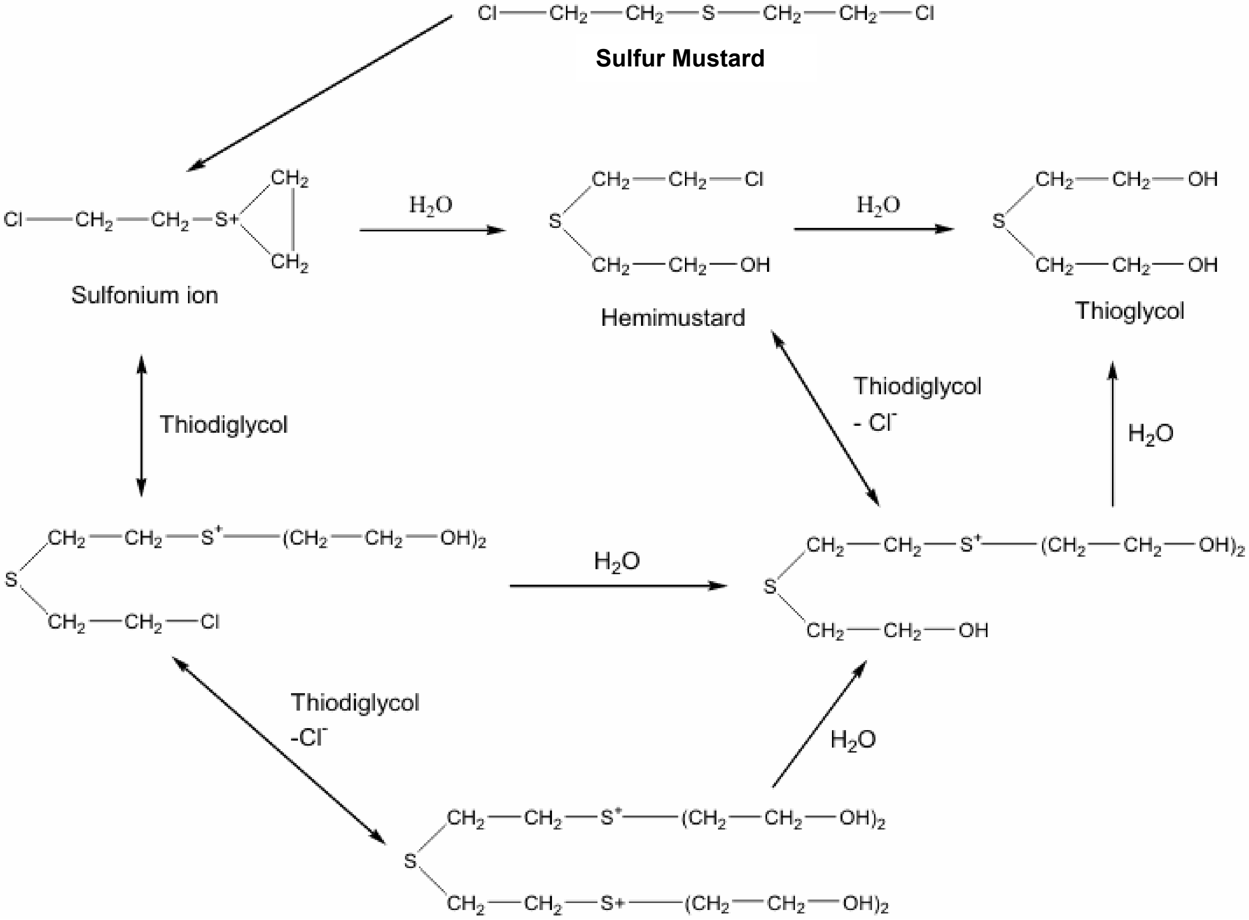
Sulfur mustard does not absorb ultraviolet (UV) radiation above 290 nm (Rewick et al. 1986); thus, photodegradation should not be an important fate process. The rate constant for the vapor-phase reaction of mustard with photochemically-produced hydroxyl radicals has been estimated as 7.82×10^{-12} cm^3/molecule-s at 25 °C using a structure estimation method (Meylan and Howard 1993). This corresponds to an atmospheric half-life of about 2.1 days at an atmospheric concentration of 5×10^5 hydroxyl radicals/m^3 (assumed average concentration in non-smog conditions). Under smog conditions, reaction with nitrate radicals may be important.

6.3.2.2 Water

While hydrolysis of sulfur mustard is relatively rapid in water once dissolved, sulfur mustard dissolution is relatively slow (Bartlett and Swain 1949; Clark 1989; Rosenblatt et al. 1975; Small 1984; Stein 1946). Dissolved sulfur mustard has a hydrolysis half-life of 4–8 minutes at 25 °C in distilled water (Bartlett and Swain 1949). In several studies reviewed by Small (1984), the hydrolysis half-life (first-order rate) of dissolved sulfur mustard ranges from 158 minutes at 0.6 °C to ~1.5 minutes at 40 °C. The hydrolysis products of sulfur mustard are primarily mustard chlorohydrin, thiodiglycol, and hydrochloric acid; others include intermediates such as cyclic sulfonium salts (Rosenblatt et al. 1975, 1996). The hydrolysis of mustard chlorohydrin is somewhat faster than the hydrolysis of sulfur mustard. Consequently, mustard chlorohydrin does not accumulate to high concentrations. Conditions involving relatively small quantities of water give rise to higher concentrations of the cyclic sulfonium salt intermediates, which are rather toxic. Hydrolysis pathways of sulfur mustard in the environment are illustrated in Figure 6-2.

Sufficient levels of chlorine in the water (e.g., salt water) will inhibit the hydrolysis reaction; hydrolysis is decreased by a factor of 2.5 in salt water over fresh water (Clark 1989; Rosenblatt et al. 1975, 1996). Chloride ions react with the cyclic sulfonium intermediates to reform sulfur mustard. Impurities found in sulfur mustard (e.g., polysulfides) might slow the dissolution of the agent, and if they dissolve in water, they will react more slowly with water than sulfur mustard (Rosenblatt et al. 1996). One impurity, 1,2-bis(2-chloroethylthio)ethane, is about 5 times as vesicant as sulfur mustard itself; others, such as 1,8-dichloro-3-oxa-6-thiaoctane, are probably about as toxic as sulfur mustard.

Figure 6-2. Primary Hydrolysis Pathways of Sulfur Mustard in the Environment



Source: Munro et al. 1999

Because sulfur mustard has limited solubility (920 mg/L in water; Rosenblatt et al. 1996), hydrolysis is limited by its slow rate of solution (i.e., 6.77×10^{-8} $g/cm^2 \cdot s$ at 10 °C). During the dissolution process, the outer surface of a sulfur mustard droplet dissolves and is rapidly hydrolyzed to sulfonium ions and thiodiglycol (see Figure 6-2). These compounds then react with sulfur mustard to form 1,2-bis[(2-chloroethyl)thio]ethane and 1,2-dichloroethane or together to form stable sulfonium polymers. Without agitation, sulfonium polymers build up, creating a thick boundary layer, which interferes with the transfer of sulfur mustard into bulk water. Dissolution of bulk sulfur mustard slows because the driving force for diffusion sulfur mustard into the bulk aqueous phase decreases (Rosenblatt et al. 1975, 1996). Without agitation, bulk sulfur mustard may persist in water for up to several years (Small 1984). Epstein et al. (1973) estimated that a 1-ton lump of sulfur mustard would require 5 years to dissolve in water.

The addition of water-soluble organic solvents, such as acetone and ethanol, permits greater concentrations of sulfur mustard to solubilize in water so as to facilitate hydrolysis (Clark 1989). For example, when a small amount of acetone (e.g., 5% solution in water) was used to dissolve sulfur mustard in water at 25 °C, the hydrolysis half-life was 9.0 minutes (first-order rate constant =0.00129 s^{-1}).

Oxidation of sulfur mustard is also known to occur. Reactions with hypochlorite, chlorine water, ozone, and hydrogen peroxide yield mustard sulfoxide, which is extremely stable to hydrolysis and slightly toxic. Further oxidation under more severe conditions forms mustard sulfone, a relatively nontoxic compound. However, in weakly alkaline solution, mustard sulfone is dehydrochlorinated to divinyl sulfone, which is highly toxic (Clark 1989; Price and Bullitt 1947; Rosenblatt 1975).

6.3.2.3 Sediment and Soil

Natural degradation of sulfur mustard in soil is a result of chemical hydrolysis and biodegradation. The major product of chemical hydrolysis is thiodiglycol. Chemical hydrolysis of sulfur mustard and its chlorine derivatives in soil depends on soil type and moisture content, degree of contamination, and temperature. If the moisture content of soil is <50% of its moisture capacity, then chemical hydrolysis in soil does not occur (Medvedeva et al. 2000). With higher temperatures and moisture content, the extent of hydrolysis of sulfur mustard increases, but never to 100% completion. Sulfur mustard is known to degrade faster in alkaline soils (Franke 1967). If sulfur mustard droplets are considerably below the soil surface, then sulfur mustard can persist for several years (Munro et al. 1999; Watson and Griffin 1992).

For example, sulfur mustard has been known persist for weeks to decades in military testing areas and land dumps where large quantities have been deposited underground.

Sulfur mustard can be biodegraded in soil via the thioether oxidation pathway, forming bis-(2-chloro-ethyl)-sulfoxide and corresponding sulfone (U.S. Army Dugway Proving Ground 1985). Recently, Wariishi et al. (2002) demonstrated that fungi (e.g., basidiomycetes) are able to degrade sulfur mustard in soil by directly cleaving the carbon-sulfur bond and by hydrolytic dechlorination. Sulfur mustard can also be biodegraded via reductive dehalogenation and dehydrohalogenation, although these pathways are predicted to be slow.

Degradation of the hydrolysis products of sulfur mustard (e.g., thiodiglycol) proceeds very slowly because these compounds are poorly utilized by microorganisms. For example, in a medially contaminated peaty gley soil characterized by a high rate of microbiological processes, the concentration of thiodiglycol decreased 50% after a year. However in a highly contaminated peaty gley soil, <10% of thiodiglycol degraded in a period of a year (Medvedeva et al. 2000). The reduction in microbial activity is a consequence of the high toxicity of sulfur mustard to soil microorganisms.

6.3.2.4 Other Media

No information was found in the literature regarding transformation and degradation reactions in other media.

6.4 LEVELS MONITORED OR ESTIMATED IN THE ENVIRONMENT

6.4.1 Air

No information was found in the literature regarding environmental concentrations of sulfur mustard in the ambient atmosphere. Ambient concentrations of sulfur mustard are expected to be zero except near military facilities where former production occurred or where current disposal may be in progress. During World War I, when sulfur mustard was used, the average and maximum atmospheric concentrations in the combat zones were estimated at 3 and 5 ppm, respectively (IARC 1975).

6.4.2 Water

In 1943, sulfur mustard was released into the waters of Bari Harbor, Italy with the sinking of the American freighter, S.S. John Harvey (Mitretek Systems 2002). Since the end of World War II, ocean dumping has occurred in many areas (SIPRI 1971), such as the Baltic Sea (Mazurek et al. 2001); the coastal waters around Japan (Kurata 1980); the Adriatic Sea near Bari, Italy; and the coastal waters of the United States (Brankowitz 1987). Some of the known ocean dumping sites off the continental United States are summarized in Table 6-1. No information was located that describes the concentration of sulfur mustard at these locations.

6.4.3 Sediment and Soil

No information was found in the available literature regarding current soil concentrations of sulfur mustard. For some time after World War I, much of the French soil in the region of battle lines was contaminated, although it is unlikely to have persisted to the present day (IARC 1975). If any sulfur mustard still exists, it would be present only as pockets of liquid, perhaps dissolved in discarded oil, or absorbed on an inert anhydrous soil medium (Rosenblatt et al. 1975). Before 1945, sulfur mustard was produced at the Rocky Mountain Arsenal in Colorado. Only traces of sulfur mustard have been found in soil samples at 3 or 4 locations out of 15,000 sampled during the recent clean-up of this site (Cohn 1999). Soils in Fort McClellan, Alabama are highly polluted with sulfur mustard and its many impurities (Dacre 1994). No additional information was found that quantifies the level of contamination at this site. Other sites where sulfur mustard may be present include non-stockpile sites across the United States (see Figure 5-1). No information was located that quantifies the concentrations of sulfur mustard at these sites.

6.4.4 Other Environmental Media

Normal urinary levels of thiodiglycol, a hydrolysis product of sulfur mustard, are <1 ng/mL, but levels up to *ca.* 16 ng/mL are found in blood (Black and Read 1991). The source of this low backgrounds level is unknown, but sulfur-rich foods in the diet may be one possibility. No other information was found in the available literature regarding concentrations of sulfur mustard in environmental media.

6.5 GENERAL POPULATION AND OCCUPATIONAL EXPOSURE

The general population in the United States is not exposed to sulfur mustard since it is found primarily at seven Army bases in stockpiles (Munro et al. 1999) and at 45 non-stockpile sites across the United States (see Figure 5-1). Populations located near these sites have a potentially greater risk of exposure to sulfur mustard. However, because of the Army's efforts to mitigate exposure of the general population to sulfur mustard (as well as to other stockpile chemical agents), no releases of sulfur mustard have been reported beyond the confines of these facilities. Also, since the entire stockpile of sulfur mustard agent and munitions is presently being destroyed onsite at several locations around the United States, the risk of exposure from accidental leaks and spills of sulfur mustard at these locations is decreasing for the general population. In countries where sulfur mustard was released during warfare (e.g., Belgium, Morocco, Ethiopia, China, and Iran-Iraq), it is possible that conditions have been favorable to allow small quantities to persist (Mitretek Systems 2002). Non-stockpile sites may contain buried munitions or contaminated soils containing sulfur mustard, which may be disturbed with excavation activities. Small quantities of sulfur mustard may persist at these bases. Populations in these areas are at higher risk than those in areas that were never contaminated.

Occupational exposure may occur for fishermen who inadvertently snare lumps of sulfur mustard in their nets. This type of exposure has occurred in areas of historical dumping of sulfur mustard in the seas and ocean. Accidents such as this continue to be reported in the Baltic Sea, Adriatic Sea, Pacific Ocean, and Japanese coastal waters, and have resulted in several hundred deaths over the past 50 years (Brankowitz 1987; Kurata 1980; Mazurek et al. 2001; SIPRI 1971). Individuals involved in activities related to the storage and destruction of this compound are also occupationally exposed. Construction workers may become exposed at Army bases where sulfur mustard was previously released and persisted in the soil or in an excavated munitions dump. Laboratory workers may be exposed to sulfur mustard through their research activities if they do not take the necessary precautions to prevent exposure. Soldiers may be exposed to sulfur mustard with its use as a chemical warfare agent. The most recent report of its use is from the Iran-Iraq War in the 1980s when it was detected in the urine of some soldiers (Vycudilik 1985).

6.6 EXPOSURES OF CHILDREN

This section focuses on exposures from conception to maturity at 18 years in humans. Differences from adults in susceptibility to hazardous substances are discussed in 3.7 Children's Susceptibility.

Children are not small adults. A child's exposure may differ from an adult's exposure in many ways. Children drink more fluids, eat more food, breathe more air per kilogram of body weight, and have a larger skin surface in proportion to their body volume. A child's diet often differs from that of adults. The developing human's source of nutrition changes with age: from placental nourishment to breast milk or formula to the diet of older children who eat more of certain types of foods than adults. A child's behavior and lifestyle also influence exposure. Children crawl on the floor, put things in their mouths, sometimes eat inappropriate things (such as dirt or paint chips), and spend more time outdoors. Children also are closer to the ground, and they do not use the judgment of adults to avoid hazards (NRC 1993).

Children in the United States are not likely to be exposed to sulfur mustard since it is found only at military bases (Munro et al. 1999), and access to these sites is highly restricted.

6.7 POPULATIONS WITH POTENTIALLY HIGH EXPOSURES

Since the U.S. stockpile of sulfur mustard is currently found in only at seven storage facilities (Munro et al. 1999), the potential for high exposures is limited to these areas and their surrounding communities. Exposure at or near these Army storage facilities may occur if the munitions or storage containers explode or leak. However, the U.S. Army currently takes corrective and preventive actions to mitigate the risks of exposure to the general population. In addition, the stockpile of chemical weapons containing sulfur mustard is currently being destroyed and is scheduled to be completed by 2004. Thus, the risk of accidental exposure to sulfur mustard is decreasing.

6.8 ADEQUACY OF THE DATABASE

Section 104(i)(5) of CERCLA, as amended, directs the Administrator of ATSDR (in consultation with the Administrator of EPA and agencies and programs of the Public Health Service) to assess whether adequate information on the health effects of sulfur mustard is available. Where adequate information is not available, ATSDR, in conjunction with the National Toxicology Program (NTP), is required to assure the initiation of a program of research designed to determine the health effects (and techniques for developing methods to determine such health effects) of sulfur mustard

The following categories of possible data needs have been identified by a joint team of scientists from ATSDR, NTP, and EPA. They are defined as substance-specific informational needs that if met would reduce the uncertainties of human health assessment. This definition should not be interpreted to mean that all data needs discussed in this section must be filled. In the future, the identified data needs will be evaluated and prioritized, and a substance-specific research agenda will be proposed.

6.8.1 Identification of Data Needs

Physical and Chemical Properties. The physical and chemical properties of sulfur mustard are available (Tables 4-1 and 4-4). Experimental determination of properties for sulfur mustard such as log K_{ow}, log K_{oc}, and Henry's law constant values would be useful to determine its environmental fate.

Production, Import/Export, Use, Release, and Disposal. Since 1968, sulfur mustard has not been produced, imported, or exported by the United States. Future production is not expected since international treaties prohibit the manufacture of sulfur mustard. The quantities of sulfur mustard at various locations across the United States are known. The entire stockpile of sulfur mustard munitions and bulk agent is currently in the process of being destroyed. The destruction of the stockpile, mandated by Congress, is to be completed by December 31, 2004. Information on the amounts of sulfur mustard being disposed of by each disposal method is available. Sulfur mustard is not used in the home environment or workplace. Sulfur mustard is also not present in food, and thus, will not be present as a food contaminant.

Environmental Fate. There is limited information on the environmental fate of sulfur mustard. It is known to vaporize and hydrolyze in water (Clark 1989; Rosenblatt et al. 1975; Stein 1946). However, sulfur mustard will persist in the environment in both soil and water. Information of the half-life of sulfur mustard in the environment is known. Additional environmental fate information (e.g., biodegradation) would help to adequately characterize the compound. Information on the fate of sulfur mustard degradation products in the environment would also be useful.

Bioavailability from Environmental Media. Sulfur mustard can be absorbed following inhalation (Drasch et al. 1987; Somani and Babu 1989) and dermal (Cullumbine 1946, 1947; Drasch et al. 1987; Nagy et al. 1946; Renshaw 1946) exposure from air and soil. This was its intended use and it is well studied (see Chapter 3).

Food Chain Bioaccumulation. No information was found regarding the bioconcentration of sulfur mustard by plants, animals, and aquatic organisms, or the biomagnification in terrestrial or aquatic food chains. However, due to the toxicity and metabolism of sulfur mustard, it is unlikely that it will bioconcentrate or biomagnify.

Exposure Levels in Environmental Media. There are limited reports of sulfur mustard being detected in environmental media (e.g., soil and water) at hazardous waste sites, Army chemical weapon stockpile and non-stockpile facilities, ocean disposal sites, or other locations. Additional and up-to-date information is needed on media concentration levels near former and current facilities where sulfur mustard has been produced, stored, or destroyed. This information will be useful in predicting human exposure levels at these locations. Additional data on the amount of sulfur mustard at historical ocean dumping sites would be useful.

Exposure Levels in Humans. No estimates have been for human intake of sulfur mustard from various environmental media. However, since potential exposure to sulfur mustard is currently limited to hazardous waste sites, Army chemical weapon stockpile and non-stockpile facilities, and ocean disposal sites, human intake of sulfur mustard by the general population is expected to be very low or none. Sulfur mustard metabolites have been detected in the urine and blood of exposed humans after its use as a chemical weapon (see Chapter 7). For example, thiodiglycol has been detected in the urine of soldiers after an acute exposure to sulfur mustard (Wils et al. 1985). However, the use of levels in urine or other biomarkers has not been reported in any other exposed populations. More sensitive methods of detection may be useful for assessment of chronic exposure to individuals working at or living near facilities that store or destroy sulfur mustard.

Exposures of Children. Sulfur mustard has been detected in exposed children after its use as a chemical weapon (See Chapter 3) during the Iran-Iraq War (Momeni and Aminjavaheri 1994). More sensitive methods of detection for sulfur mustard may be useful for assessment of chronic exposure to children living near facilities that store or destroy sulfur mustard.

Child health data needs relating to susceptibility are discussed in Section 3.12.2 Identification of Data Needs: Children's Susceptibility.

Exposure Registries. There are no exposure registries for sulfur mustard. This compound is not currently one of the compounds for which a subregistry has been established in the National Exposure

Registry. The compound will be considered in the future when chemical selection is made for subregistries to be established. The information that is amassed in the National Exposure Registry facilitates the epidemiological research needed to assess adverse health outcomes that may be related to the exposure to this compound.

6.8.2 Ongoing Studies

The ongoing studies focusing on environmental fate and human exposure of sulfur mustard are presented in Table 6-2 (DTIC 2002; FEDRIP 2002).

Table 6-2. Ongoing Studies on the Environmental Fate of Sulfur Mustard

Investigator	Affiliation	Study	Sponsor
Myer, SB	Tienzyme, Inc., State College, Pennsylvania	Use of fungal peroxidases for neutralization of sulfur mustard	Army
Shaw, RW	University of Florida, Gainesville	Catalytic oxidation of mustard simulants in basic solution	Army Research Office

Sources: DTIC 2002; FEDRIP 2002