NRT Quick Reference Guide:
Sulfur Mustard (HD)
[January 2015 Update]

For references, please see Key References Cited/Used in National Response Team (NRT) Quick Reference Guides (QRGs) for Chemical Warfare Agents. QRGs are intended for Federal OSC/RPMs.

Agent Characteristics

Agent Classification: Schedule 1 Chemical Warfare Blister (Vesicant) Agent; **CAS:** 505-60-2; **Formula:** $C_4H_8Cl_2S$; **Molecular Weight:** 159.08 g/mol.
Description: Sulfur mustard is sometimes called "mustard gas" but is actually a yellow to brown oily liquid with a garlic, onion, horseradish or mustard-like odor. It is a blister (vesicant) agent that will have delayed health effects on the order of hours, and is reported to be a known human carcinogen. It can be manufactured at different concentrations; with impurities, additives, or thickening materials that will all affect physical properties, appearance, persistence and analytical detection limits. Distilled mustard (HD) is considered the most potent form and is the basis of this QRG. Environmental breakdown products of HD, including thiodiglycol (TDG) and hydrochloric acid, are relatively non-toxic, but some decontamination by-products can be toxic (e.g., sulfones).
Persistence: HD is considered a "semi-persistent" chemical warfare agent with liquid deposition on surfaces lasting for hours to days. Persistence will depend upon amount and purity of the agent, method of release, environmental conditions, and the types of surfaces and materials impacted. Under certain environmental conditions, HD liquid may go through a partial hydrolysis that results in an outer protective coating around "globules" that are resistant to further hydrolysis and can persist for decades if not physically disturbed. Porous, permeable, organic or polymeric materials such as carpets and vinyl tiles can act as "sinks" for absorbing HD vapors and liquids, prolonging persistence.

Physical properties are listed at/near STP unless otherwise indicated. Conversion Factors: ppm = mg/m³ x 0.1538; mg/m³ = ppm x 6.503

Vapor Density	Vapor Pressure	Volatility	Boiling Point	Freezing Point	Flash Point	Liquid Density	Aqueous Solubility	Non-aqueous Solubility
5.4 (air = 1)	0.072 mm Hg (68°F/20°C)	610 mg/m³ (68°F/20°C)	~422°F/217°C	58.1°F/14.5°C	223°F/106°C	1.27 g/mL (77°F/25°C)	0.92 g/L (72°F/22°C)	Common solvents, alcohols, gasoline, oils, fats

Release Scenarios

AIR RELEASE SCENARIOS ARE ASSUMED MOST PROBABLE; HOWEVER, OTHER RELEASE SCENARIOS AND EXPOSURE ROUTES SHOULD BE CONSIDERED.
Open Areas: HD is difficult to disperse in air due to low volatility; however, it may be possible to disperse HD as a vapor/aerosol plume if an appropriate heat/explosive device is employed. The low volatility of HD would limit the size and extent of plume dissipation, posing localized hazards. **HD has a freezing point at 15°C (58°F), so the re-aerosolization of liquids and solids, as ambient temperatures rise, may present a real hazard.** HD vapors are heavier than air, so vapors can accumulate in lower terrains.
Water/Water Systems: HD released into water may dissolve and hydrolyze with a half-life of about 8.5 minutes at 25°C, but in sufficient amounts (relative to water volume) HD may also form globules surrounded by a protective outer layer resistant to hydrolysis. These globules may settle out or be entrapped, persisting for years and posing a contact hazard to anyone disturbing them. Areas in which the globules may persist include stagnant volumes of water as small as puddles formed by precipitation events. Water systems, plumbing, surfaces and equipment that have contacted HD globules, must be evaluated for decontamination.
Indoor Facility: HD is a semi-persistent agent with low to moderate volatility, and would be difficult to distribute effectively throughout a building or facility from a point source. Liquid HD will result in localized areas of surface contamination. HVAC system intakes near to liquid HD should be investigated for contamination from HD vapors and aerosols. HD vapors are heavier than air so vapors can accumulate in lower levels or utility corridors inside the buildings.

Health Effects

Onset	Onset and severity of effects depend on dose, duration and route of exposure (not all signs/symptoms may develop). The effects caused by HD are not typically fatal immediately, but can require substantial supportive medical care as there is no antidote, and secondary infections from blisters/tissue damage may also be fatal. HD produces effects by causing DNA damage/cell death in seconds (this is not like an acid burn). Despite the immediate DNA damage actual **signs/symptoms are delayed 1-48 hours** after exposure, so those exposed may not be aware.
Signs/ Symptoms	Symptoms will vary depending on exposure route; however, the following is a general list of all possible symptoms. The severity of effects depends upon the dosage. **Mild:** Effects delayed 1-48 hours (severity depends on dose): Eye irritation (tearing, grittiness), runny nose, sneezing, nosebleed, hoarseness, hacking cough. **Moderate:** Effects delayed 1-24 hours: Mild effects plus reddening and swelling of eyelids, severe cough, shortness of breath, reddening of skin. **Severe:** Effects delayed 1-24 hours: Upper respiratory/lung damage may occur at high concentrations and longer exposure durations.
Exposure Routes	**Inhalation:** Injury develops slowly, intensifies over several days. Vapor exposure is absorbed in mucous membranes (mouth, throat and lungs). **Skin:** Direct contact with HD liquid can cause redness or blisters in 2-24 hours. Warm and sweaty skin areas (underarms, groin) are most susceptible to exposure. **Eyes:** Eyes are the most sensitive to HD injury; effects noted after 1-12 hours include irritation, burning, gritty feeling, itching, weeping, reddening, lid swelling, light sensitivity, pain and corneal injury. High concentration effects are extremely painful and generally require extended medical treatment. **Ingestion:** Consumption of contaminated food or drink could cause burning, nausea and vomiting.

Effect Levels

Air: Acute Exposure Guideline Levels (AEGLs) for general population one-time exposure emergency scenarios for HD (complete definitions are available in Key References Cited/Used in NRT Quick Reference Guides for Chemical Warfare Agents):

AEGL Level in mg/m³, at various exposure durations	10 min.	30 min.	1 hr.	4 hr.	8 hr.
AEGL 1: Threshold mild effects	0.40	0.13	0.067	0.017	0.0083
AEGL 2: Potentially irreversible effects or impaired ability to escape	0.60	0.20	0.10	0.025	0.013
AEGL 3: Threshold for severe effects/medical needs/increasing potential for lethality	3.9	2.7	2.1	0.53	0.27

Exposure Guidelines: IDLH = 0.7 mg/m³; STEL = 3.0 x 10^{-3} mg/m³; **Worker Population Limit (WPL)** [an 8-hr time-weighted average occupational value] = 4.0 x 10^{-4} mg/m³; **General Population Limit (GPL)** [a 24-hr time-weighted average] = 2.0 x 10^{-5} mg/m³. **Soil: Industrial Exposure Scenario** = 0.3 mg/kg (10^{-4} cancer risk); **Residential Exposure Scenario** = 0.01 mg/kg (10^{-5} cancer risk). **Drinking Water:** Provisional Advisory Levels (PAL-1) for HD are not available due to the rapid hydrolysis of dissolved HD to TDG. In the absence of PALs, the U.S. Army's Military Exposure Guidelines (MEGs) may be used; the MEG at 5 L/day, for 7 days = 140 µg/L.

Personnel Safety

Note	Personal Protective Equipment (PPE) selection (levels A-D), medical surveillance requirements, First Aid options and personnel decontamination may vary depending upon the amount and purity of agent, site conditions and the release scenario. Additional information on personnel safety and PPE selection criteria can be found at: www.cdc.gov/niosh/ershdb. We also recommend that responders check their own internal procedures (i.e., SOPs) if they have them.
Medical	**Pre-incident:** Annual physical and respiratory function exams. **During Incident:** Conduct periodic on-site medical monitoring, observe for any signs and symptoms as per Health Effects section above and treat accordingly as per First Aid section below.
First Aid	Immediately remove person from affected area and remove contaminated clothing and articles. Wash bare skin immediately with water, or warm, soapy water if available, at normal household pressures (~50-60 psi) for three minutes, ensure thorough soaking. Rinse eyes exposed to liquid agent with potable water for 15 minutes. Antidote: NO ANTIDOTE AVAILABLE. Send person for follow-up medical attention and evaluation; **be aware effects are delayed 1-48 hours.** If cleared to resume work, continue to monitor for signs/symptoms and treat accordingly.
PPE	GENERAL INFORMATION: NIOSH-certified Chemical, Biological, Radiological, Nuclear (CBRN) Self Contained Breathing Apparatus (SCBA), Air Purifying Respirators (APR) or Powered Air Purifying Respirators (PAPR), full-face masks, & protective clothing should be used. Pre-incident training & exercises on the proper use of PPE are recommended. Per NIOSH guidance - **LEVEL A:** Recommended for the initial response to an HD incident. Level A provides the greatest level of skin (fully encapsulating suit), respiratory (SCBA), & eye protection when the contaminant identity or concentration is unknown. Select Level A when the HD concentration is unknown or above the IDLH or AEGL-2, & when there is a potential of ocular or dermal exposure. **LEVEL B:** Provides the highest level of respiratory protection (SCBA) when a lesser level of skin protection is required. Select Level B when the HD concentration is unknown or above the IDLH or AEGL-2 & dermal exposure is less of a risk. Level B differs from Level A in that it incorporates a non-encapsulating, splash-protective, chemical-resistant outer suit that provides protection against most liquids but is not airtight. **LEVEL C:** Select Level C when the contaminant identity & concentration are known & the respiratory protection criteria factors for the use of APR or PAPR (i.e., < IDLH, warning properties) are met. Level C may be appropriate when decontaminating personnel or equipment. **LEVEL D:** Select Level D when the contaminant is known & the concentration is below the appropriate occupational exposure limit or less than AEGL-1 for the stated duration times. **Downgrading PPE levels can be considered only when the identity and concentration of the contaminant and the risks of dermal exposure are known, and must be accompanied by on-site monitoring.**

Field Detection

Real-time field screening tools (results not confirmatory or quantitative): Caution should be given to equipment that has not been properly evaluated. False positive and false negatives may occur in the presence of interferents common in the environment. The following is a summary of minimum screening concentration ranges for equipment procured by many EPA and HAZMAT response teams. Other screening tools may be used by these teams & other agencies & responders, some with similar capabilities & limitations.

NOTE: Detection equipment does not measure contaminant levels. Rather, they detect the presence of HD at levels as listed below.

Minimum Screening Ranges	CAM/ICAM	AP2C/AP4C	APD-2000	Dräger (CDS Kit)	M256/M256A1	M272 (water)
ppm	0.3	0.03-0.142	0.3	0.15	0.31-0.46	2.0 mg/L
mg/m³	0.1-2	0.2-1	0.22-2	1	2-3	NA

Sampling	*Note: This section on sampling contains general guidelines and does not replace the need for a site-specific sampling plan (See Key References Cited/Used)* Sampling Concerns: Detection, sampling equipment and procedures, and analytical techniques will be site-specific and depend on: 1) physical state of the agent; 2) type of surfaces contaminated (e.g., porous vs. non-porous); 3) the purpose of sampling (e.g., characterization, decontamination efficacy and clearance); and 4) specific laboratory requirements. Few laboratories currently have capability to determine HD, particularly for large numbers of samples and in all types of media. The U.S. Environmental Protection Agency (EPA) has set up mobile and fixed labs and analytical assets for chemical agent analysis of environmental samples under their Environmental Response Laboratory Network (ERLN), see ANALYSIS section below (www2.epa.gov/emergency-response/environmental-response-laboratory-network). For sampling questions, call the EPA/HQ-EOC at 202-564-3850.
	Sample Locations and Planning: Initially consider air monitoring to ensure worker safety and to determine if there is a vapor plume that could impact other areas. Characterization sampling is initiated by targeted or judgmental sampling to identify "hot spots," potential agent flow paths, and media or objects potentially acting as sinks. Additional biased or random sampling can be used to determine the extent of potential contamination or to verify the efficacy of decontamination. More thorough probabilistic sampling (e.g., grid, statistical approach) may be required for the clearance phase or if there are large uncertainties about the area impacted or the amount released. Because HD is a semi-persistent liquid, sample priorities should include surfaces that are potentially contaminated with aerosol/liquid (e.g., release site, low lying areas) and that humans are likely to contact or where vegetation is used as food.
	Note: HD breaks down in most environmental conditions to numerous breakdown products, especially TDG, which may be used as a marker to determine the extent of contamination of the parent HD. See ANALYSIS section below to ensure sampling procedures are compatible with all analytes. Types of Samples: Air (Vapors are heavier than air): Samples are collected using appropriate solid phase absorbent (tubes) or air sampler (e.g., SUMMA canister) at breathing zone level (~5 ft.) to assess inhalation exposure and at ground levels (~6 in.) to assess off gassing at surfaces. Water: Water should be collected in appropriate containers with addition of appropriate de-chlorinating agents and preservatives. Soil: For localized hot spot areas where soil deposition may occur (i.e., aerosol or liquid droplets), surface soil samples should be taken from a non-vegetated area to a depth of less than one inch. Sub-surface soil samples are typically not necessary unless a large amount of liquid was poured on the ground, or if an underlying aquifer is endangered. Surface Wipes: Wipe samples are often desired to indicate absence of HD on non-porous surfaces. Concurrent air monitoring is recommended. Bulk: For hot spot areas where liquid HD deposition may occur on porous surfaces (e.g., concrete, asphalt), actual pieces or cores of contaminated surface may be obtained using appropriate tools (scabbling, coring or drills) for subsequent laboratory extraction analysis. Bulk samples of suspected sink materials may be recommended to rule out secondary vapor phase disposition or absorption of HD into these materials. Other Sample Matrices: Contact EPA/HQ-EOC at 202-564-3850 for sampling instructions.
	Sample Packaging and Shipping: The packaging and shipping of samples are subject to strict regulations established by DOT, CDC, USPS, OSHA and IATA. Contact the sample-receiving laboratory to determine if they have additional packaging, shipping or labeling requirements.
Analysis	CAUTION: Many labs may not be able to perform analysis on all matrices (e.g., wipes and soil). The ERLN will use uniform, compatible sample prep and analytical methods. (See www2.epa.gov/emergency-response/environmental-response-laboratory-network). For access to the nearest ERLN laboratory specially trained and equipped for HD analysis, contact the EPA/HQ-EOC at 202-564-3850.
Decontamination/Cleanup	Decontamination/Cleanup Planning: Once site controls are in place, develop a site-specific decontamination/cleanup plan. Decontamination may require a "tiered approach" using a variety of techniques and products. Call the EPA/HQ-EOC at 202-564-3850 for more information. General Considerations: A cost vs. benefit evaluation should be undertaken for each decontamination strategy and approach that considers: public safety, total cost, impact on the facility, wastes generated, as well as the time the facility or item will be out of service and any socio-economic, psychological, and/or security impacts that may result. Large volumes of decontamination wastes may be generated that will need to be collected, treated and disposed of properly. Waste handling and disposal must be addressed as early in the decontamination and cleanup process as possible (see Waste Management section below). Disposal Option: The urgency to restore a facility as quickly as possible may result in the outright and timely removal and disposal of contaminated materials. Certain materials may be resistant to decontamination formulations, or may be cheaper to discard and replace than to decontaminate and restore. Monitored Natural Attenuation: HD degrades via natural processes. Environmental monitoring must be maintained during decontamination and recovery phases. Monitored natural attenuation may require institutional controls (e.g., access restriction and contaminant containment measures). The time to achieve clearance must be considered in the overall cost/benefit evaluation. This option is more passive than other options but is non-destructive to materials. Fix-in-Place Option: The contaminated area may be resistant to decontamination products or may be unable or impractical to be treated. Physical barriers can be used to separate and immobilize the agent contamination from coming into contact with the environment or the public. This can be a temporary or permanent solution. Decontamination Strategy: A decontamination strategy can be developed by designating contaminated areas into three broad categories: 1) surfaces or hot spots, 2) large volumetric spaces, and 3) sensitive equipment or items. Areas in each category may be treated using one or more unique decontamination processes in a tiered approach to the overall site-specific decontamination strategy. Surfaces/Hot Spots: This category is for areas smaller in size but with higher levels of agent contamination. They may require more rigorous decontamination products and methods. In contrast to the rapid hydrolysis when HD is dissolved in water, the hydrolysis of HD on surfaces is slow. 1) Hypochlorite solutions are effective but can be very corrosive to certain surfaces and materials and should be rinsed thoroughly afterwards. Household bleach solutions (≥5% sodium hypochlorite) are very effective for HD with efficacy achieved with contact time of 15-60 minutes depending on surface material. Calcium hypochlorite, present in commercial products, such as HTH (10% hypochlorite solution), is better for surfaces with high concentrations of liquids in localized areas. 2) Proprietary decontamination foams and gels such as DF-200®, CASCAD®, Decon Green®, or L-Gel® have been reported to be effective against HD on the order of minutes to hours, but not all have been thoroughly tested. Availability, cost and the need for specialized equipment may limit their use early in the response. Large Volumetric Spaces: This category is for areas larger in size but with lower levels of agent contamination. They may require less aggressive but more broadly applied decontamination products and methods. 1) Monitored Natural Attenuation is more passive than other decontamination options and is non-destructive to materials. This option may be preferable given the scope and severity of contamination. 2) Forced or Hot Air ventilation methods are recommended for vapor plume contamination or low concentration of HD in large volumetric spaces or open areas; efficacy typically can be achieved in hours to days with less waste and adverse impacts to materials. 3) Fumigation with modified vaporous hydrogen peroxide (VHP®) has been reported to be effective against HD. HVAC systems in large indoor spaces may require a separate decontamination strategy that could include the use of Hot Air ventilation or fumigation. Sensitive Equipment and Items: 1) Forced or Hot Air ventilation may be used for HD and can be used either in-situ or ex-situ to decontaminate these items. 2) modified VHP® fumigation can be used on these items with less corrosion to electronics than dilute hypochlorite solutions. CAUTION: Decontamination products may have unique safety/PPE requirements due to their own toxicity or that of breakdown products during use (e.g., bleach results in chlorine vapors). Strong oxidizers, such as hypochlorite, may react violently with organics. Under oxidizing conditions (i.e., bleach), HD can break down into several toxic by-products, such as mustard and vinyl sulfones. Hydrolysis of HD releases Cl ions that can affect the pH of solutions. Formulations should be chosen that do not allow the formation of these toxic breakdown products. Dirt, grime and other coatings can reduce the efficacy of decontamination; pre-cleaning surfaces with soap and water may be needed before the application of decontamination formulations but resulting pre-cleaning rinsates may contain and spread agent. Verification of Decontamination: Site and situation specific. Please contact EPA/HQ-EOC at 202-564-3850 for further assistance.
Waste Management	CAUTION: Federal requirements for transporting hazardous materials and procedures for exemptions are specified in www.fmcsa.dot.gov/safety-security/hazmat/complyhmregs.htm#hmp. These regulations differ from state-to-state. Detailed state regulations can be found at www.envcap.org. Current resources on packaging, labeling and shipping are available at: www.phmsa.dot.gov/hazmat.
	Waste Management: Under the Resource Conservation and Recovery Act (RCRA), waste generally is classified as hazardous waste (subtitle C) or solid waste (subtitle D). Under RCRA's statutory authority, a waste is considered hazardous if it: (A) causes or significantly contributes to an increase in mortality or an increase in serious, irreversible or incapacitating reversible illness or (B) poses a substantial, present or potential hazard to human health or the environment when improperly treated, stored, transported or disposed of or otherwise managed. The RCRA regulations generally define a waste as hazardous if it is: (1) a listed waste (40 CFR§261.21, §261.32), (2) exhibits specific characteristics (§261.21-261.24) or (3) is a spilled or discarded commercial chemical product (§261.33). The States (except for Alaska and Iowa) have the primary responsibility to implement the hazardous waste regulations and can impose more stringent requirements than the Federal program, so it is critical to open a dialogue with regulators as early as possible. Several states (CO, IN, KY, MD, OR, UT) have their own waste designations for CWA, which may be applicable for the cleanup of contaminated residues. HD is not a hazardous waste under the Federal regulations, but state codes may apply for HD-contaminated residues, soils and debris. Management of toxic decomposition products, associated residual decontamination solutions, local waste acceptance criteria, and transportation and handling requirements should be considered. The EPA has developed I-WASTE, a web-based tool that contains links to waste transportation guidance, treatment and disposal facilities, state regulatory offices, packaging guidance, and guidance to minimize the potential for contaminating the treatment or disposal facility. Access to this decision support tool requires pre-registration (www2.ergweb.com/bdrtool/login.asp).