

## 5. PRODUCTION, IMPORT/EXPORT, USE, AND DISPOSAL

### 5.1 PRODUCTION

Mustard gas is a synthetic organic compound. It was first manufactured in 1822 by the action of ethene on sulfur monochloride or dichloride. Since then, the methods of manufacture have been refined although they have not been changed substantially. Three main processes have been used. The Germans produced mustard gas using the Meyer process, which involved treating ethylene with hypochlorous acid followed by sodium sulfide, yielding  $\beta,\beta'$ -dihydroxy-methyl sulfide. This was heated in turn with hydrochloric acid and produced mustard gas. In the United States, it was formerly made using the Levenstein process in which ethylene was reacted with sulphur monochloride at 30–35 EC. Mustard gas produced by this process contains 62–64% distilled mustard gas (or HD) (Munro et al. 1999). This process produces a complex mixture that includes constituents that are more toxic than mustard gas itself (Rosenblatt et al. 1975). The most recent process used in the United States involved the formation of bis-(2-hydroxyethyl)-thioether from ethylene oxide and hydrogen sulfide; this was then reacted with hydrochloric acid to form mustard gas (Franke 1967; IARC 1975; Rosenblatt et al. 1975). Mustard gas produced by this process contains 89% HD (Munro et al. 1999).

Mustard gas was manufactured in large quantities during World Wars I and II, but has not been manufactured on an industrial basis in the United States since 1968 (NRC 1994). Stockpiles of mustard gas are stored in 1-ton containers at Anniston Army Depot in Alabama, Umatilla Depot Activity in Oregon, Pine Bluff Arsenal in Arkansas, Tooele Army Depot in Utah, and Aberdeen Proving Ground in Maryland. Mustard gas is also stored as nonstockpile chemical materials in various containers and munitions at Pueblo Depot Activity in Colorado and Blue Grass Army Depot in Kentucky. Stockpiles of mustard gas are also located at the U.S. territory of Johnston Atoll in the North Pacific Ocean. These locations are illustrated in Figure 5-1 (Munro et al. 1999; NRC 1996). Mustard gas is probably still being made for laboratory experiments on a small scale.

### 5.2 IMPORT/EXPORT

Mustard gas is not imported into or exported from the United States.

**Figure 5-1. Locations of Mustard Gas Storage Sites in the United States**



\*\*\*DRAFT FOR PUBLIC COMMENT\*\*\*

Source: NRC 1996

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**5.3 USE**

The principal use of mustard gas was as a vesicant chemical warfare agent. The Germans first used it against the British during World War I during the battle of Flanders, near Ypres, Belgium, in 1917 (Franke 1967; Rosenblatt et al. 1975). It was used by the Allies in 1918 and by the Italians in Ethiopia in 1936. It has also been used recently in the Iran-Iraq War in 1984–1988 and by Iraq against its Kurdish minority in Halabjah in 1988 (Black et al. 1993b; Budiansky 1984).

Attempts have been made to use mustard gas as an antineoplastic agent, although this has not met with much success due to its high toxicity. A similar product, nitrogen mustard, has been successfully employed as an anticancer agent (IARC 1975). Mustard gas has provided a useful model in biological studies concerning the behavior of alkylating agents (IARC 1975).

**5.4 DISPOSAL**

For the past several decades, the United States has stored its stockpile of mustard gas at seven Army facilities under a policy of total containment (Colburn 1978). The total quantity of mustard gas (i.e., H, HD, and HT) in the original stockpile was 17,358 tons (34,716,945 pounds) (DOA 2000). The stockpile consists of both munitions and 1-ton containers of bulk agent (see Table 5-1; DOA 2000; NRC 1994). In addition to mustard gas, munitions may contain energetics (e.g., explosives and propellents). Public Law 99-145 (as amended by PL 100-456) and PL 104-484 (October 23, 1992) requires the Army to destroy the U.S. stockpile of all lethal unitary chemical agents and munitions by December 31, 2004 (DOA 1988; NRC 1994). As part of the Chemical Stockpile Disposal Program (CSDP) mandated by Congress, the Army currently uses the “baseline system” for destruction of munitions and bulk agents containing mustard gas (NRC 1994).

The “baseline system” consists of several steps: (1) storage, transportation, and unloading of munitions and containers, (2) disassembly and draining, (3) agent destruction, (4) energetics destruction, (5) metal parts decontamination, and (6) dunnage (i.e., other contaminated materials) disposal (NRC 1994).

Currently, munitions are stored and monitored in vented igloos; bulk containers are stored in the open or in monitored warehouses. The munitions or bulk mustard gas are transported to the on-site disposal facility and unloaded. Munitions are disassembled, drained of mustard gas, and separated into streams of bulk liquid agent, metal parts, energetics, and dunnage, all of which contain different amounts of mustard

**Table 5-1. Original Stockpile Quantities of Mustard Gas as Munitions and Bulk Agent<sup>a</sup>**

Chemical munitions or bulk agent	APG	ANAD	BAD	JAP	PBA	PUDA	TEAD	UMDA
HD								
105-mm projectile		68,500		140		1,138,760	5,860	
155-mm projectile		206,420	181,260	66,340		3,504,780		
4.2-inch mortar		452,160		116,294		460,340		
M60 projectile				261,960				
Ton container	3,249,740	185,080		116,294	188,400		11,383,420	
H								
155-mm projectile							639,540	
Ton container								4,679,040
HT								
4.2-inch mortar		1,064,600				118,220	363,020	
Ton container					6,249,100			
Total	3,249,740	1,976,760	181,260	578,705	6,437,500	5,222,100	12,391,840	4,679,040
Percent of total mustard gas stockpile	9.4	5.7	0.5	1.7	18.5	15.0	35.7	13.5

<sup>a</sup>Quantities of agent reported in pounds. Original stockpile quantities reflect amounts before the onset of Chemical Stockpile Disposal Program. Up-to-date information about stockpile quantities is available at <http://www-pmcd.apgea.army.mil/>.

ANAD = Anniston Army Depot, Alabama; APG = Aberdeen Proving Ground, Maryland; BAD = Blue Grass Army Depot, Kentucky; H = undistilled mustard gas; HD = distilled mustard gas; HT = 60% mustard gas + 40% Agent T; JAP = Johnston Atoll, Pacific Ocean; PBA = Pine Bluff Arsenal, Arkansas; PUDA = Pueblo Depot Activity, Colorado; TEAD = Tooele Depot, Utah; UMDA = Umatilla Depot Activity, Oregon

Source: DOA 2000

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gas. Liquid agent from drained munitions and bulk containers are fed into a primary incinerator preheated to an operating temperature of 2,700 EF (1,480 EC). Exhaust gases from the primary incinerator are fed into a secondary incinerator at a temperature of 2,200 EF (1,200 EC) for 2 seconds, after which 99.9999% of the agent is destroyed (DOA 2000). The gaseous effluents then flow into pollution abatement system before release into the atmosphere. Energetic materials are burned in a counterflow rotary kiln and then heated on a discharge conveyor at 1,000 EF (540 EC); the solid waste produced is nonhazardous and may be shipped for land disposal. Discharged gases pass through a secondary incinerator and a pollution abatement system, and then are released to the atmosphere. Metal parts are heated to 1,000 EF for 15 minutes in a fuel-fired metal parts furnace; the heat-treated metal parts are then released as scrap metal. Gases discharged pass through a secondary incinerator and a pollution abatement system, and then are released to the atmosphere. Dunnage generated during the entire process may be either incinerated (with pollution abatement) or shipped for land disposal as hazardous waste. At all steps, monitoring for chemical agents is performed to detect concentrations of agent well below those that present an immediate threat to personnel or the surrounding population. There are no measurable mustard gas effluents leaving the baseline system facilities under normal operating conditions (MacNaughton 2001). At present, Johnston Atoll is the first site to destroy its portion of the chemical agent and munitions stockpile in the United States (Kosson 2000). Incineration of mustard gas is currently underway at Umatilla, Oregon; Tooele, Utah; Anniston, Alabama; and Pine Bluff, Arkansas (SWRI 2001). There are two more sites at Blue Grass, Kentucky and Pueblo, Colorado, which have assembled chemical munitions. Incineration using the baseline system is scheduled to begin at these sites before 2005 (NRC 1994).

To address growing public concern over incineration, Congress in 1992 directed the Army to evaluate alternative disposal methods that might be significant safer and more cost effective than the baseline system (NRC 1994). Two alternatives were accepted by the Army for further development: (1) stand-alone neutralization followed by incineration and (2) neutralization followed by bio-treatment (NRC 1996). Neutralization of mustard gas is achieved by hydrolysis with hot water (90 EC) and vigorous mixing. This process reduces the mustard gas concentrations to levels <200 ppb and selectively converts 90% of the mustard gas to thiodiglycol and hydrochloric acid (Currie et al. 1977; May 1998; NRC 1996). Once the reaction is complete, base (e.g., sodium hydroxide or lime) is added to neutralize the acid and adjust the pH of the hydrolysate (i.e., product of hydrolysis). The dilute processing of mustard gas and the addition of base after completion of the neutralization reaction are designed to minimize the production of unwanted by-products during reaction (NRC 1996). Hydrolysis has been used effectively

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to detoxify over 700 tons of mustard gas located at a Canadian defense facility in Cornwell, Ontario (Currie et al. 1977). After hydrolysis, the hydrolysate can be either incinerated using the baseline system or bio-treated. Bio-treatment requires adjusting the pH of the hydrolysate to neutral by adding sodium bicarbonate buffer and some added nutrients. Bacteria oxidize thiodiglycol to carbon dioxide, water, and sulfate with high efficiency. During the actual process, approximately 0.8 g of cell mass (dry weight) will be produced for every 1 g of organic carbon removed from solution. The biomass is further oxidized through aerobic digestion, and then dried and disposed of at commercial water treatment facility. Any volatile organic compounds (VOCs) that are present are condensed and the resulting condensate removed by direct photodegradation and photo-oxidation by OH radicals. The treated bioresidue is then filtered, dried, and sent to landfill (May 1998; NRC 1996). The chemical hydrolysis system is currently being developed for use at Aberdeen, Maryland, where mustard gas is stored only as a bulk liquid in 1-ton containers (NRC 1994).