Breakthrough Value Concentrations for SCBA Time Limit Tests for Sulfur Mustard (HD) and Sarin (GB)

PURPOSE: This paper describes the basis for the health-based criteria used to verify adequacy of existing Self-Contained Breathing Apparatus (SCBA) respiratory systems to protect wearers against potentially dangerous airborne levels of chemical warfare agents – specifically nerve agent sarin (GB) and the blister agent sulfur mustard (HD).

BACKGROUND: In the aftermath of September 11th, the need for supplementing existing resources and capabilities of state and local responders such as firemen and HAZMAT personnel has received much attention. One concern is the capability of such personnel to operate in conditions where weapons of mass destruction such as chemical warfare (CW) agents have been released. While existing protective equipment used by such personnel have been designed to meet stringent requirements for fire, safety, and toxic chemicals, they have not usually been tested against CW agents GB or HD. As CW agents are particularly potent, an evaluation of existing commercial systems capabilities is warranted. Use of existing commercial equipment is desired because military chemical agent protective masks do not meet other protective factors required for fire and HAZMAT-related applications. Further, use of commercial equipment can ensure that appropriate equipment will be readily available on a large scale.

APPLICATION: The scenario of concern is that of a terrorist incident involving the intentional release of either GB or HD. The scenario includes the potential for other hazard conditions, including fire, to exist concurrently. This would be a one-time, relatively brief exposure event for the personnel involved as opposed to ~~a~~ routine working environments that involved daily 8-hr shifts. The subject personnel entering an area with SCBA protection would be performing operations such as assisting with civilian evacuation of an area, limited reconnaissance and observation, hazard marking, temporarily manning of roadblocks and traffic control points, and damage assessment/survey of the area or obtaining samples to ascertain types and/or levels of released agent. Due to the capacity limit of a SCBA tank of less than 1 hr (approximately 45 minutes, including the donning and decontamination stages), the overall exposure of personnel is limited to less than 1 hr. As such, the testing requirements of the SCBA systems focus on a one time, 1-hour exposure. It is noted that though some respirators/SCBA systems are tested against more conservative standards, these are designed for extended, daily exposure conditions. The testing requirements under consideration here are designed to address a unique exposure scenario that will be very limited but must also consider other potentially hazardous conditions. The goal is to identify any existing SCBA systems that can ensure that overall physical and chemical safety are maximized.

CHEMICAL AGENT CHARACTERISTICS:

GB and HD are 'warfare' chemicals that were specifically designed to incapacitate humans. Though each of these chemicals differs substantially in both physical and toxic properties, they are each considered extremely potent relative to most common toxic industrial chemicals. A generalized discussion of each chemical is presented below. Additional information can be found in referenced documents

Sarin (GB) – GB, along with several other G-agents (GD, GA, and GF) are a part of a class of warfare chemicals called "nerve agents." These are considered 'non-persistent' warfare agents and were designed to quickly dissipate so that, wen used against an enemy, they do not persist long enough to present a residual risk to friendly forces entering the area. GB is very volatile and though stored as a liquid, would be released in the environment as a vapor that rapidly degrades. Its persistence is on the order of minutes to hours. Because of its high volatility, the primary route of exposure is from the vapor - which includes vapor inhalation and vapor-eye contact. In liquid form as well as vapor it is typically colorless and odorless so has no inherent warning properties.

GB is called a nerve agent because its primary mechanism of action in the human body is on the nervous system. Very generically described, the response on the nervous system results in over-excitation of various muscles and glands. Data indicates that the most sensitive effects (i.e. first effect occurring at the lowest dose) from vapor GB (or other nerve agents) would be pinpointing of the pupils of the eye (miosis). Other initial mild effects include dimness of vision, runny nose, and headache. More significant exposures may result in nausea, tightness of chest/ breathing difficulties, drooling, excessive sweating, involuntary defecation/urination, and seizures. At high enough doses the human nervous system can be overcome, resulting in coma and/or death. All of these effects are similar to those associated with exposures to various organophosphate pesticides, to which the nerve agents are chemically related. Key differences between GB/G-agents and typical organophosphate compounds is that the nerve agents are more volatile and generally more potent.

Sulfur Mustard (H/HD) – Sulfur Mustard (agent HD) is an alkylating chemical blister agent (vesicant). Although the chemical is liquid at normal temperatures, it is relatively volatile and, particularly in warmer environments, may generate vapors that have a garlic-like odor. It is not very soluble in water; as a result quantities may persist in the environment for days, weeks, or potentially longer (especially in colder climates). Agent HD freezes at 55-59 degrees F, and persists as a solid or semi-solid at those temperatures. As a consequence, vapor exposure is not a major issue at ambient temperatures <55 degrees F. Potential exposure scenarios could involve contact to either or both liquid and vapor. The severity of effects is directly associated with temperature and humidity, with increasing temperature and humidity posing greater risks.

Through direct cellular damage, HD will affect bodily surfaces with which it comes in contact. A latency period of hours is characteristic of acute sulfur mustard exposure, such that effects are not observed until some time after the injurious exposure. Though often associated with a garlic like odor – HD exposure below the odor threshold can still pose health effects. First effects noted upon exposure to HD vapor would be minor ocular irritation, since eyes are the most sensitive organ/tissue. Higher-level exposures would potentially result in irritation and/or damage to the respiratory tract or even skin. High enough exposures could prove to be fatal – deaths are generally associated with severe damage to the respiratory tract. Direct liquid contact will produce more severe skin damage as well as blisters. Historic data indicates that high HD exposures that result in chemical burns to the skin or respiratory tract can be associated with later development of cancers at the site of original damage. However, there is no evidence that low exposures that do not result in significant tissue damage are associated with any increase in cancer risk.

SELECTING AN EXPOSURE LIMIT. A chemical exposure limit is a pre-calculated value that represents an estimated maximum concentration level for a defined scenario that could be tolerated before potential undesirable health effects could occur. For a specified health outcome, an exposure limit (a concentration 'C') can be determined if the time (t) of exposure can be estimated. For this evaluation of SCBA, an exposure limit will define the maximum allowable HD and GB breakthrough concentrations for the tested systems.

As the use of SCBA tank capacity will limit exposure, the estimated time 't' of exposure is between 0.5 – 1.0 hours. The goal is to ensure that accepted systems protect the wearer from any significant CW agent exposures during that time of use. As the health criteria to test the systems then, a concentration that represents a non-incapacitating health impact (specifically, no respiratory dysfunction) is required. Various existing health criteria meeting the time and health outcome criteria were considered for this evaluation:

Worker IDLH: As these are worker populations, one proposal was to use the Immediately Dangerous to Life and Health (IDLH) standards adopted by the U.S. Army. While IDLH values could be justified for the specified application, these are only Army-approved values (they do not currently have other Federal agency endorsement). In addition, though conservatively estimated, they are designed for only 30-minute exposures.

AEGLs: More appropriate criteria are Acute Exposure Guideline Levels (AEGLs) being established by a National Advisory Committee for Acute Exposure Guideline Levels and the National Research Council. AEGLs are for use in emergency planning and decision-making to safeguard unprotected members of the general population. AEGLs address various levels of health impacts represented by concentrations at AEGL Levels 1, 2, and 3. Each of these levels represents the lowest (most conservative) estimate of a threshold concentration at which one might begin to observe a specified effect amongst small portion-in an exposed population. Between Levels 1 and 2, any effects noted would be mild and transient (disappear after exposure)

and are not expected to cause incapacitation or respiratory distress. Between Levels 2 and 3, the health impacts (and percentage of the population exhibiting effects) would be expected to increase and result in some persons having more severe effects – possibly either enough to cause some incapacitation (decreased ability to function normally), an impaired ability to escape, or potentially long-term health effects. Concentrations above Level 3 could potentially result in life-threatening effects.

Ensuring that breakthrough concentrations are *below* AEGL Level 2 concentrations will provide adequate chemical agent protection for the described SCBA application. It is acknowledged that some consider AEGL-Level 1 concentrations to be an extremely conservative exposure limit for this SCBA evaluation. However, AEGL-1 establishes an overly stringent criteria that could rule out many (if not most) systems that provide necessary protection against other critical hazards such as heat or flame. If any SCBA systems achieve such a level of chemical agent protection *and* meet other safety/protection requirements, then such systems deserve particular high marks.

CONCLUSION:

AEGL-Level 2 values for HD and GB are recommended as the exposure limit (breakthrough) criteria most appropriate to the issue of respiratory protection for this SCBA evaluation. This level of agent concentration will ensure that no significant effects (including no respiratory or long-lasting effects) would result if approved systems are properly worn. A description of the concentration levels and associated threshold health effects for the HD and GB AEGL-Level 2 values are presented in the following Table.

The AEGL-2 values are substantially more conservative than the IDLH values (also noted in the Table). AEGL values have been designed for the general population (not a limited male worker population) and include consideration of potential human variation and sub-groups in the population who may be particularly susceptible to chemical effects (e.g. due to physiological or genetic causes). In addition, AEGLs are developed by application of standard procedures, published for public comment in the *Federal Register*, and reviewed at a national level by civilian members of the scientific community (i.e., these are not established by the Army or DoD). Conservative methods incorporating significant safety factors are followed. Also, the AEGLs are established for single exposure scenarios, but for several different time durations that include the period of concern for SCBA systems. **For primary testing criteria of the SCBA, the 1-hour level for AEGL-Level 2 will be used as the maximum breakthrough concentration. In addition, and to verify that potentially high brief 'peaks' do not exceed levels of concern, peak concentrations identified in the test results will also be evaluated against the 10-minute values for AEGL-Level 2**.

Table. Summary of Evaluated Health Criteria for Use as Maximum Breakthrough Concentrations for Tested SCBA Systems (*Selected Criteria)

Chemical	Type of criteria	10 minute mg/m^3	30 minute mg/m^3	1 hour mg/m^3	Potential health effects beginning above described level
Sulfur Mustard HD	AEGL Level 1	0.40	0.13	0.067	Conjunctival injection (red eye) with minor discomfort but no functional decrement (often delayed)
	***AEGL Level 2**	**0.60**	**0.20**	**0.10**	**Generalized eye irritation and conjunctivitis, sensitivity to light, and swelling (delayed)**
	IDLH	na	2.0†	na	Severe eye irritation and conjunctivitis,-sensitivity to light, and swelling (often delayed)
	AEGL Level 3	3.9	2.7	2.1	Experimental mouse lethality data
Sarin GB	AEGL Level 1	0.0069	0.0040	0.0028	Mild miosis (pinpointing of the pupil), eye pain, rhinorrhea (runny nose), headache, tightness of chest
	***AEGL Level 2**	**0.087**	**0.05**	**0.035**	**Notable miosis, other signs/symptoms as above, blood enzyme activity inhibition, and singlefibre electromyographic (SFEMG) change (non-clinical and reversible/non-permanent effect; not considered adverse)~~,~~**
	IDLH	na	0.1†	na	Borderline incapacitation with generalized weakness, nausea and vomiting, as well as eye and respiratory effects
	AEGL Level 3	0.38	0.19	0.13	Experimental rat lethality data

† These IDLH values have been calculated and proposed by the US Army (see reference 3 and 4 below), but are not currently established as policy (currently being staffed).

REFERENCES:

Final Acute Exposure Guideline Levels (AEGLs) for Sulfur Mustard (Agent HD), submitted by the National Advisory Committee for AEGLs to the National Research Council, Committee on Toxicology, Subcommittee for AEGLs *in press* – National Academy Press, November 2001.

Interim Acute Exposure Guideline Levels (AEGLs) for Nerve Agents GA, GB, GD, GF, submitted by the National Advisory Committee for AEGLs to the National Research Council, Committee on Toxicology, Subcommittee for AEGLs *in review, December 2001*.

Evaluation of Airborne Exposure Limits for Sulfur Mustard: Occupational and General Population Exposure Criteria; U.S. Army Center for Health Promotion and Preventive Medicine, Technical Report 47-EM-3767-00, November, 2000.

Evaluation of Airborne Exposure Limits for G-Agents: Occupational and General Population Exposure Criteria; U.S. Army Chemical and Biological Defense Command/Research, Development, and Engineering Center, ERDEC-TR-489, April, 1998.