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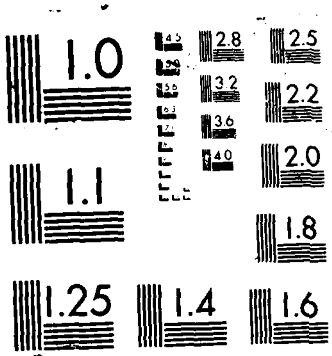
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USA-CERL TECHNICAL REPORT N-87/26
September 1987
The Use of Hexachloroethane Smokes
in Training of the Soldier

2

A Revised Health Risk Assessment for the Use of Hexachloroethane Smoke on an Army Training Area

by
Edward W. Novak
Lester B. Lave
James J. Stukel
David J. Schaeffer

This report supercedes U.S. Army Construction Engineering Research Laboratory (USA-CERL) Technical Report N-164, *A Health Risk Assessment of the Use of Hexachloroethane Smoke on an Army Training Area*, December 1983.

Hexachloroethane (HC) smoke in pots, grenades, and artillery rounds has been used in military training exercises since the Second World War. Chamber tests generating HC smoke with scaled-down smoke pots consistently show the presence of perchloroethylene, carbon tetrachloride, hexachloroethane, hexachlorobenzene, cadmium, and arsenic, all of which have been determined to be carcinogenic in laboratory animals or in humans.

The objective of this study was to develop a "worst-practicable-case" scenario of Army troop exposure in training and then to calculate the total absorbed dosage and attendant cancer risk from a feasible number of repetitive exposures at the site. Risk estimates were also made for civilian populations surrounding the installation.

This study recommends (1) the Army enforce its directive to mask in the presence of HC smoke, (2) the Army closely regulate the deployment of HC and other smokes on all of its installations, (3) studies should be conducted on Army installations to determine the risk from HC smokes to which the soldier and local populace are exposed, (4) an annual HC smoke risk of cancer to soldiers of greater than 1 in 10,000 should be reduced where perceived, and (5) the Army should adopt a safety principle—"as low as reasonably achievable"—for both troop and civilian exposure to HC smokes.

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exposures at the site. Risk estimates were also made for civilian populations surrounding the installation.

By summing risks for each carcinogen from potential total absorbed lung dosages, risk estimates for soldiers ranged from 17.5 to 155.8 x 10^{-5} (17.5 to 155.8 cancers per 100,000 persons exposed) over a 2-year period under varying weather conditions. Among worker populations, the lifetime risks (61.25 to 545.3 x 10^{-4}) are exceptionally large. Community risk calculated on the basis of a lifetime exposure was 9.75 cancers per million. These risk calculations do not include potentially antagonistic or synergistic effects that may occur in field exposures due to HC's potential interaction with fog oil, diesel and other smokes, resuspended residues, and dust particulates and the gas/particulate interface. These interactions may enhance effects, because HC and fogoil particles and aerosols are within the size range where particles would be desposited in the deep lung.

The Army must determine if such risk levels from HC munitions are acceptable. At present, the Nuclear Regulatory Commission (NRC) accepts risks to workers of up to 50 cancers per 100,000 population per year--a level far higher than most Occupational Safety and Health Administration standards. In contrast, the NRC goal for the general population is 1.9 per million population per year.

In setting acceptable risk levels to military personnel, the Army should consider (1) how much control soldiers have over their potential exposure, (2) if soldiers are being informed about the potential risk, and (3) if so, whether they would object to that level of risk. Soldiers should receive special instruction for the safe, effective deployment of all munitions having potential long-term troop and community exposures.

The calculated risks to the military in this worst-practicable-case scenario could be mitigated through the use of masks during HC smoke exercises. The current requirement to mask appears to be unenforced and most soldiers are either not informed of the requirement or not directed to mask during exposure.

In reducing the potential risk to civilians, the Army might consider a policy for using smoke munitions similar to that for deployment of other explosive, projectile-emitting munitions. Smoke deployment could be restricted to areas of the installation as far as practically possible from cantonments and other populated areas. Currently, an unwritten understanding at most training areas is that smokes cannot be used within 1000 meters of the installation's boundary. However, this distance is far too close to civilians under worst-case conditions.

This study recommends (1) the Army enforce its directive to mask in the presence of HC smoke, (2) the Army closely regulate the deployment of HC and other smokes on all of its installations, (3) studies should be conducted on Army installations to determine the risk from HC smokes to which the soldier and local populace are exposed, (4) an annual HC smoke risk of cancer to soldiers of greater than 1 in 10,000 should be reduced where perceived, and (5) the Army should adopt a safety principle--"as low as reasonably achievable"--for both troop and civilian exposure to HC smokes.

FOREWORD

This investigation was performed by the Evironmental Division (EN), U.S. Army Construction Engineering Research Laboratory (USA-CERL) for the U.S. Army Medical Bioengineering Research and Development Laboratory (USAMBRDL) under Project 3E162720A835, Task AA, Work Unit 027, "The Use of Hexachloroethane Smokes in Training of the Soldier." The USAMBRDL Technical Monitor was MAJ David Parmer.

This research was originally performed by Dr. Edward W. Novak and his associates while he was on sabbatical leave during 1983 as a Federal Executive Fellow at the Brookings Institution, Washington, DC, under the guidance of Dr. Lester B. Lave, Senior Fellow at Brookings. The research was updated by Novak and associates in 1986. Dr. James J. Stukel is Vice Chancellor for Academic Affairs, University of Illinois. Dr. L. R. Schaeffer is an environmental toxicologist at USA-CERL. The support of the Brookings staff and the USA-CERL administrative, editorial, word processing, and printing staff is gratefully acknowledged. The support of the chemical training officers and Environmental Office at Fort McClellan, AL, is greatly appreciated. The support of Ralph Sterns of DAMO-TRS in providing smoke expenditure data is appreciated as well. Support by the Smokes/Obscurants Program Manager's office is acknowledged.

Headquarters, U.S. Army Training and Doctrine Command (TRADOC) and Headquarters, U.S. Army Forces Command (FORSCOM) and installation environmental offices provided information on the use of smokes. The support of the Opposing Forces unit and administrative staff at Fort Irwin, CA, is greatly appreciated, as is support from Mr. Ron Pennsyle of U.S. Army Chemical Research Development and Engineering Center (CRDEC), MD, who provided smoke models. Valuable background information was provided by the Environmental Office at CSL, with special thanks to Mr. Jerry Cichowicz, Mr. Steve Lawhorne, and CPT Dama Wirries (USAMBRDL). The support of the mask management group at Chemical Systems Laboratory (CSL) is also appreciated. Technical suggestions, review, and comments from Dr. Gil Omenn, Dr. Mary Henry, Mr. Jesse Barkley, Mr. Alan Snelson, MAJ David Parmer, and Dr. Ellen Dierenfeld are appreciated.

Dr. R. K. Jain is Chief of CERL's Environmental Division. COL Norman C. Hintz is Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.

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A REVISED HEALTH RISK ASSESSMENT OF THE USE OF HEXACHLOROETHANE SMOKE ON AN ARMY TRAINING AREA

1 INTRODUCTION

This report supercedes U.S. Army Construction Engineering Research Laboratory (USA-CERL) Technical Report N-164.[1]

Historical Background

Type C hexachloroethane (HC) smoke mixes containing grained aluminum, hexachloroethane, and zinc oxide have been loaded in grenades, artillery shells, rockets, bombs, and smoke pots since the early 1930s. All of these munitions were used during World War II, but by far the most widely used HC munition was the smoke pot.[2] At the time of Pearl Harbor, the Chemical Warfare Service (CWS) standard smoke pot (M1) was a cylindrical can, 8 in. high and 5 in. in diameter, holding about 10 lb of HC type C mixture. Fired by hand or electric current, the M1 released a cloud of grayish-white smoke for a period of 5 to 8 minutes. The CWS had developed this pot in the early 1930s as a munition for training exercises, but when the war began, it was the only munition of its type available; the U.S. Army used it in North Africa. Because they release smoke within seconds after ignition, these pots were useful in setting up a preliminary screen during the 5 or so minutes it took large mechanical generators to warm up and start functioning. They helped shield harbors and installations on the coast of North Africa as well as the harbors at Palermo and Licata in Sicily.

In 1944, the CWS began to manufacture pots holding three times as much HC which could burn twice as long. Almost a million large pots designated as model M5 came from filling lines before the end of the Second World War. However, they did not reach Europe in appreciable quantities before VE Day and the original M1, of which more than five million were produced, remained the workhorse of the ground troops.

Although HC, like the other CWS screening agents, was regarded as nontoxic, as early as 1944 its use in troop training exercises showed that when inhaled in a confined area, it could produce fatalities through extreme lung irritation. The airborne particles of zinc chloride dispersed during the burning of HC were believed to be the only toxic elements until further tests revealed that HC mixtures contaminated with ammonium chloride were even more

[1] E. W. Novak, L. G. Lave, J. J. Stukel, and S. Miller, A Health Risk Assessment of the Use of Hexachloroethane Smoke on an Army Training Area, Technical Report N-164/ADB079544 (United States Army Construction Engineering Research Laboratory, December 1983).

[2] L. Brophy, W. Miles, and R. Cochrane, "Smoke," In U.S. Army in World War II--The Chemical Warfare Service from Lab to Field (Department of the Army, 1959), pp 200-204.

lethal.[3] Currently, the acute toxic effects of type C HC smoke are better understood. These effects include edema and possible hemorrhage, resulting primarily from the high concentrations of zinc chloride in the lungs ($ZnCl_2$) and the high proportion ($\leq$ 3%) of hydrochloric acid in the reaction byproducts (see Table 2).

Project Rationale

Smoke pots similar to the M5, as well as most of the rest of the munitions shown in Table 1, have been used in training since the Second World War and all of them are being used in today's field training exercises. The table shows representative data for the HC munitions expended at Fort Irwin, California during FY82-84.

A recent study aimed at characterizing the HC smoke pot, including its reagent materials, generation process, product gases, and aerosol particles, generated the chemical data upon which this risk assessment is based.[4] The reagent material taken from smoke pots consisted of hexachloroethane (HCE), zinc oxide, and grained aluminum.

Chamber tests generating HC smoke with simulated (scaled-down) smoke pots consistently formed the gases listed in Table 2. Metals and metalloids quantified from actual HC smoke canisters are listed in Table 3. The basic chemical reaction of the HC mix is:

$$2\ Al + C_2Cl_6 + 3\ ZnO \rightarrow 3\ ZnCl_2 + Al_2O_3 + 2\ C + heat \quad [Eq\ 1]$$

The metal compounds identified or believed to be formed in the HC smoke emission byproduct include zinc chloride, cadmium chloride, lead chloride, arsenic (chlorides and oxides), and aluminum oxide. Tables 2 and 3 also give an upper limit estimate of the amount of each compound from 133659 kg of HC mix expended at Fort Irwin, California, during FY 82-84, assuming a 70 percent burn efficiency.

The grenades, artillery shells, and smoke pots all contain slightly different chemical mixes for producing HC smoke. These differences, coupled with variations in weather characteristics, quantities of smoke generated, orientation of the pot during ignition, and training protocol for each exposed or potentially exposed solider in any given training exercise, assure a wide variety of exposures to the individual.

[3] Toxicological Research Laboratories, Informal Monthly Progress Report 2 (15 June, 1944).

[4] S. Katz, A. Snelson, R. Farlow, R. Welker, and S. Mainer, Physical and Chemical Characterization of Fog Oil Smoke and Hexachloroethane Smoke--Final Report on Hexachloroethane Smoke, ADA080936 (Fort Detrick, MD, January 1980).

Table 1

Currently Used HC Smoke Munitions

Type	Model	Net Fill Weight (kg)	Fort Irwin, CA FY82-84 No. Munitions Expended***	Fort Irwin, CA FY82-84 Total HC Mix, kg
Grenade	AN-M8	0.54*	54740	29560
Smoke Pot	M4-A2	10.7 - 12.5*	461	5763
Smoke Pot	M1	4.3 - 5*	25	125
Smoke Pot	ABC-M5	13.6*	6885	93636
Cartridge	M84A1	2.1**	376	790
Projectile	M116A1	8.7**	435	3785
			TOTAL	133659

*From Technical Manual (TM) 750-5-15, Chemical Weapons and Defense Equipment--Army Data Sheet (Headquarters, Department of the Army, August 1972), pp 97, 119, 123, 125.

**From Personal Communication with D. Bromley (Chemical Research and Development Center, Aberdeen Proving Ground, MD, 1982).

***Summarized from Army Regulation (AR) 5-13, Training Ammunition Management System -- Management (Headquarters, Department of the Army, 1979).

Table 2

Analysis of HC Smoke Reaction Byproduct Gases for Estimated 70 percent Burn Efficiency

Gases	Mass % of Reagent Wt.	Fort Irwin, CA FY82-84 Total kg
(C_2Cl_4) perchloroethylene (PERC)	3 - 17	22722
(CCl_4) carbon tetrachloride	1 - 3	4010
(C_2Cl_6) hexachlorobenzene (HCE)	0.3 - 5	6683
($COCl_2$) carbonyl chloride (phosgene)	0.1 - 1	1337
(C_6Cl_6) hexachlorobenzene (HCB)	0.4 - 0.9	1203
(CO) carbon monoxide	≤ 4	
(HCl) hydrogen chloride	≤ 3	12029
(Cl_2) chlorine	≤ 2	
	TOTAL	47984

Table 3

Metal Analysis of HC Canister Composition

	Mass % of Reagent Wt.	Fort Irwin, CA FY82-84 Total kg
Zinc	47.5 - 48.3	64557*
Aluminum	5.2 - 7.0	9356
Cadmium	0.005 - 0.15	200
Lead	0.005 - 0.086	114
Arsenic	0.13×10^{-4} - 5.0×10^{-4}	
Mercury	3.5×10^{-5} - 5.2×10^{-5}	
	TOTAL	74228

*(Mass % of Reagent Wt.) X (Total HC mix. kg) X 0.01 where Total HC mix = 133659 Kg (Table 1).

The acute risks of HC smoke are not merely theoretical. A number of deaths have been reported even as late as July 1983.[5] Table 4 lists constituents of HC smoke that have been found to be carcinogenic to humans or experimental animals. The classifications are those of the International Agency for Research on Cancer (IARC), which are often referred to by U.S. scientists and regulatory authorities. All compounds found in the smokes that are identified by IARC as suspected or known carcinogens were used in the risk calculations. Although there is sufficient evidence that some soluble lead salts are carcinogenic in experimental animals, no positive evidence was presented by IARC for lead chloride, the salt identified as an HC byproduct;[6] therefore, lead was not considered in this study as a potential carcinogen.

For each compound, an estimate has been made of a quantitative dose-response relationship indicating the risk of cancer to a soldier. Some of these compounds may be synergistic, causing much greater risk together than would be predicted by examining them separately (Appendix A); or some may be antagonistic, canceling each others' effects. In the absence of information

[5]H. Fischer, "Accidents Caused by Combat and Smoke Chemicals and Their Sequelae," Wehrmed. Monatsschr., Vol 13 (1969), pp 355-359; C. Lyon, Deaths from Improper Use of Hexachloroethane Smoke Generators and Adamsite Generators in Enclosed Spaces, ETF550E-1607 (American Embassy, Office of Naval Attache, February 1943); Personal Communication with J. Smith (National Guard Bureau, Edgewood Arsenal, Aberdeen Proving Ground, MD, 1983).
[6]S. Katz, A. Snelson, R. Farlow, R. Welker, and S. Mainer.

Table 4

HC Smoke Reaction Byproducts Suspected or Known to be Human and/or Animal Carcinogens

Compound	Degree of Evidence: Humans	Degree of Evidence: Exptl. Animals	Evaluation of Carcinogenic Risk to Humans*
Perchloroethylene (C_2Cl_4)**	Inadequate	Limited	---
Carbon tetrachloride (CCl_4)***	Inadequate	Sufficient	2B
Hexachloroethane**	Inadequate	Limited‡	---
Hexachlorobenzene**	Inadequate	Sufficient	---
Cadmium and cadmium chloride***	Limited	Sufficient	2A
Arsenic***	Sufficient	Inadequate	1

*Group 1: The chemical is carcinogenic for humans. This category was used only when there was sufficient evidence to support a causal association between the exposure and cancer.
Group 2: The chemical is probably carcinogenic for humans. Includes chemicals for which evidence of carcinogenicity is almost sufficient (2A) and those for which evidence is only suggestive (2B).

**International Agency for Research on Cancer (IARC), IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans--Some Halogenated Hydrocarbons, Vol 20 (1979), pp 169, 473, 505.

***IARC, "Chemicals and Industrial Processes Associated with Cancer in Humans," IARC Monographs, Vols 1-20 (1979), pp 15-17.

‡National Cancer Institute, Bioassay of Hexachloroethane for Possible Carcinogenicity (Technical Report Series No. 68), DHEW Publication (NIH) No. 77-1318 (U.S. Department of Health, Education and Welfare, 1978).

on interaction effects, these effects are usually treated as additive.[7] These potential carcinogen materials are present in smokes containing hydrochloric acid, phosgene, chlorine gas, zinc chloride in large quantities, aluminum, lead, mercury, arsenic, fog oil mists, other smoke and pyrotechnic residues, and suspended dust particles. This report also does not estimate doses absorbed through the stomach or skin, or inhaled via resuspended fugitive dust containing smoke residues that have settled out from previous HC smoke clouds.

This report covers exploratory research attempting to assemble and interpret available data. Where data did not exist, assumptions were made. A decision must be made about the extent to which HC and other smokes will be used in future training exercises based on available estimates of the health risks to troops and civilians in the surrounding communities from exposure to these smokes.

The Army's Position Regarding Protection

Army reports as early as 1943 cited the acute toxicity of HC smoke.[8] However, there is no overt evidence that soldiers undergoing active field training were warned of the acute hazards of HC smoke exposure until 1977-78. Nor were troops advised to wear protective masks in the presence of HC smoke except when it simulated a chemical warfare agent in specialized training. In March 1977, the Surgeon General instructed the Army Major Commands to advise troops to wear protective masks, bathe, and launder clothing to preclude skin irritation when exposed to any concentration of HC smoke.[9] Based on evidence from the National Cancer Institute (1978) that the compound hexachloroethane (HCE) is a carcinogen in experimental animals, and on potential occupational health problems reported by personnel in the facility preparing HC munitions, the smokes and obscurants program manager instituted a "get well" smokes replacement program for HC munitions.[10]

The Surgeon General has informed Major Commands of the hazards and protective actions necessary to minimize exposure to HC smoke. However, evidence from the training experiences of persons interviewed in this study indicate training continues without use of masks in the presence of HC and other obscuration smokes.

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[7] TLVs--Threshold Limits to Chemical Substances and Physical Agents in the Work Environment and Biological Exposure Indices with Intended Changes for 1984-1985 (American Conference Government Industrial Hygienists).

[8] F. McDonald and R. Porton, Toxicity of Zinc Chloride Smoke and Treatment With BAL, Report No. 2703 (September 1945); G. Lyon.

[9] Letter DASG-HCH-O (Office of the Surgeon General, Department of the Army, 16 March 1977).

[10] Personal Communication with COL S. Eure (Office of the Project Manager, Smoke/Obscurants, Aberdeen Proving Ground, MD, 1983).

Objective and Scope

This study set out to answer two questions: (1) Could the extent of Army personnel exposure to HC smoke in training be a significant chronic-exposure health problem (2) could there also be a significant health risk resulting from exposures to communities near training areas that use HC smoke?

The scope of these objectives was to estimate the risk of cancer to military and civilian populations from HC smoke exposures at a specific installation. In attempting to select an appropriate worst practicable case, it became necessary to look at many installations to insure that specific "hot spots" of community exposure were not overlooked. Consequently, the data presented in Table 5 provide a picture of total FY82 HC smoke munitions expenditures at U.S. Army installations that use the most HC smoke in training.

Approach

1. Update the literature review on byproducts in HC smoke to include bioassays, environmental fate and persistence, bioaccumulation, and physical and chemical properties.

2. Identify the most likely harmful chronic impactors (carcinogens) in the HC combustion byproducts.

3. Select a study installation based on the degree to which smokes were being used at that installation and potentials for exposure primarily to military populations.

4. Determine short-term and chronic exposure levels of the civilian and military populations at risk.

5. Extrapolate the likelihood for an increased risk of cancer based on the selected compounds, individually and collectively.

Chapter 2 explains how the chronic "worst-practicable-case" exposure scenario was derived. Chapter 3 details the carcinogenic risk assessment method and presents results. Chapter 4 interprets what the risk means and puts it into a national context. Chapter 5 states conclusions of the study and recommends further actions that might be taken based on the study results.

Table 5

TAMIS Data Base Excerpts of HC Munitions (Expended/Authorized for Use) on U.S. Army Installations in FY82

Expended/ Authorized for Use	Units in Thousands				
	Projectiles			Smoke Pots	
	105mm	155mm	Grenade	ABCM-5	Floating M4A2
Fort Benning	.4/.5	.0/.0	49.9/49.8	.5/.7	.2/.5
Fort Campbell	.9/1.4	.0/.2	4.4/5.8	.0/.1	
Fort Carson		.1/.3	4.5/5.0	.1/.1	.1/.1
Fort Hood		.6/.6	5.9/6.8	.1/.2	.1/.1
Fort Irwin		.4/.0	15.4/9.8	3.1/1.8	.1/.0
Fort Knox		.1/.1	11.2/11.8	.8/.9	.0/.0
Fort Lewis	.4/.4	.0/.2	4.8/4.7	.1/.1	.0/.2
USAREUR	.4/.4	.1/1.8	23.7/52.1	.4/1.5	1.5/3.2
Fort McClellan	.0/.0		7.0/6.6	.4/.4	.3/.4
Fort Sill	1.1/1.9	.8/1.5	10.3/13.0	.0/.1	.0/.0
Fort Jackson			8.7/8.7		
Fort Ord	.4/.4	.0/.1	2.9/3.0	.0/.1	.0/.0
Fort Polk		.2/.2	3.7/4.7	.0/.0	.1/.1
Panama	.3/.3		1.7/1.6	.0/.0	
Alaska	.2/.2		1.1/1.1	.0/.0	.1/.1

2 ESTIMATING EXPOSURE TO HC SMOKE

Determination of the Potential for a Chronic Exposure Problem

To determine the nature and extent of human risk due to chronic exposures of HC smoke, it was first necessary to confirm that the chemical byproducts of the smoke are potentially dangerous at those levels. The IARC Monographs were reviewed to identify whether any of the compounds are confirmed or suspected human/animal carcinogens.[11] After it was confirmed that six compounds fell into this category, the literature was further examined to obtain dose-response curves for carcinogenicity. It was found that the U.S. Environmental Protection Agency (USEPA) had calculated usable dose-response curves for cadmium, hexachlorobenzene, hexachloroethane, perchloroethylene, carbon tetrachloride, and arsenic in their water quality criteria documents.[12]

When it had been found that HC smoke contains material potentially hazardous upon chronic exposure, the next step was to determine if such smokes were being used in the Army at present, and if so, what installations were using them and to what degree. Two primary methods were used to supply this information. First, Army Training Ammunition Management Information System (TAMIS) records were examined, revealing that HC munitions were being used to varying degrees at Training and Doctrine Command (TRADOC) and Forces Command (FORSCOM) installations.[13] Table 5 identifies major user installations and quantities of munitions expended at each during FY82. Second, Major Commands (MACOMs) were asked to supply information for all of their installations regarding (1) where on the installation such munitions were being used, and (2) the proximity of these locations to populated areas. All of the major users reported this information except Fort Irwin, CA. This survey showed that, for the most part, no written guidelines exist for using smoke munitions at Army training sites; thus, with the exception of built-up and off-limits areas (e.g., for artillery impact areas), all training locations are candidates for smoke deployment. HC artillery rounds are fired into isolated impact areas--generally 5000 m to 15,000 m from populated areas--so it was concluded that relatively little military or civilian exposure would occur. HC grenades and smoke pots, however, are used at numerous training areas where exposure to military populations can occur. In addition, the proximity of

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[11] International Agency for Research on Cancer (IARC) Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans; Some Halogenated Hydrocarbons, Vol 20 (1979), pp 155, 371, 467, 491; IARC Monographs on the Evaluation of the Carcinogenic Risk of the Chemicals to Humans; Cadmium, Nickel, Some Epoxides, Miscellaneous Industrial Chemicals and General Considerations on Volatile Anesthetics, Vol 11 (1976).

[12] U.S. Environmental Protection Agency, Ambient Water Quality Criteria for Cadmium (USEPA, Office of Water Regulations and Standards Division, October 1980); USEPA, Ambient Water Quality Criteria for Tetrachloroethylene (USEPA, Office of Water Regulations and Standards Division, October 1980); USEPA, Ambient Water Quality Criteria for Chlorinated Benzenes (USEPA, Office of Water Regulations and Standards Division, October 1980).

[13] Army Regulation (AR) 5-13, Training Ammunition Management System--Management (Headquarters, Department of the Army, 1979).

civilian populations to such areas (1000 m to 5000 m) means some nonmilitary exposure from deployment of grenades and smoke pots is likely.

A review of the Army documentation concerning the use of HC smokes and an analysis of the installation survey results confirmed several things. First, no formal studies had been published on the nature and extent of chronic HC smoke exposure during training. Second, there was no official policy guidance on how HC smoke was to be deployed on military training installations to insure minimization of community exposures. Third, no policy existed on the length of time that smoke generating companies should be allowed to continue to deploy and be exposed to HC smoke.

The Army Smoke/Obscurants Project Manager's plan for reducing toxic hazards to HC smoke[14] as well as the numerous Army letters, phone conversations, and memoranda cited earlier hinted at potentially significant exposures during training. However, none of this documentation delineated the nature or extent of exposure or estimated the potential chronic risk resulting from training with HC.

The Army Surgeon General had advised MACOMs to have troops in training mask in the presence of HC smoke on the basis of established safety criteria for training with smoke; however, an FY82 Memorandum for Record indicated that soldiers may have been advised to mask only to enable training under simulated enemy-produced chemical warfare conditions, and not because of potential health effects of HC smoke.[15] A U.S. Army Medical Bioengineering Research and Development Laboratory (USAMBRDL) memorandum directed to the Surgeon General advised that the medical guidance in a 1977 Surgeon General's letter be reviewed based on FY82 knowledge to determine whether its stated personal protective measures for troops exposed to HC smoke were sufficient.[16] Thus, if troops in training are only masking under simulated chemical warfare conditions, and not when the objective of smoke dispersion is for creating a visual obscurance with a smoke cloud, screen, or curtain, then sizable exposures are likely.

Interviews were conducted with six chemical officers (references will remain anonymous) who were trained and in charge of smoke deployment training, and with six other officers and enlisted personnel on smoke generating squads who had participated in smoke training after FY78. The opinion of those interviewed was that relatively few soldiers mask in the presence of HC smoke unless it is intense enough to create and reverse symptoms or unless a chemical attack is being simulated. Establishment of this general perception was critical in determining if the study should continue since calculations showed that, with properly sized M3-A3 masks, the chronic absorbed dose from HC smoke exposure would likely be insignificant.

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[14] Management Plan for Reducing Toxicity Hazards of Army Inventory Pyrotechnic Smoke Screening, Marking, and Signaling Devices (Department of the Army Armament Command, April 1980).

[15] LTC Delaney, Memorandum: Use of HC Smoke for Field Training (U.S. Army Medical Bioengineering Research and Development Laboratory, Fort Detrick, MD, 12 February 1982); Letter DASG-HCH-O.

[16] LTC Delaney; Letter DASG-HCH-O.

Rationale for Selecting a "Worst-Practicable-Case" Scenario

At this point, it was necessary to identify a worst-believable case military exposure. The rationale was that if a worst-believable case exposure did not show a significant level of risk, then it would be safe to assume other military training exposures would also be insignificant. The method used in developing a worst, but believable, scenario involved (1) surveying and analyzing the Army training literature for deployment of HC smoke, (2) confirming that the documented scenarios were carried out in real Army training situations, and (3) identifying where such scenarios were being enacted.

Army documentation indicating how HC smoke should be deployed comes primarily from one manual,[17] as confirmed by several chemical officers, but other guidance documents exist. There was almost universal agreement among the soldiers interviewed during 1982-1983 that the number of smoke pots actually deployed rarely reaches the number prescribed for use under worst-case conditions (greatest number of HC munitions per unit time according to the field manual) because such munitions are scarce. The munitions in shortest supply prior to 1982, M1 and M5 smoke pots, have become more available and usage has increased steadily. Therefore, modeling the worst-case scenarios as prescribed in smoke training manuals may reasonably state the actual amounts that will be used per exercise in the future.

Chemical officers and trainers at Fort McClellan, AL, were interviewed during 1982-1983 and asked to develop a worst-case scenario from their own experience. From their responses, a worst-case scenario was generated on the basis of confirmation that masks were not used by soldiers exposed to the smoke, maximum exposure time, a definite history of smoke deployment, and validation that personnel actually use such procedures during exercises. The scenario for Fort Irwin, CA, developed by personnel who had commanded the smoke units at Fort Irwin during the time of the study, met all of these criteria.

The Fort Irwin Scenario

Fort Irwin, CA, is the Army's National Training Center where units are deployed for 2 weeks at a time at approximately 18-month intervals. Units there spend a minimum of 1 week engaging the opponent forces (OPFOR) in battles or "wars" realistic in every way except in the use of live ammunition. In place of live fire, lasers are used to engage and "kill" a target. When a tank is "hit" for instance, it is out of action and must remain stationary until the battle is over and a victor has been declared.

The OPFOR, a special unit organized to simulate Russian tactics, uses large amounts of HC, fog oil, and diesel smoke when attacking the visiting "friendly" unit. The objective is to create "large area" smoke between opposing forces to obscure the attacking OPFOR from the entrenched friendly unit on the open terrain. This procedure often requires the OPFOR to clear

[17]Field Manual (FM) 3-50, Chemical Smoke Generator Units and Smoke Operations (Department of the Army, April 1967).

minefields and obstacles such as barbed wire and tank diversion ditches while moving through smoke during the attack. Without smoke, the attacking OPFOR would be easy targets for the entrenched friendly force. Since a computerized scorecard is kept and later analyzed by the officers in charge, both sides are expected to fight the best battle possible and make every attempt to win.

Personnel assigned to generate the smoke needed by both forces consist of two squads who employ M5 and M1 smoke pots to obscure their positions from enemy artillery or to simulate HC artillery rounds. Smoke-generating squads generally can control exposures from their smoke pots because they can stand upwind of the emitters. However, when winds are fluctuating or nearly nonexistent, when smoke emitters are placed in heavily wooded environments (not at Fort Irwin), or when HC smoke pots are placed 50 to 75 m upwind to deliberately obscure the position of a fog oil generator, these squads also become exposed to HC smoke.

At Fort Irwin, three distinct exposure possibilities exist (Figure 1): the individuals comprising the smoke generator squads, the OPFOR battalions attacking through the smoke, and the friendly forces entrenched to defend against the attack.

Individuals in the smoke generator squads are directly downwind of smoke pots placed at a distance of 50 to 75 m and are required to stay close to their fog oil generators. Thus, they can be assured of fairly consistent exposure regardless of weather conditions. The OPFOR may be in the mixed fog oil and HC smoke haze for even longer periods of time as they are attacking the friendly forces, and may receive greater exposure, especially when severe inversions and lower wind speeds cause cloud persistence.

Of all the Army smoke-generating squads, the Fort Irwin unit almost surely experiences the worst-case exposure at present; indeed, it is one of the few active smoke units in operation. In addition, the fighting OPFOR battle tactics call for extensive use of smokes, especially in the fighting environment found at Fort Irwin. In 1982 these squads were in the field generating smoke 2 weeks per month, 10 months per year, for a total period of up to 2 years. (1986 units were in the field at least 3 weeks per month, 12 months per year. 1982 exposures are used in this report.)

The OPFOR also spends extensive amounts of time in the field to accommodate the monthly rotation of Army units. It is doubtful that units stationed anywhere else in the continental United States are in the field training for more than 2 to 3 months per year; also, most units' use of smoke per exercise would be far less, primarily due to limited availability of smoke pots (prior to 1982) and a lack of rigor in using smoke munitions realistically. This is likely to change for the worse because the use of HC smokes has risen steadily since 1982.

Table 5 shows that Fort Irwin expended 3200 ABC-M5 and M4-A2 smoke pots during FY82. Other FORSCOM installations issuing smoke pots in FY82 used fewer than 1000 each, with most numbering between 1 and 300. However, three TRADOC installations (Forts Benning, Knox, and McClellan) used totals (rounded) of 700, 900, and 600 smoke pots, respectively. It is difficult to estimate the exact number of pots used with the TAMIS because

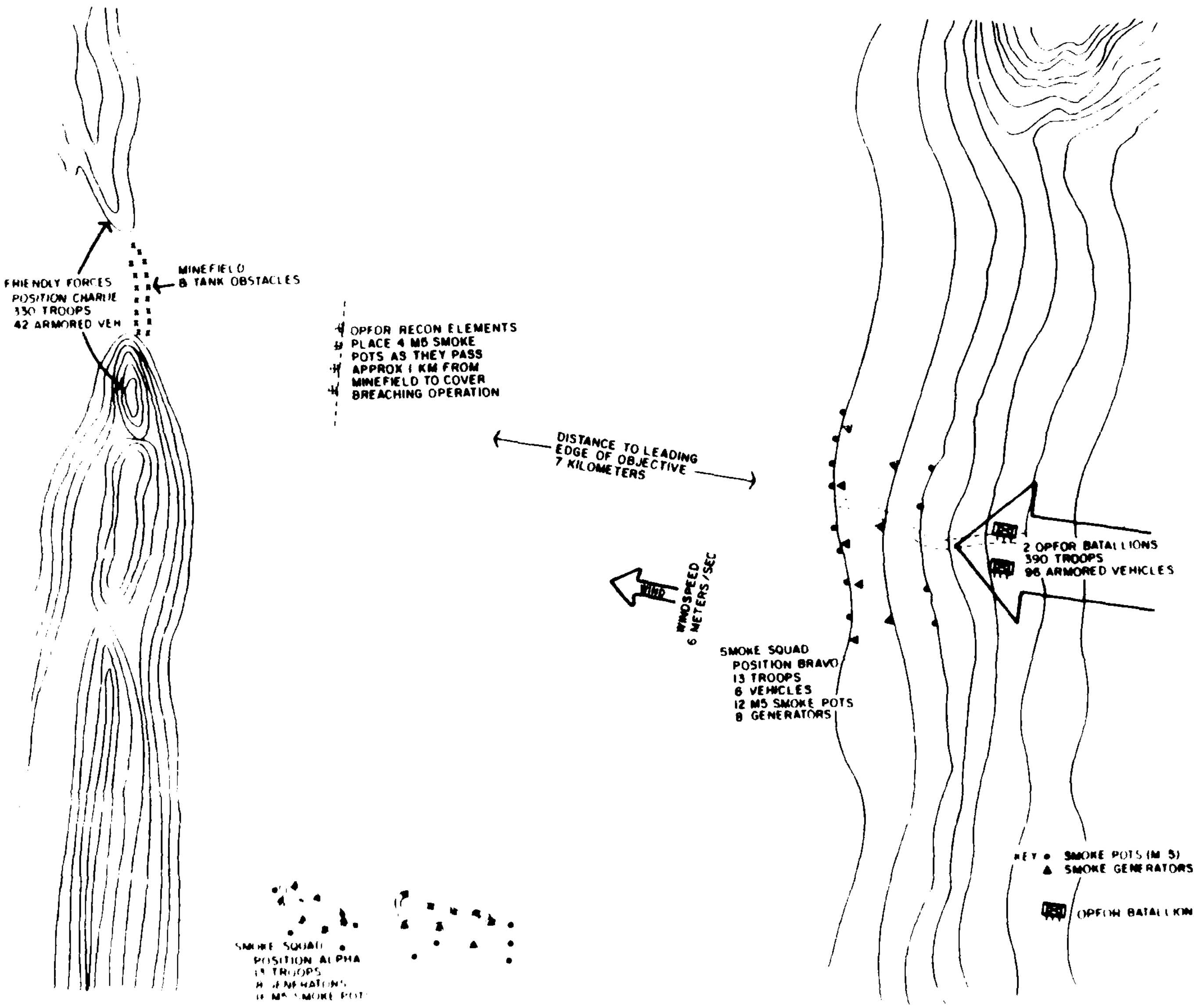

Figure 1. Fort Irwin smoke exposure scenario (opponent forces (OPFOR) attack sequence).

(1) authorization and expenditure values are rounded to the nearest 100 and (2) M1 HC smoke pots are incorrectly identified in the data base as ABC-M5 pots.[18]

Forts Irwin and McClellan both reported using the M1 pot. The number of M5 pots estimated to be used at Fort Irwin in FY82 is 4200, a number taken from an earlier TAMIS estimate (April 1982), based on how many had been expended to date (2400) plus those yet authorized to be expended (1800). Again, the "worst-practicable-case" rule applied, with the highest possible number of pots (4200/year for 2 years) used in scenario exposure estimates.

Other Potential Exposures to HC Smoke

At Fort McClellan, AL, the Army Chemical School instructs classes year-round in the proper methods of disseminating chemical warfare munitions and all types of smoke, including HC and fog oil. The chemical officers there reported that little exposure to the trainers or trainees occurs because trainees are taught to detonate smoke pots effectively and to observe smoke releases instead of maneuvering within the smoke cloud. In addition, Fort McClellan trainers reported insisting on using masks in the presence of HC smoke and instructing generator squads always to stand upwind of activated smoke pots.

The only other potentially large exposures are at Fort Benning and European posts, where in FY82 the TAMIS data base showed a total authorization for expenditure of 1200 and 4700 M5 and M4-A2 smoke pots, respectively. The European exposure scenario was beyond the scope and resources of this project.

Large numbers of HC smoke grenades are used at several U.S. installations and in Europe, and exposure to grenade smoke is just as likely as that from smoke pots. However, grenades are used in an almost infinite number of scenarios, making it impossible to fit them into a "most likely" situation or to establish a realistic per-use exposure estimate. Suffice it to say that additional exposure from use of grenades does occur to soldiers across the Army, including the Fort Irwin personnel considered in this study.

Modeling the "Worst-Practicable-Case" Scenario

Tables 2 and 3 (Chapter 1) show the chemicals identified in HC smoke generated in a laboratory setting. A composition range (percentages by weight of the reagent mixture) was reported for each of these compounds. The highest percentage reported for each compound[19] was used in calculating exposure levels. A burn efficiency of 70 percent was assumed for the laboratory pots. Work in progress (at USA-CERL) suggests that the burn efficiency of real pots is close to 100 percent under field conditions.

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[18] Personal Communication with J. Kirby (Logistics Management Branch, Ammunition Directorate, Rock Island Arsenal, Rock Island, IL, 1985).

[19] S. Katz, R. Snelson, R. Farlow, R. Welker, and S. Mainer.

This report assumes that the proportion of each compound remains the same during a "worst-practicable-case" exposure and is uniform throughout the life of the cloud. Because larger particles will settle out and lighter gases will rise as the cloud disperses, the estimates developed here may exaggerate the exposures of individuals located relatively far from the smoke source.

In calculating the number of times an individual soldier is exposed to the entire cloud from an M5 HC smoke pot, the total number of pots authorized for Fort Irwin expenditure was factored into the "worst-practicable-case" scenario. This calculation did not allow for use of the available smoke pots by individuals other than the smoke squads and OPFOR, and it only considered the scenario conditions described. The calculation thus maximized the proportion of total pots used for executing this "worst-practicable-case" scenario. It should be noted here that the live fire exercises performed at Fort Irwin also deploy the smoke pots being considered and although a detailed exposure scenario has not been determined, exposures would not approach the "worst-practicable-case" exposures described in this document.

3 RISK ASSESSMENT OF FORT IRWIN HC SMOKE EXOSURES

Maximum Allowable Body Dose

In assessing the risks associated with exposure to cadmium, hexachlorobenzene, hexachloroethane, perchloroethylene, carbon tetrachloride, and arsenic, the USEPA has used incidence probability statistics to establish the minimum total absorbed dose required to induce a predetermined probable number of cancers for the compounds of interest. USEPA has reported these probabilities using the linear relationship:

$$P = SE \qquad \text{[Eq 2]}$$

where P is the probable incidence of cancer in nondimensional units, S is the potency of the toxin (constant of proportionality) expressed as $(mg/kg\text{-}day)^{-1}$ and E is the exposure rate of the population to the toxic substance in mg/kg-day. With the exception of cadmium, USEPA derived the potency values given in Table 6 from animal data using the linearized multistage model. Dosage values were scaled from animal to man using a surface area relationship. (The effects of model and scaling method choices are illustrated for perchloroethylene in Appendix B.) The cadmium incidence statistics, obtained with human subjects inhaling air-suspended cadmium, were transformed into units equivalent to those of the other substances as described below.

Table 6

Calculated Maximum Allowable Doses for a 70-Year Lifetime with P of 10^{-5}

Compound	$S \left(\frac{mg}{kg\text{-}day}\right)^{-1*}$	E_{max} $\frac{mg}{kg\text{-}day}$**	$d_{max\text{-}mg}$***
Hexachlorobenzene	167×10^{-2}	5.98×10^{-6}	10.7
Hexachloroethane	1.4×10^{-2}	7.14×10^{-4}	1277.
Perchloroethylene	3.98×10^{-2}	2.51×10^{-4}	448.9
Carbon tetrachloride	8.28×10^{-2}	1.21×10^{-4}	216.4
Cadmium	665×10^{-2}	1.50×10^{-6}	2.7
Arsenic	1400×10^{-2}	7.14×10^{-7}	1.28

Values of S, the potency, are the q_1 values reported by USEPA. The q values from which q_1* values were computed were obtained by USEPA using the multistage model [FR45(231):79351, 1980] after scaling animal exposure data to equivalent human ingestion values in mg/body surface area/day.

**E_{max}, or maximum, exposure is calculated for each compound under the condition that $P = 10^{-5}$, or the probability of cancer is 1 in 100,000.

***d_{max} is the maximum lifetime dose to derive a cancer probability of $P = 10^{-5}$. d_{max} is calculated for a 70-year lifetime (standard) and a 70-kg person (standard).

USEPA has stated that an exposure to a cadmium concentration of 1 $\mu g/m^3$ over a lifetime results in a 1.9×10^{-3} probability of developing cancer. The exposure rate for airborne substances can be calculated from Equation 3:

$$E = \frac{C\dot{V}}{M} \qquad \text{[Eq 3]}$$

where C is the concentration, $\dot{V}$ is the breathing rate, and M is the mass of the individual. For a 70-kg person breathing 20 m^3/day of air containing cadmium in concentrations of 1 $\mu g/m^3$, the exposure rate is

$$E = \frac{1\ \mu g}{m^3} \times \frac{20\ m^3}{day} \times \frac{1}{70\ kg} \times \frac{1\ mg}{1000\ \mu g} = \frac{2}{7000}\ \frac{mg}{kg\text{-}day} \qquad \text{[Eq 4]}$$

Since the relationship between the exposure rate and probability is assumed to be linear for cadmium, Equation 2 can be used to obtain the comparable slope, S, for cadmium:

$$S = \frac{P}{E} = \frac{1.9 \times 10^{-3}}{\frac{2}{7000}\ \frac{mg}{kg\text{-}day}} = 6.65 \left(\frac{mg}{kg\text{-}day}\right)^{-1} \qquad \text{[Eq 5]}$$

The maxiumum allowable lifetime dose, d_{max}, for a 70-kg man living 70 years is:

$$d_{max} = E \times 70\ kg \times 25{,}550\ days \qquad \text{[Eq 6]}$$

E is calculated for a particular probability P and compound with slope S using Equation 2. For example, the maximum lifetime exposure rate to perchloroethylene that results in 1 cancer per 100,000 people ($P = 10^{-5}$), E_{max}, is obtained using Equation 2 as:

$$E_{max} = \frac{P}{S} = \frac{10^{-5}}{3.98 \times 10^{-2}}\ \frac{mg}{kg\text{-}day} = 2.51 \times 10^{-4}\ \frac{mg}{kg\text{-}day} \qquad \text{[Eq 7]}$$

When this value is substituted into Equation 6 the maximum allowable lifetime dose, d_{max}, for a probability of one cancer in 100,000 (10^{-5}) from exposure to perchloroethylene is:

$$d_{max} = 2.51 \times 10^{-4}\ \frac{mg}{kg\text{-}day} \times 70\ kg \times 25{,}550\ days = 448.9\ mg \qquad \text{[Eq 8]}$$

Using this procedure, the maximum allowable lifetime doses were calculated for the substances in Table 6 for a 70-year lifetime, a slope S, and a P of 10^{-5}. A rationale for using these lifetime values to estimate effects of exposures occurring over only a fraction of the lifetime is given in Appendix C.

Training Doses by Inhalation

The body dose resulting from HC smoke exposures can be calculated by first examining the amount of pollutant being inhaled. This value, I, (mg) is given by

$$I = C\dot{V}t \qquad \text{[Eq 9]}$$

where C is the pollutant concentration $mg\text{-}m^{-3}$, $\dot{V}$ is the breathing rate ($m^3\text{-}min^{-1}$) and t (min) is the exposure time. (The exposure time is given by the burntime of one pot.) If one defines the air dosage, D, as

$$D_{air} = C \cdot t \quad \frac{mg\text{-}min}{m^3} \qquad \text{[Eq 10]}$$

then Equation 9 becomes:

$$I = D_{air} \cdot \dot{V} \qquad \text{[Eq 11]}$$

Not all of the inhaled pollutant is retained in the lung. If one assumes that only a fraction, K_2, of the total is retained, then the body dose becomes:

$$d_B = K_2 D_{air} \dot{V} \qquad \text{[Eq 12]}$$

Maximum Allowable Exposures

The maximum number of allowable exposures, N, is, of course, dependent on the strength of each dose, d_{Bi}. Therefore,

$$\sum_{i=1}^{N} d_{Bi} \leq d_{max} \qquad \text{[Eq 13]}$$

If all the doses are equal, then

$$\sum_{i=1}^{N} d_{Bi} = Nd_B \leq d_{max} \qquad \text{[Eq 14]}$$

and,

$$N \leq \frac{d_{max}}{d_B} \qquad \text{[Eq 15]}$$

where N is the number of equal exposures allowed.

To assess the risk associated with training exercises one must be able to calculate d_{Bi} for each of the exercises. Thus, the dosage, D_{air}, associated with each exercise must be known. For this evaluation, D_{air} is calculated using air dispersion models like the one described in Appendix D.

Dose Estimate for Smoke Generator Operators

The scenario used to represent the "worst-practicable-case" condition for personnel deploying smoke pots and fog oil generators stations is a serviceman 50 m directly downwind of a smoke pot. The 50 m was chosen because experience has shown this to be the closest position a person would assume in these worst-case exercises. Over a period of 2 years (estimated to be the normal assignment of smoke generating and OPFOR units), 8400 equivalent M5 smoke pots are estimated to be used in training maneuvers (two times the FY82 highest estimate). For each OPFOR attack (Figure 1), 32 smoke pots are set off during the maneuver. Therefore, during a 2-year period, the firing of 32 smoke pots is assumed to be repeated approximately 262 (i.e., 8400/32) times. It is conservately assumed that a serviceman is responsible for, and is exposed to, one pot per exercise. This means that in the "worst-practicable-case" scenario, each serviceman deploying the pots is exposed to 262 smoke pots if the tour of duty lasts 2 years. Assuming smoke squads and OPFOR are in the field 7 days/week, 2 weeks/month, 10 months/year for 2 years, there are 280 days on which exercises are conducted for the 262 scenarios to be carried out.

Air dispersion modeling results indicate that at a distance 50 m directly downwind of a single smoke pot under D stability conditions (see Appendix D), the serviceman is exposed to a total dosage of 1120 mg-min/m^3 (D_{air}). The unit mg-min/m^3 is defined as the total available dosage at a given point in the cloud.[20] All calculations in this study assume the serviceman is exposed to the entire life of the cloud, except where noted. The distribution of potentially harmful constituents in this dosage is perchloroethylene, 17 percent; hexachloroethane, 5 percent; carbon tetrachloride, 3 percent; hexachlorobenzene, 0.9 percent; cadmium, 0.15 percent; and arsenic, 0.005 percent of the cloud mass (Tables 2 and 3), assuming 100 percent reaction of the M5 pot's 30-lb (13.5 kg) fill mix. Cadmium and arsenic percentages were taken from measurements of the initial smoke pot mix and gas percentages were taken from lab measurements of those present in laboratory generated smoke. This means, for example, that the dosage of perchloroethylene 50 m downwind of the pot is:

$$(D_{air})_{PERC} = 1120 \frac{\text{mg-min}}{\text{m}^3} \times 0.17 = 190 \frac{\text{mg-min}}{\text{m}^3} \qquad \text{[Eq 16]}$$

Air dosages for the other constituents were calculated similarly and are given in Table 7.

As noted earlier (Equation 12), the dose for a person breathing any substance is:

$$d_B = K_2 \, D_{air} \cdot \dot{V} \qquad \text{[Eq 17]}$$

[20] Handbook for Chemical Hazard Prediction, DARCOM Handbook No. 385-2-1-80 (U.S. Army Material Development and Readiness Command, February 1980).

Table 7

Maximum Allowable Exposures to Six Components for D Atmospheric Stability

Compound	D_{air} $\frac{mg\text{-}min^*}{m^3}$	d_B-mg**	d_{max}-mg***	N_{max}-pots+	N_{2yr}-pots++
Hexachlorobenzene	10.1 0.30	10.7	35.7	262	
Hexachloroethane	56.0 1.68	1277.	760.1	262	
Perchloroethylene	190.0 5.70	448.9	78.8	262	
Carbon tetrachloride	33.6 1.00	216.4	216.	262	
Cadmium	1.68	0.05	2.68	53.6	262
Arsenic	0.056	0.002	1.28	640.	262

*Based on (D_{air}) total = 1120 $\frac{mg\text{-}min}{m^3}$ D stability class, u = 6 m/sec.

**Obtained using Equation 12 with K_2 = 1 and $\dot{V}$ = 0.03 m^3/min, one smoke pot.

***From Table 6, P = 10^{-5}.

+Obtained using Equation 20 for P = 10^{-5}.

++Fill weight of an M5 smoke pot assumed to be 30 lb (13.5 kg). Assumes 100 percent burn.

For a serviceman participating in these exercises, the breathing rate is assumed to be 0.03 m^3/min (43.2 m^3/day; about twice the minute volume at rest) based on moderate to strenuous exercise while training. The constant K_2 reflects the fact that some substances are not completely retained in the lungs. However, due to additional dosages of these compounds through the skin and/or gut, a 100 percent absorption of the available respirable dose is assumed. Thus, as used here, K_2 for all chemicals is equal to 1.* Calculations for the single pot dosage, d_B, for each substance are given in Table 7. For the perchloroethylene example:

$$d_B = 1 \times 190 \ \frac{mg\text{-}min}{m^3} \times 0.03 \ \frac{m^3}{min} \qquad [Eq\ 18]$$

$$d_B = 5.7 \ mg \qquad [Eq\ 19]$$

Since we have assumed each exposure to a pot is the same, we can calculate the maximum number of exposures allowable for a specified risk level, P,

$$N = \frac{d_{max}}{d_B} \qquad [Eq\ 20]$$

*USEPA has set a respirable absorption for perchloroethylene at 0.5, carbon tetrachloride at 0.4, cadmium at 0.16, and arsenic at 0.2. The remaining compounds are 1.0.

where values for d_{max} are given in Table 7 for $P = 10^{-5}$. The d_{max} for the perchloroethylene example is 448.9 mg. Therefore, the maximum allowable number of exposures for that compound is:

$$N = \frac{d_{max}}{d_B} = \frac{448.9}{5.7} = 78.8 \qquad \text{[Eq 21]}$$

Again, the maximum allowable dosages for all substances are given in Table 7 for a cancer incidence of 1 in 100,000 ($P = 10^{-5}$). Data in the table suggest that the most hazardous compounds are hexachlorobenzene and cadmium, with maximum allowable numbers of equal exposures equaling 35.7 and 53.6, respectively (per a 10^{-5} upper limit risk).

As noted in Appendix D, most training exercises probably take place when the atmospheric stability class is E or F and not D. For this reason, it is instructive to calculate the maximum allowable exposures under F stability (see Table 8 and Appendix D). It should be noted that the number of allowable exposures is exceeded during the exercises for all compounds at the 10^{-5} probability level. A comparison of Tables 7 and 8 reveals that the choice of stability class alone gives an order of magnitude change in the dose. Therefore, because of the time of day the maneuvers take place (i.e., with variation in stability classes), the actual dose probably is somewhere between these two conditions.

Table 8

Maximum Allowable Exposures to Six Components for F Atmospheric Stability

Compound	D_{air} $\frac{mg\text{-}min}{m^3}$*	d_B-mg**	d_{max}-mg***	N_{max}-pots+	N_{2yr}-pots++
Hexachlorobenzene	89	2.67	10.7	4.0	262
Hexachloroethane	496	14.9	1277.0	85.7	262
Perchloroethylene	1685	50.6	448.9	8.9	262
Carbon tetrachloride	297	8.91	216.4	24.3	262
Cadmium	14.9	0.449	2.68	5.97	262
Arsenic	0.496	0.015	1.28	85.3	262

*Based on (D_{air}) total = 9915.8 $\frac{mg\text{-}min}{m^3}$. F stability class, u = 2 m/sec.

**Obtained using Equation 12 with $K_2 = 1$ and $\dot{V} = 0.03\ m^3/min$, one M5 smoke pot.

***From Table 6, $P=10^{-5}$.

+Obtained using Equation 20 for $P = 10^{-5}$

++Fill weight of an M5 smoke pot assumed to be 30 lb (13.5 kg). Assumes 100 percent burn.

Table 9 gives the probabilities associated with the smoke generator squads' 2-year training exposure for both D and F atmospheric stabilities. The table shows that 2-year cancer incidences for the D and F stability classes are 1.75 and 15.58 cancers per 10,000 persons, respectively. This translates into a cancer risk of 0.875 and 7.79 cancers per 10,000 population per year, respectively, for the 2-year assignment.

Troop Movement Exposure for the Opponent Forces (OPFOR)

Because smoke pots are used to obscure the OPFOR unit from the friendly forces, the OPFOR are also exposed to the smoke. If the troop movement has a speed of V (m/min) and the wind speed is u (m/min), then three cases are of interest in determining exposure levels: $V > u$, $V = u$ and $V < u$.

Case I: $V - u > 0$

For this case, let us assume the attacking forces are delayed long enough that they emerge from the smoke cloud just as it reaches the friendly forces. For modeling purposes, this situation is equivalent to passing the smoke over a stationary OPFOR unit with a wind speed V-u. Thus, dosage at distance X*(m) directly downwind of the pots is:

$$D = \frac{Q}{\pi \sigma_y \sigma_z u^*} \quad \text{[Eq 22]}$$

where: Q = mass (mg) of smoke released

$u^* = |V-u|$

$\sigma_y = \sigma_y(X^*)$ standard deviation of cross wind concentration at point X*(m).

$\sigma_z = \sigma_z(X^*)$ standard deviation of vertical concentration at point X*(m).

$X^* = ut$

t = wind travel time (min) from the smoke generator to point X* downwind.

Note that the change in dosage under this transformation results from a reduction in the dilution caused by the wind velocity and not from the spread of the plume caused by turbulent diffusion. Under D stability, let us assume $u^* = 1$ m/sec. The wind travel time for traversing the 7000 m range with a wind at 6 m/sec is therefore 19.4 min. The maximum concentrations at the plume center line for various points downwind of the pots are given in Table 10. Further details of the air dispersion model are contained in Appendix D.

Again, the OPFOR troops are assumed to be about 50 m downwind of the pots when exposed. Table 10 shows that troops immediately downwind of the pots are exposed to approximately the same levels of pollutants as the smoke-generating squad.

Table 9

Total 2-Year Training Risk for Smoke Generating Personnel

Compound	P_D^*	P_F^*
Hexachlorobenzene	7.34×10^{-5}	65.5×10^{-5}
Hexachoroethane	0.34×10^{-5}	3.06×10^{-5}
Perchloroethylene	3.32×10^{-5}	29.5×10^{-5}
Carbon tetrachloride	1.21×10^{-5}	10.8×10^{-5}
Cadmium	4.88×10^{-5}	43.9×10^{-5}
Arsenic	0.41×10^{-5}	3.07×10^{-5}
P_{TOTAL}	17.5×10^{-5}	155.8×10^{-5}

*Subscripts D and F refer to calculations made using atmospheric stability categories D and F, respectively (see Appendix D).

$$P_{compound} = \frac{262 \times 10^{-5}}{\left(N_{max\text{-}pots}\right)_{compound}}$$

Table 10

Total 2-Year Training Risks for OPFOR Unit

Distance downwind (meters)	Exposure D_D $\frac{mg\text{-}min^*}{m^3}$	Excess Risk $(P_T)_D$	Exposure D_F $\frac{mg\text{-}min^{**}}{m^3}$	Excess Rate $(P_T)_F^{**}$
50	0.675×10^4	1.05×10^{-3}	0.197×10^5	3.09×10^{-3}
60	0.490×10^4	7.66×10^{-4}	0.151×10^5	2.36×10^{-3}
70	0.374×10^4	5.84×10^{-4}	0.121×10^5	1.90×10^{-3}
80	0.296×10^4	4.63×10^{-4}	0.998×10^4	1.56×10^{-3}
90	0.241×10^4	3.77×10^{-4}	0.841×10^4	1.32×10^{-3}
100	0.201×10^4	3.14×10^{-4}	0.722×10^4	1.13×10^{-3}
500	0.121×10^4	1.18×10^{-4}	0.700×10^3	1.10×10^{-4}
1000	0.522×10^2	8.16×10^{-6}	0.256×10^3	4.00×10^{-5}

*Mixing layer height of 200 m, stability class D (Appendix E). $(P_T)_D = \frac{D_D \cdot P_D^*}{1120}$ where P_D^* is given in Table 9.

**Mixing layer height of 80 m, stability class F (Appendix E). $(P_T)_F = \frac{D_F \, P_F^*}{9915.8}$ where P_F^* is given in Table 9.

Case II: $V - u = 0$

This condition will not be realized in practice because it is unlikely that troop movement and wind speed will be equal throughout the attack. It is more likely that the wind speed difference will always be some increment $\pm u^*$. For modeling, $u^* = 1 \pm 1$ m/sec has been used, and under this assumption, the condition is covered by the other two modeling scenarios.

Case III: $V - u < 0$

In this case, wind speed is greater than the OPFOR's speed. Hence, pots set off before the OPFOR unit passes the pot positions will never expose the OPFOR to smoke. However, pots released after the unit passes the pot positions will cause exposure. The modeling for this unit is identical to Case I except that the charge, Q, must be adjusted downward to reflect that part of the smoke released that never comes into contact with the OPFOR unit. Concentrations to which troops are exposed will therefore be lower in this case than in Case I.

Friendly Force Exposure

Because the friendly forces are approximately 7000 m downwind of the smoke pots, a "box" model can be used to estimate the dosage levels to which these troops are exposed. As given in Appendix D:

$$D = \frac{Q}{\sqrt{2\pi} \cdot \sigma y \cdot H_m \cdot u} \quad \text{[Eq 23]}$$

where H_m is the mixing height.

The estimated total smoke dosages (12 pots) for the friendly forces under class D stability with a mixing height of 200 m, and class F stability with a mixing height of 80 m, are 0.04 mg-min/m^3 and 0.48 mg-min/m^3, respectively. These values are negligible compared to the other troop exposures.

Community Exposure

The community nearest the training area at Fort Irwin is Baker, CA, which is approximately 30 km from the training site. The terrain between the maneuver area and the community is quite mountainous, with the Soda mountains forming a natural barrier. There are, however, valleys around the mountains--one to the north and one to the south--that could provide a pathway to Baker for smoke released during the training exercises. Occasions may exist, under very stable atmospheric conditions, when Baker residents are exposed to smoke.

Because of the complex terrain configuration between Fort Irwin and Baker, accurate dispersion model estimates of the smoke dosage experienced by the residents are not possible. A very crude dosage estimate, however, can be made by assuming that under very stable atmospheric conditions (stability class F in Appendix D), the cloud "hangs" together and drifts into one of the two valleys connecting Fort Irwin and Baker. Dosage estimates for sources located in valleys of width W and mixing height H_m can be obtained from the expression:

$$D = \frac{f_1 \cdot f_2 \cdot f_3 \cdot f_4 \cdot Q}{H_m \cdot W \cdot U} \qquad \text{[Eq 24]}$$

where f_1 is the fraction of the time the wind direction is toward Baker, f_2 is the frequency of very stable atmospheric conditions (stability class F, Appendix E), f_3 is the number of maneuvers during a Baker resident's lifetime (131 maneuvers/yr x 70 yr), f_4 is the fraction of the time the cloud "hangs" together and reaches Baker, and Q is the mass of smoke released per maneuver.[21] For our worst-case estimate, assume that $f_1 = 0.5$, $f_2 = 0.15$, $f_3 = 9170$, $f_4 = 0.01$, $Q = 4.35 \times 10^8$ mg/maneuver (32 M5 pots x 13.5 kg x 10^6 mg/kg), $H_m = 80$ m (from table E-1), W = 5000 m, and U = 120 m/min.

$$D = \frac{(0.5) \cdot (0.15) \cdot (9170) \cdot (.01) \cdot (4.35 \times 10^8) \text{ mg-min}}{(80 \text{ m}) \cdot (5000 \text{ m}) \cdot (120 \text{ m})} \qquad \text{[Eq 25]}$$

$$D = 62.3 \frac{\text{mg-min}}{\text{m}^3}$$

The probability of a cancer developing during the lifetime of a resident of Baker solely from smoke exposure, P*, is obtained by direct scaling: $P^* = 62.3 \times P^*_F/9915.8 = 9.79 \times 10^{-6}$ or (9.79/1,000,000). Among worst-case estimates, this figure is conservative. Other installations using significant quantities of HC smoke, including overseas training areas where civilian populations may be much closer to the smoke release points, should be seriously considered as candidates for risk assessment, and smoke releases should be monitored closely.

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[21] D. B. Turner, Workbook of Atmospheric Dispersion Estimates, Public Health Services Publication #999-AP-26 (National Center for Air Pollution Control, Cincinnati, OH, 1969).

4 RISK INTERPRETATION

The policy adopted by Congress in the Delaney Amendment to the Food, Drug and Cosmetic Act in 1958 states that any risk of cancer due to food additives is unacceptable. However, this "no-risk" goal has new meaning through advances in toxicology and analytical chemistry; a harmful chemical can now be detected in concentrations as small as one part per billion or even one part per trillion. At these levels, we are regularly exposed to a host of carcinogens[22] and little or nothing can be done to remove these risks among people living in a modern, industrial country. At the same time, what had been thought to be only a few carcinogenic substances amounts now to several hundred, with a significant proportion of new chemicals tested being found carcinogenic as well.

Federal agencies charged with protecting people against cancer therefore have moved away from a goal of no risk; instead, they have attempted to quantify the risk to establish quantitative risk goals.[23] For example, the Food and Drug Administration (FDA) has classified a cancer risk of one per million lifetimes as "negligible." In addition, the USEPA's Carcinogen Assessment Group has been estimating the level of risk from particular chemicals since 1976. A number of scientists and policy analysts have pointed out the uncertainties associated with this risk estimation; however, description and quantitative estimation of risk are far more informative and practical than policies of no risk or arbitrary action.

Several agencies have proposed or established explicit risk goals. For example, the FDA sets a risk goal for a chemical of not producing more than one cancer in a population of 1,000,000 persons over their lifetimes. USEPA's risk goals under the Toxic Substances Control Act are somewhat less explicit but appear to be on the order of 1 cancer in 100,000 lifetimes.[24] The Nuclear Regulatory Commission (NRC) has proposed a risk goal for cancer deaths due to nuclear power of no more than 0.1 percent greater than background risk which is 1500 per 10,000. Thus, the additional cancer risk cannot be larger than 1.5 in 10,000 lifetimes or more than 19 per 10,000,000 people per year. The NRC's proposed goals for accidents that could lead to prompt deaths are similar and come to 0.35 per 10,000 lifetimes or 5 per 10,000,000 per year, about one-fourth the risk goal for cancer deaths.

The Occupational Safety and Health Administration (OSHA) tolerates higher risks for workers than USEPA or FDA tolerate for the general public. Similarly, the NRC has much more stringent standards for public exposure to ionizing radiation than for workers. The underlying principle is that workers generally have some idea of the risks associated with their work. They may exercise special precautions or use personal protective equipment, and they generally receive a wage premium for bearing these risks. Furthermore, any time they decide the risk is too great, they can quit and walk away from it,

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[22] B. N. Ames, "Dietary Carcinogens and Anticarcinogens, Oxygen Radicals, and Degenerative Diseases," <u>Science</u>, Vol 221 (1983), pp 1256-1264.

[23] D. Byrd and L. Lave, "Significant Risk is not the Antonym of De Minimis Risk," In C. Whipple (Ed.), <u>De Minimis Risk: Proceedings of a Workshop</u> (New York, Plenum Press, 1986).

[24] D. Byrd and L. Lave.

assuming they can find other work. In contrast, the general public may be little informed about the risk or unable to take action to reduce it.

Acceptable risk levels for soldiers exposed to HC smoke should be set with knowledge of the levels regarded as acceptable to other categories of workers exposed to chemicals and those required for the general public. Although all soldiers enlist, they do not have control over assignments or exposure to risk. Even if they were always informed of the degree of risk, being under military discipline they would find it difficult to avoid a situation involving exposure levels higher than they felt acceptable. However, the risk is unlikely to persist for long periods of time so that the soldier represents a mixed situation.

Perhaps the clearest example of risk goals is the NRC's regulation of no more than 5 rem exposure to radiation each year per worker. Translating, if 10,000 persons were exposed to 5 rem, five more than the usual number of 2,500 would be expected to develop cancer. This risk level is far higher than those of various OSHA standards. Nonetheless, it compares to a cancer risk of 7.8 per 10,000 per year among soldiers maximally exposed to HC smoke. In contrast, NRC's goal for general population exposure to radiation is a risk level of 0.019 per 10,000 per year.

As another example, in setting standards of 1 ppm for worker exposure to vinyl chloride monomer or benzene, OSHA was setting a risk goal much more stringent than 2 per 10,000 per year. The OSHA Act requires that workers be protected subject only to "feasibility," and OSHA has interpreted this goal to mean both technological and economic feasibility, with the emphasis on "technology." In other words, since it is technologically feasible to lower soldier exposures to HC smoke, OSHA's criteria would require a risk goal much more stringent than 2 per 10,000 per year.

The above examples show a range of risk goals for carcinogenicity established by Federal regulatory agencies for workers.[25] The highest risk goals appear to be an annual risk of 5 in 10,000 for cancer from ionizing radiation. The annual risk for workers exposed to vinyl chloride would be 1 to 2 orders of magnitude smaller. For the general population, a risk level of 1 to 9/1,000,000/year is the goal for ionizing radiation. The risk levels implied by some other standards are more than an order of magnitude smaller.

For a situation as easily controlled as exposing soldiers to smokes, it seems inconceivable that a Federal regulatory agency would set a risk goal for cancer as lax as 5 in 10,000 per year. More likely, a safety factor an order of magnitude smaller would be selected. While no individual risk level can be considered to be definitive, a risk level greater than 1 in 10,000 per year would probably be unacceptably high, whereas a risk level an order of magnitude smaller would probably be considered negligible. For the risk to the surrounding population, a lifetime risk of cancer of 1 in 100,000 would probably be considered unacceptably large. A lifetime risk level of 1 in 1,000,000 would probably be considered negligible.

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[25]D. Byrd and L. Lave.

New approaches to risk management are based on establishment of "de minimis" risk criteria. The common law concept of "de minimis" holds that the court does not concern itself with trivia. Although a finding of "de minimis" risk would be sufficient to conclude that an exposure was not a significant risk and not of concern, a risk that is not "de minimis" may not be significant.[26] Milvy has stated the "de minimis" lifetime risk criterion, R, for a population at risk, P, as R = 0.015/P.[27] Lifetime risks falling below R are to be considered to represent "de minimis" or acceptable carcinogenic risks. Data points falling above R are not to be so considered. For example, for an exposed population of P = 100, the lifetime "de minimis" risk is R = 1.5×10^{-3} and the annual risk is R = 2.14×10^{-5}. This proposal is consistent with regulatory decision making. Of 94 compounds being considered for regulation by USEPA, 15 fall below R (for a given exposed population) and 70 fall above it. Ten of the 15 chemicals that fall below the line are not being further considered for regulation. Lifetime risks to soliders exposed to HC smoke are 61.25 (0.875/yr x 70 yr) and 545.3 (7.79/yr x 70 yr) per 10,000 under D and F stability conditions, respectively. These risks greatly exceed the lifetime risk criterion given by R = 0.015/10,000 = 0.00015, or 1.5 per 10,000.

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[26] D. Byrd and L. Lave.

[27] P. Milvy, "A General Guideline for Management of Risk From Carcinogens," Risk Analysis, Vol 6 (1986), pp 69-79.

5 CONCLUSIONS AND RECOMMENDATIONS

HC smoke contains a number of toxic materials, including six carcinogens identified in this report. Currently, exposure to this smoke can cause acute health effects that are serious and sometimes life-threatening. This exposure could be essentially eliminated by requiring troops to wear their protective masks. Improved reporting of acute health effects would provide further rationale to control masking among troops.

Under current training conditions some individuals receive doses of carcinogens in HC smoke that create risks of concern. If use of HC smokes in training were to increase markedly, these concerns would become commensurately greater. Moreover, nearby civilian populations may have some exposure to the smokes and therefore must be considered in the risk assessment.

Current training regulations should be amended to ensure better protection to civilians by keeping the smoke source as far as practically possible from the nearest population. For example, an alternative training site should be selected when meteorological conditions indicate an incompletely dispersed cloud might pass over such areas.

HC and other smokes should be investigated further to estimate the acute and chronic health risks to troops and civilian populations. The method should first identify which toxic components poses the greatest risk, so that attention may be focused on those of highest priority. More careful modeling of the atmospheric chemistry and physics on a site-by-site basis is needed to estimate dispersion, chemical changes, and the dose received by troops and civilians in various locations under various conditions. It may be inferred from current USEPA informal risk management guidelines that a lifetime cancer risk of 1 in 100,000 to a worker population (in our case soldiers) triggers actions by USEPA ranging from study to control. A lifetime risk of 1 in 10,000 tends to trigger immediate actions by USEPA to reduce and eliminate exposure.

For HC smoke, the lifetime risks to soliders are 61.25 and 545.3 per 10,000 under D and F stability conditions, respectively. These risks greatly exceed any formal or informal risk management guidelines used by Federal agencies[28] and a newly proposed de minimis criterion.[29] At a minimum, steps should be taken to lower the lifetime risks to troops to less than 1 in 100,000. For HC smoke, several measures can be used to reduce the risk: requirement for use of proper fitting masks in the presence of HC and other smokes; rotation of cadre personnel to reduce cumulative exposures; use of nontoxic smokes[30] for training exercises except when HC smoke is absolutely required; change of composition of the HC smoke to remove the offending compounds, if possible.

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[28] D. Byrd and L. Lave.

[29] P. Milvy, "De Minimis Risk and the Integration of Actual and Perceived Risks from Chemical Carcinogens," In C. Whipple (Ed.), De Minimis Risk: Proceedings of a Workshop (New York, Plenum Press, 1986).

[30] Rosco Fog & Smoke System, H/84 (5.2) (Rosco Laboratories, Inc., 36 Bush Ave., Port Chester, NY 10573).

USEPA informal risk management guidelines consider a lifetime risk to civilians of less than 1 in 1,000,000 acceptable. Again, steps should be taken to lower the risk to nearby civilian populations if possible. Under these informal guidelines, a lifetime risk of cancer to civilians exceeding 1 in 100,000 is unacceptably large. Because the lifetime risk of 0.98 in 100,000 estimated for civilians exposed to HC smoke approaches this trigger point, actions to reduce risks to offbase civilians is warranted. In addition to the measures listed above for troops, consideration should be given to keeping the operations farther away from civilians by moving the training exercises to more remote locations and securing a larger geographical area from which civilians are excluded.

This preliminary analysis provides information about U.S. Army HC smoke-generating activities that pose a potential risk to troops and nearby civilians under worst-case conditions. Care should be taken to analyze and document exposures from HC smoke. A system for documenting acute effects would help identify the population at greatest risk so that preventive measures could be taken. Because current weapons and training involve troop and civilian exposure to numerous toxic chemicals, the Army should formally estimate potential risks to these populations and take actions to lower them where necessary.

It is recommended that the Army adopt a policy of "as low as reasonably achievable," or ALARA.

The Army should be committed to a policy similar to ALARA for troop and civilian exposure to toxic substances. The ALARA principle provides concrete guidelines for lowering such exposure; for example, if a number of training areas are available, the one used most should be the one leading to the lowest civilian exposures. Moreover, since HC smoke is the most toxic of the several smokes available, it should not be used in training where other smokes would be equally effective.

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APPENDIX A: EFFECTS OF SYNERGISM ON RISK ESTIMATES

If synergism does exist for the chemicals in question, the calculated risks are probably too low. One way of estimating the magnitude of the underestimate is to use epidemiologic data on the relative risks of cancer from joint exposures to several carcinogens. Because the purpose in this Appendix is to suggest an approach which might be used to incorporate joint toxic action into risk assessments, epidemiologic data is used as reported by the original author(s), although this may not be the best use of epidemiologic data.

Reif[31] has recently examined the concept of synergism in human carcinogenesis. Six examples of exposures of humans to two carcinogens were studied. He reported that in all instances the minimum statistical requirements were met for determining whether the risk ratio for cancer in the group exposed to both carcinogens was equal to or greater than the product of the risk ratios of the singly exposed groups.

The most directly relevant case Reif studied was cadmium exposure and cigarette smoking. Cadmium, a known human carcinogen, was considered in the risk assessment for HC smokes. For the present purposes it is assumed that all troops either smoke, are exposed to tobacco smoke, or are exposed to tobacco-like chemicals (polynuclear aromatic hydrocarbons, nitrogen heterocycles, etc.) in the field as a result of vehicle emissions or through the use of tank diesel (TD) and fog oil (FO) smokes. Reif used data of Kolonel[32] to examine the relative risks of renal cancer to smokers and nonsmokers occupationally exposed to cadmium.

According to Reif the data in Table A1 show that, singly, neither smoking nor exposure to cadmium appears to be a carcinogen for renal cancer. Because actual value for the relative risk for the group exposed to both factors, 4.4, exceeds the control by 450 percent, Reif concluded that the data indicated a hypermultiplicative action of the two agents.

One way of incorporating this synergistic effect into the risk assessment calculations for HC smoke is to increase the potency value given in Table 6 for Cd by 4.4. Making this correction, $S = 29.26\ (\text{mg/kg-day})^{-1}$, from which $E_{max} = 3.42 \times 10^{-7}$ mg/kg-day, and $d_{max-mg} = 0.61$. Using this value of d_{max-mg}, $N_{max-pots}$ under stability class D is 12.2 and under stability class F is 1.36. The 2-year training risks given in Table 9 for smoke generating personnel from Cd alone become:

$$P^*_D = 21.48 \times 10^{-5} \text{ and}$$

$$P^*_F = 193.2 \times 10^{-5}$$

[31] A. E. Reif, "Synergism in Carcinogenesis," Journal of The National Cancer Institute, Vol 73 (1984), pp 25-39.

[32] L. N. Kolonel, "Association of Cadmium with Renal Cancer," Cancer, Vol 37 (1976), pp 1782-1787.

The total risks almost double:

$$(P_{total})_D = 34.15 \times 10^{-5}$$

$$(P_{total})_F = 304.92 \times 10^{-5}$$

A case controlled study by Lin and Kessler[33] showed that males in the dry cleaning business (primarily exposure to perchloroethylene [PERC]) or in occupations involving close exposure to gasoline, had up to five-fold increased risks for pancreatic cancer. As shown in Table A2, risk increased with duration of occupational exposure.

Lin and Kessler also identified a possible synergism in the production of pancreatic cancer resulting from perchloroethylene or gasoline exposure, coffee, and alcohol use, as shown in Table A3.

Incorporating the synergistic factors in Tables A2 and A3 would additionally increase the HC risk estimates.

[33]R. S. Lin and I. I. Kessler, Journal of the American Medical Association, Vol 245(2) (1981), pp 147-152.

Table A1

Relative Risks of Renal Cancer from Exposure to Cadmium and Cigarette Smoking*

Subjects	Relative Risk of Renal Cancer** Smokers	Nonsmokers	Smokers/Nonsmokers
Exposed to Cd	4.4	0.8	5.5
Controls	1.0	1.0	1.0
Cd exposed/controls		0.8	4.4

*From A. E. Reif, "Synergism in Carcinogenesis," Journal of The National Cancer Institute, Vol 73 (1984), pp 25-39, adapted from L. N. Kolonel, "Association of Cadmium with Renal Cancer," Cancer Vol 37 (1976), pp 1782-1787.

**Based on age-specific data.

Table A2

Relative Risk for Pancreatic Cancer Among Men by Occupational Exposure to Dry Cleaning Fluid and Gasoline*

Duration of Exposure, yr	Cases, No. (%)	Controls, No (%)	Relative Risk**
0	46 (67.2)	57 (85.1)	1.00
$\leq$ 2	4 (6.0)	3 (4.5)	1.69
3-5	3 (4.5)	3 (4.5)	1.27
6-10	3 (4.5)	1 (1.5)	3.80
>10	12 (17.9)	3 (4.5)	5.07***

*From A. E. Reif, "Synergism in Carcinogenesis," Journal of The National Cancer Institute, Vol 73 (1984), pp 25-39.
**Estimated from the odds ratio.
***Significantly increased above unity.

Table A3

Relative Risks of Pancreatic Cancer Among Male Subjects Exposed to a Variety of Risk Factors*

Number of Risk factors**	Cases No.	Controls No.	Relative Risks***
0	27	40	1.0
Any 1	25	23	1.6
Any 2	13	4	4.8‡
All 3	2	0	5.9‡

*From A. E. Reif, "Synergism in Carcinogenesis," Journal of The National Cancer Institute, Vol 73 (1984), pp 25-39.
**Risk factors: (1) occupational exposure to dry cleaning or gasoline derivatives; (2) drinking caffeine-free coffee; and (3) habitual wine drinking ($\geq$ 2 glasses per day).
***Estimated from the odds ratio.
‡Significantly increased above unity.

APPENDIX B: RELATED RISK ANALYSIS FOR THE COMPOUND PERCHLOROETHYLENE (PERC)

The purpose of this Appendix is to examine the effects of risk model selection on risk estimates. Tetrachloroethylene is used as a working example. Tetrachloroethylene, also called perchloroethylene (PCE or PERC), is a solvent used for about 75 percent of the dry cleaning in the United States. The potential for liver damage and other acute toxicity effects in humans is the basis for the occupational standard of 100 ppm of PERC in the air. Its chemical structure is similar to that of vinyl chloride monomer, a known human carcinogen, and there is some epidemiological evidence of higher cancer occurrence among dry cleaning workers. Perchloroethylene caused cancer when fed to mice. It is mutagenic in short-term tests.

Recently, Campbell et al.[34] used methods of decision analysis to develop a quantitative description of the cancer risks posed by PERC to dry cleaning workers, users of dry cleaning services, and members of the public who live or work near dry cleaning plants. Because PERC is also a constituent of HC smokes, it is instructive to compare the risks from PERC developed in HC smoke residue with the base case results from Campbell et al. Their data is summarized below.

In order to carry out the analysis, Campbell et al. obtained data on the dry cleaning plants' use of PERC (type of operation, number of plants, number of plants using PERC). Inhalation of vapors is the primary route of exposure to PERC; absorption through the skin is not considered significant.[35] The procedure of USEPA[36] and NIOSH[37] were used to determine exposure. This consisted of estimating the average exposure to each category of person under consideration and then estimating the number of people in each category. We consider here only workers and exclude other groups considered by Campbell et. al. (e.g., customers, community).

Exposure was estimated from measured air samples in dry cleaning facilities and from assumptions concerning the amount of time spent in the facilities. The annual average exposure (AAE) was calculated as:

$$AAE = \frac{(\text{Exposure level})(\text{Hours of Exposure per Year})}{8760 \text{ Hours per year}}$$

[34] G. L. Campbell, D. Cohan, and D. W. North, "The Application of Decision Analysis to Toxic Substances: Proposed Methodology and Two Case Studies," National Technical Information Service (NTIS) PB82-249103 (NTIS, Springfield, VA, 1982).

[35] R. E. Albert, et al., The Carcinogen Assessment Group's Carcinogenic Assessment of Tetrachloroethylene (Perchloroethylene) (1980).

[36] C. E. Anderson, et al., "Human Exposure to Atmospheric Concentrations of Selected Chemicals" (Prepared by Systems Applications, Inc. for USEPA Office of Air Quality Planning and Standards, 1980).

[37] H. R. Ludwig, "Occupational Exposure to Perchloroethylene in the Dry Cleaning Industry" (National Institute for Occupational Safety and Health, Cincinnati, OH, 1980).

and hours of exposure/year/worker = 40 hr/wk x 50 wk/yr = 2000 hr/yr. The annual average exposure gives somewhat higher cancer incidence estimates than would average lifetime exposure.

Using NIOSH data[38] from a survey of 44 commercial dry cleaners, Campbell et al. estimated that average exposures are 31 ppm (45 mg/m^3) for machine operators and 6 ppm (10 mg/m^3) for other workers. The data in Table B1[39] was used to calculate Table B2. Campbell et al. converted average concentrations to average daily dose by assuming an inhalation rate of 20 m^3 per 24 hr, a body weight of 70 kg, and 50 percent absorption.

In developing their approach, Campbell et al. tried to account for major sources of uncertainty in estimating the human health impact of a given level of PERC. Using two alternative cases for each of the questions, the sources of uncertainty were:

1. Should extrapolation from rodents to humans be based on surface area (SA), body weight (BW), or some other basis?

2. Should extrapolation be from the most sensitive species (mouse B6C3F1) or from a species (rat) metabolically more similar to humans?

3. Should a linear nonthreshold dose-response relationship be used or should a nonlinear or nonzero threshold relationship be used that is more representative of the hypothesis that PERC acts indirectly in causing mouse tumors through a cell toxicity mechanism?

Results for the base case are summarized in Table B3. This table pools the results for each category of worker given by Campbell et al. into three groups based on exposure: commercial and industrial "machine" operators; commercial and industrial "other" workers; and "machine" and "other" coin-op workers. The Table shows that scaling by SA gives higher risk values than does scaling by BW. Similarly, linear extrapolation gives higher (more conservative) estimates than does quadratic extrapolation. These transformations will operate in the same direction for any compound. Generally, the estimated risk from various transformations and models is:

Linear, SA > (Quadratic, SA; Linear, BW) > Quadratic, BW

The two groups in parantheses appear in variable order, as shown for the mouse versus rat in Table B3.

The slope of the regression through the origin of the expected lifetime incidence (ELI) on dose (mg/kg body weight/day) is an estimate of S, $\underline{S}$ (mg/kg-day)$^{-1}$: ELI = $\underline{S}$ (dose). From the surface area scaling and linear extrapolation of the mouse data, we obtained $\underline{S}$ = 0.037 (mg/kg-day)$^{-1}$, which is virtually identical with the value used in Table 9. The values of $\underline{S}$ used in

[38] H. R. Ludwig.

[39] S. J. Mara, E. Suta, and S. S. Lee, "Assessment of Human Exposures to Atmospheric Polyethylene" (Prepared by SRI for USEPA, Office of Air Quality Planning and Standards, 1979).

Table 9 were obtained by USEPA[40] (1980) using the most conservative scaling (SA) and extrapolation (quasi-linear). Hence, the risk estimates given in the study are also conservative. Effects of other types of scaling and extrapolation can be surmised from the above results.

[40] USEPA, "Water Quality Criteria Documents; Availability," USEPA Federal Register, Vol 45 (28 November 1980), pp 79318-79379.

Table B1

Number of Dry Cleaning Plants by Size of Operation

Number of Employees: Range	Number of Employees: Assumed Average	Number of Cleaning Plants: Commercial	Industrial	Coin-op
1-4	2	4194	16	3695
5-9	7	1906	11	499
10-19	14	846	18	119
20-49	30	691	98	57
50+	100	119	112	12
Estimated Average Number of Employees			8	603

Table B2

Estimated Number of Workers and PERC Exposure

Worker Category	Number of Workers	Average Annual Air Concentration mg/m^3	PERC Exposure* mg/kg/day
Machine Operators			
Commerical	16000	45	6.43
Industrial	700	45	6.43
Coin-Op	11000	6	0.86
Other Workers			
Commercial	110000	10	1.43
Industrial	20000	10	1.43
Coin-Op	22000	6	0.86

*Exposure = Air concentration x Inhalation volume x (body weight)$^{-1}$ x absorption coefficient:

$$6.43 = 45 \frac{mg}{m^3} \times 20 \frac{m^3}{day} \times 70 \frac{mg}{kg}^{-1} \times 0.5$$

Table B3

Expected Lifetime Incidence of Cancer from Exposure to PERC (from Tables in Campbell et al. 1982)

Group*	Expected lifetime incidence	Exposure (mg/kg)	**Scaling Surface=1 Weight=0	†Mode Linear=1 ††Quadratic=0	Number Exposed	†††Expected Cases
			Mouse			
Mach	0.2363	6.430	1	1	16700	[illegible]
Other	0.0353	0.857	1	1	33000	[illegible]
Coin	0.0582	1.430	1	1	130000	[illegible]
S	0.0370				Total	[illegible]
Mach	0.0669	6.430	1	0	16700	[illegible]
Other	0.0012[illegible]	0.857	1	0	33000	[illegible]
Coin	0.003413	1.430	1	0	130000	[illegible]
S	0.00988				Total	[illegible]
Mach	0.0201	6.430	0	1	16700	[illegible]
Other	0.002707	0.857	0	1	33000	[illegible]
Coin	0.004507	1.430	0	1	130000	[illegible]
S	0.00313				Total	[illegible]
Mach	0.000394	6.430	0	0	16700	[illegible]
Other	0.00001943	0.857	0	0	33000	[illegible]
Coin	0.000006998	1.430	0	0	130000	[illegible]
S	0.0000580				Total	[illegible]
			Rat			
Mach	0.007593	6.430	1	1	16700	[illegible]
Other	0.001016	0.857	1	1	33000	[illegible]
Coin	0.001692	1.430	1	1	130000	[illegible]
S	0.00118				Total	[illegible]
Mach	0.001132	6.430	1	0	16700	[illegible]
Other	0.0000202	0.857	1	0	33000	[illegible]
Coin	0.0000559	1.430	1	0	130000	[illegible]
S	0.000167				Total	[illegible]
Mach	0.001302	6.430	0	1	16700	[illegible]
Other	0.000174	0.857	0	1	33000	[illegible]
Coin	0.000290	1.430	0	1	130000	[illegible]
S	0.000203				Total	[illegible]
Mach	0.00003314	6.430	0	0	16700	[illegible]
Other	0.000000588	0.857	0	0	33000	[illegible]
Coin	0.00000164	1.430	0	0	130000	[illegible]
S	0.00001489				Total	[illegible]

*Group: Mach = commercial + industrial machine operators

Other = commercial + industrial other workers

Coin = machine + other coin-op workers

**Scaling: Surface = scaled by surface area (SA)

scaling factor: mouse -- $(70/0.03)^{1/3} = 13.26$

rat -- $(70/0.35)^{1/3} = 5.85$

***Weight scaled by body weight (BW)
dosages in mg/kg body weight/day are equivalent

†Model: Linear = linear extrapolation $[P(d) = 1 - \exp(-Ld)]$

L_{mouse} = 0.00316 (BW) 0.0419 (SA)

L_{rat} = 0.000203 (BW) 0.00119 (SA)

††Quadratic quadratic extrapolation $[P(d) = 1 - \exp(-Ld^2)]$

L_{mouse} = 9.52 E-06 (BW) 0.00167 (SA)

L_{rat} = 8.01 E-07 (BW) 2.74 E-05 (SA)

†††Expected Cases (Expected lifetime incidence) (number exposed) (70 [illegible]

APPENDIX C: RATIONALE FOR USING D_{max-mg} ESTIMATES FOR LIFETIME EXPOSURE TO ESTIMATE EFFECTS FROM SHORTER EXPOSURES

The risk assessment method described in this report might be faulted because of the assumption made about the toxic effects of d_{max-mg} given in a 2-year period rather than over a lifetime. Because of this, the degree of increased risk for developing cancer after exposure to the toxic chemicals in the smoke may be underestimated.

According to Doull, fractionation of a toxic agent almost always reduces toxicity. There are exceptions, however. It is well known that fractionation of radiation exposures produces varying effects, depending on the time between exposures. In some experiments of cellular mutation, fractionation increased mutation rates over single exposure rates. When the time between fractions was altered, mutation rates for fractionated exposures and single exposures were the same. For still other times, mutation rates for fractionated exposures were smaller than rates for single exposures for the same total dose. The factors responsible for this variation in response under different fractionation schemes are complex and not well understood.

Induction of cancer by chemicals also appears to be an exception to the generality. Both exceptions given by Casarett are relevant. The general rule presumes the body's metabolism or excretion serve as mechanisms for removal of the substance between administered doses. Also, it is presumed there is no effect or injury because none is detected, or injury, if produced, is completely reversed between administered doses. However, Druckrey and later Albert and Altshuler stated that the product of the daily dosage of carcinogen and time-to-tumor can be described by the formula $K = dt^n$, where K is a constant, d = dose, t = time, and n is greater than one. As noted by Littlefield et al., small doses can cause the same carcinogenic response as large doses if the time is extended and the time-to-tumor is decreased or shortened as the dosage is increased.

Unlike classical responses, division of a large dose of some carcinogens into smaller repeated doses does not abolish the response. With

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J. Doull, "Factors Influencing Toxicology," Chapter 5 In L. J. Casarett and J. Doull (Eds.), Toxicology. The Basic Science of Poisons (Macmillan Publishing Co., New York, 1975), pp 133-150.

L. J. Casarett, "Toxicologic Evaluation," Chapter 2 In L. J. Casarett and J. Doull (Eds.), Toxicology. The Basic Science of Poisons (Macmillan Publishing Co., New York, 1975), pp 11-25.

H. Druckrey, "Quantitative Aspects of Chemical Carcinogenesis," U.I.C.C. Monograph Series, Vol 7, In R. Truhaut (Ed.), Potential Carcinogenic Hazards from Drugs (Evaluation of Risk) (Springer-Verlag, New York, 1967), pp 60-78.

R. E. Albert and B. Altshuler, "Considerations Relating to the Formulation of Limits for Unavoidable Population Exposures to Environmental Carcinogens," In J. E. Ballou et al. (Eds.), Radionuclide Carcinogenesis, AEC Symposium Series, CONF-72050 (NTIS, Springfield, VA, 1973), pp 233-253.

N. A. Littlefield, J. H. Farmer, and D. W. Gaylor, "Effects of Dose and Time in a Long-Term, Low-Dose Carcinogenic Study," Journal of Environmental Pathology and Toxicology, Vol 3 (1979), pp 17-34.

dimethylaminobenzene, the total cumulative dose necessary for carcinogenesis with small daily doses is lower than the single dose required for an equivalent response. The size of the reported dose can be reduced further, resulting first in an increased latency for development and finally in no experimentally discernible response."

The largest data set which is available for studying the effect of serial dosing was conducted as part of the ED01 study with 2-acetylaminofluorene (2-AAF). Mice were dosed for 9, 12, and 15 months at exposures of 60, 75, 100, and 150 ppm (in feed), and sacrificed at 18 and 24 months. Exposures of 60 ppm for 15 months, 75 ppm for 12 months, and 100 ppm for 9 months, represent different fractionations of a total dose of 900 ppm-months. Incidences of bladder and liver neoplasms at 18 and 24 months (Table C1) did not differ for the various exposure schedules.

These results are in agreement with results from an extensive evaluation by Olson and Schaeffer of exposure-response data from carcinogenicity experiments using vinyl chloride (VC). They concluded that there is a population threshold for the carcinogenic action which is a function of exposure level, not duration level. This finding is consistent with the meaning of "threshold" and contrasts sharply with duration-dependent incidence rates.

The effect of dose fraction over 2 years versus 70 years is, therefore, not obvious. Although it is likely that a fractionation effect for exposure to HC smoke would result in an underestimate of the risk, it is more likely that Druckrey's model holds. Thus, if the incidence is dependent upon the total exposure and not its duration, rates will be the same after 2 years of high exposures or after a lifetime of low exposures.

H. Druckrey; R. E. Albert and B. Altschuler.

N. A. Littlefield, J. H. Farmer, and D. W. Gaylor.

N. A. Littlefield, J. H. Farmer, and D. W. Gaylor.

C. S. Olson and D. J. Schaeffer, "Application of the 'Filter Model' to a Risk Assessment for Vinyl Chloride," Journal of Toxicology Environmental Health, Vol 17 (1986), pp 25-39.

Table C1

Incidence of Bladder and Liver Neoplasms in Serially Dosed Mice

	Sacrifice Interval (Months)			
	Bladder		Liver	
Dose (ppm)	18	24	18	24*
60	1/196	0/114	4/96 (2.0%)	15/114 (13.2%)
75	0/130	0/86	5/130 (3.8%)	14/86 (16.3%)
100	0/64	1/35	1/64 (1.6%)	6/35 (17.2%)

*Chi-square for this set is 0.540 (P = 0.85).

APPENDIX D: AIR DISPERSION MODELING

By modeling the dispersion characteristics of toxic substances, we can relate the mass emitted by a smoke generator to the downwind dosages. The air dispersion model used in this study is the U.S. Army Material Development and Readiness Command model described in a DARCOM handbook.[50] This model uses Gaussian-type dispersion, which relies on Pasquill stability categories to characterize dispersion coefficients.

In Pasquill's[51] approach, stability is classified as a related function of wind speed and the radiation being received (or emitted) by the terrain. The stability categories are:

Surface Wind Speed (at 10m), m/sec	Day: Incoming Solar Radiation			Night or Cloud Cover	
	Strong	Moderate	Slight	>4/8	<3/8
<2	A	A-B	B		
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
>6	C	D	D	D	D

The basic equation for computing the axial dosage from a point or virtual point source is given by

$$D(x) = \frac{Q}{\pi \sigma_y \sigma_z u} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] + \sum_{i=1}^{n} \left\{ \exp\left[-\frac{1}{2}\left(\frac{2iH_m + H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{2iH_m - H}{\sigma_z}\right)^2\right] \right\}$$

where: $D(x)$ = axial dosage at the point x downwind (mg-min/m^3)

Q = source strength (mg)

σ_y or $\sigma_y(x)$ = standard deviation of crosswind concentration at x (m)

σ_z or $\sigma_z(x)$ = standard deviation of vertical concentration at x (m)

i = summation index

u = mean wind speed (m/min)

H_m = height of the surface mixing layer (m)

H = effective height of the source (m)

Handbook for Chemical Hazard Prediction.

F. A. Pasquill, "The Estimation of the Dispersion of Windborne Material," The Meteorological Magazine, Vol 90, No. 1063 (February 1961), pp 33-[illegible].

The σ_y^2 and σ_z^2 terms in the Gaussian diffusion model represent the variance of the concentration distribution in the y and z directions respectively. For practical use to be made of the diffusion formulas, values for the diffusion coefficients, σ_y and σ_z, must be determined empirically for various stability classes of the atmosphere.

The standard deviations, $\sigma_y(x)$, $\sigma_z(x)$, or σ_z are computed for the appropriate distance, x, as:

$$\sigma_y(x) = \sigma_{yr}\left(\frac{x + B}{x_{yr}}\right)^{\alpha}$$

$$\sigma_z(x) = \sigma_{zr}\left(\frac{x + C}{x_{zr}}\right)^{\beta}$$

where: σ_{yr}, σ_{zr} = reference sigma values at the distances x_{yr}, x_{zr}, respectively (m)

x_{yr}, x_{zr} = reference distances (100 m)

α = expansion coefficient in the crosswind direction (dimensionless)

β = expansion coefficient in the vertical direction (dimensionless)

B = virtual distance calculated for volume source (m)

$$= x_{yr}\left(\frac{\sigma_{ys}}{\sigma_{yr}}\right)^{1/\alpha}$$

σ_{ys} = standard deviation of initial source in the crosswind direction (m)

C = virtual distance calculated for volume source (m)

$$= x_{zr}\left(\frac{\sigma_{zs}}{\sigma_{zr}}\right)^{1/\beta}$$

σ_{zs} = standard deviation of initial source in vertical (m)

The recommended values for the diffusion parameters are shown in Table D1. As an example of the computions, consider exposure for D stability at 50 m. The values of the parameters are:

Parameter	Value	Source of Value
Q	1.35×10^7 mg	Table 1 (1 pot)
$Q_y(100)$	8.0 m	Table D1
Q_y (50)	4.1 m	Figure A.2.2 DARCOM Handbook
Q_z (100)	4.5 m	Table D1
Q_z (50)	2.2 m	Table A.2.3 DARCOM Handbook
μ	6 m/sec	Specified condition
H_m	200 m	Table E1, Summer
H	6.5 m	Effective source (initial Plume) Height

Under these conditions, the experimental terms in the summation are each zero. The computation becomes:

$$D_{(50)} = \frac{Q}{\pi \sigma_y \sigma_z \mu} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]$$

substituting the above values gives

$$D_{(50)} = \frac{1.36 \times 10^7}{(3.14)\ (4.1)\ (2.2)\ (6)} \exp - \frac{1}{2} \ \frac{6.5}{2.2}^2 = 1120 \text{ mg-sec/m}^3$$

The equations for dosage and diffusion parameters account for the presence ot an inversion aloft (mixing layer) at H_m; they provide for a full range of atmospheric stability classes ranging from the most unstable condition, category A, to the most stable, category F.

The vertical variations in wind velocity are described by the following empirical power law

$$u_z = u_r \left(\frac{Z}{Z_r}\right)^p$$

where: u_r = wind speed measured at height Z_r

Z = st :k height

p = wind profile exponent

The values of p are available for selected military installations at various stability classes (see Tables E1 and E2 in Appendix E). Also notable is that in the limit, as x--> ∞ , the dosage equation reverts to that of the "box" model, i.e.,

$$D(x) = \frac{Q}{\sqrt{2\pi}\sigma_y \cdot H_m \cdot u}$$

The model has provisions for correcting the predicted downwind dosages for finite source size, elevated release of the hazard, the presence of inversions aloft, and variable vertical wind speeds. All of these provisions were exercised in this modeling effort.

The Gaussian plume-Pasquill dispersion coefficient method provides modeling state-of-the-art best estimates of concentrations and dosages. Turner[52] has reported that the standard deviation of the vertical concentration σ_z may be expected to be correct within a factor of two. This is true for all stabilities for a few hundred meters downwind of the source, neutral to moderately unstable conditions for distances out to a few kilometers, unstable conditions in the lower 1000 meters of the atmosphere with a marked inversion above for distances out to 10 km or more. Model estimates under these conditions are reported to be correct to a factor of three, including errors due to σ_y and U uncertainties. Other error analyses suggest the results can be incorrect by up to a factor of 10. It is generally agreed, however, that Gaussian plume model overestimates the concentration and dosage.

Table D1

Recommended Values of Parameters
($x_{yr} = x_{zr}$ = 100 m)

Stability Category	σ_{yr} (10 min) (m)	σ_{zr} (m)	α (m)	β (m)
A	27.0	14.0	1.0	1.4
B	19.0	11.0	1.0	1.0
C	12.5	7.5	1.0	1.9
D	8.0	4.5	0.9	0.85
E	6.0	3.5	0.8	0.8
F	4.0	2.5	0.7	0.75

[52] D. B. Turner.

APPENDIX E: METEOROLOGICAL CONDITIONS

Fort Irwin is located in a semi-arid setting. Although information describing the climatological parameters is unavailable, it is assumed that meteorological conditions are not significantly different from other Army installations located in semi-arid and arid regions (e.g., Dugway, UT, and Pueblo, CO, Army Depots). Tables E1 and E2 give the meteorological parameters for these two installations. For example, the most stable condition, F, occurs 25.9 percent, 15.3 percent, 16 percent, and 22.9 percent of the time for winter, spring, summer, and fall seasons, respectively, at Pueblo. The corresponding numbers for Dugway are 19.4 percent, 17.8 percent, 18.0 percent, and 23.6 percent. The most common atmospheric condition at both installations is stability category D. It is interesting that the occurrence frequencies of the worst dispersion condition are very similar for the two installations. Given that Fort Irwin is also in a semi-arid climate, it is not unreasonable to assume that approximately the same frequency of extremely stable air also occurs there.

These stable conditions usually occur at nighttime and early morning. Radiational cooling in the desert is great, resulting in deep inversions during nighttime. The fluctuations are in the low mixing heights of 80 m under the F stability class and in the nighttime temperatures occurring with warm daytime weather. That is, because of the intensity of the nocturnal inversions, it is unlikely that the inversion "burns off" until midmorning. Therefore, it is very likely that the most common atmospheric stability class during the early morning hours is either E or F, and not D. The significance of this observation for our analysis is that the training maneuvers are generally carried out between dawn and 10:00 a.m.

Table E1

Meteorological Parameters for Dugway, UT, Army Depot*

Pasquill Stability Category	Percent Frequency of Occurrence	Median Wind Speed (m/sec)	Median Mixing Depth H_m(m)	Wind Profile Exponent p
		Winter		
A	0.1	0.9	540	0.05
B	2.3	1.1	540	0.10
C	6.7	2.6	377	0.15
D	55.4	4.1	215	0.20
E	16.2	2.9	100	0.25
F	19.4	1.4	50	0.30
		Spring		
A	1.3	1.6	2310	0.05
B	9.3	2.3	2310	0.10
C	14.9	3.7	1277	0.15
D	42.4	5.1	245	0.20
E	14.3	3.1	150	0.25
F	17.8	1.8	100	0.30
		Summer		
A	4.2	2.1	3625	0.05
B	11.4	2.8	3625	0.10
C	19.5	4.0	1892	0.15
D	30.5	5.0	200	0.20
E	16.3	3.4	100	0.25
F	18.0	2.1	80	0.30
		Fall		
A	0.2	0.9	1470	0.05
B	7.7	1.8	1470	0.10
C	12.4	3.5	845	0.15
D	37.7	4.9	220	0.20
E	18.4	3.4	100	0.25
F	23.6	1.9	80	0.30

*Data are indentical for the Tooele, UT, Army Depot.

Table E2

Meteorological Parameters for Pueblo, CO, Army Depot

Percent Pasquill Stability Category	Median Frequency of Occurrence	Median Wind Speed (m/sec)	Wind Mixing Depth H_m (m)	Profile Exponent p
		Winter		
A	0.0	0.0	--	0.05
B	3.4	1.2	1020	0.10
C	9.3	3.0	550	0.15
D	44.7	6.0	85	0.20
E	16.7	3.5	85	0.25
F	25.9	2.0	85	0.30
		Spring		
A	1.0	2.0	2780	0.05
B	8.4	2.6	2780	0.10
C	12.7	4.0	1480	0.15
D	50.3	6.6	185	0.20
E	12.3	4.0	185	0.25
F	15.3	2.1	185	0.30
		Summer		
A	2.8	2.1	3290	0.05
B	12.9	2.9	3290	0.10
C	15.0	4.5	1785	0.15
D	38.5	6.2	180	0.20
E	14.8	3.7	180	0.25
F	16.0	2.0	180	0.30
		Fall		
A	0.2	0.9	2010	0.05
B	7.8	2.2	2010	0.10
C	13.2	3.4	1050	0.15
D	39.9	5.3	95	0.20
E	16.0	3.9	95	0.25
F	22.9	2.1	95	0.30

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