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U.S. ARMY SOLDIER AND BIOLOGICAL CHEMICAL COMMAND

ECBC-TR-273

**TEST RESULTS
OF AIR-PERMEABLE CHARCOAL IMPREGNATED SUITS
TO CHALLENGE BY CHEMICAL AND
BIOLOGICAL WARFARE AGENTS AND SIMULANTS
EXECUTIVE SUMMARY**

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May 2003

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EXECUTIVE SUMMARY

As part of the Domestic Preparedness Program, five air-permeable charcoal impregnated suit designs were tested to assess their capability to protect in a "CW (chemical warfare) and BW (biological warfare)" agents environment. Swatches of material from each suit design were tested for resistance to permeation by Sarin (GB) and mustard (HD). From that data, the authors calculated the estimated time it would take for sufficient agent to permeate the suit to reach agent breakthrough criteria derived from limited physiological data. Each suit design was also tested for its protection factor in an aerosol environment. (aerosolized corn oil, which may be representative of a chemical or biological agent, was used). Protection factor (PF) is defined as the ratio between the challenge concentration outside the suit and the measured concentration inside the suit. The tests are described, and the calculated physiologically-derived breakthrough times and protection factors are presented.

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PREFACE

The work described in this report was authorized under the Expert Assistance (Equipment Test) Program for the U.S. Army Soldier and Biological Chemical Command (SBCCOM) Program Director for Domestic Preparedness. This work was started in November 1999 and completed in August 2000.

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TEST RESULTS
OF AIR-PERMEABLE CHARCOAL IMPREGNATED SUITS TO CHALLENGE
BY CHEMICAL AND BIOLOGICAL WARFARE AGENTS AND SIMULANTS:
EXECUTIVE SUMMARY

1. INTRODUCTION

In 1996, Congress passed Public Law 104-201 (Defense Against Weapons of Mass Destruction Act of 1996), directing the Department of Defense (DoD) to assist other federal, state, and local agencies in enhancing preparedness for terrorist attacks using weapons of mass destruction. The DoD responded by forming the Domestic Preparedness Program that same year. One of the objectives of the Domestic Preparedness Program is to enhance federal, state and local emergency and hazardous material (HAZMAT) response to nuclear, biological and chemical (NBC) terrorism incidents. As part of an effective response, emergency and HAZMAT personnel who are responding to an incident will use personal protective equipment (PPE) to protect them from exposure to chemical agents or biological agents. The specific PPE that would be used by these federal, state and local emergency and HAZMAT personnel would depend upon the situation encountered and what PPE is held in inventory. In some cases, air-permeable charcoal impregnated protective suits may be used to enter a contaminated or potentially contaminated area. Air-permeable charcoal impregnated protective suits are designed to protect the wearer's skin from chemical vapor. Recognizing this need, the U.S. Army Soldier and Biological Chemical Command (SBCCOM) established a program to test some of the air-permeable charcoal impregnated suit designs, using CW agents and test procedures developed for assessment of military-issue CW protective equipment. A detailed technical report was generated for each suit design tested, and a summary report was prepared that presented the essential results for all the suits in a single document. Because those reports are rather lengthy and technical, this report was prepared. This report is an overview of the results of the evaluation and this information is intended for federal, state and local emergency and HAZMAT personnel as an aid in their evaluation (and possible modification) of current work rules regarding specific air-permeable charcoal impregnated suits currently in inventory and as an aid in future procurement of appropriate air-permeable charcoal impregnated suits. This is especially important if these personnel choose to include military chemical agent protection as a criterion for purchase. This information supplements data and information provided by the suits' manufacturers. The suits were tested in new, as-received condition. The effects of aging, temperature extremes, laundering, and other factors are beyond the intended scope of this test program. These tests are conducted to assess percutaneous (i.e. skin) protection¹ only.

Each suit was examined in two different ways, called swatch tests and aerosol tests. In the swatch tests, sample swatches were cut from selected areas (the basic suit material, a

¹ Inhalation and ocular protection are typically provided by the use of a respirator that covers the eyes, nose and mouth.

suit seam, and at least four other areas that were dependent upon the suit configuration) of each suit design. These swatches were then exposed to the chemical agents Mustard (HD) and Sarin (GB), and the passage of agent through them measured. Sarin is a non-persistent (volatile) nerve agent, and HD is a persistent blister agent. In the aerosol tests, each suit design was donned by volunteer testers, who carried out a prescribed sequence of movements inside a test chamber containing a controlled aerosol of corn oil that is a non-toxic simulant for chemical and biological agent aerosols. Instrumentation continuously measured the concentration of simulant inside the suit. Each of these tests examined different aspects of the protection provided by the suits.

Protection provided by a suit system may vary from one unit to another, due to variations in body size and shape affecting the suit's fit; and from one occasion to another, due to unavoidable differences in the execution of the prescribed movements. For these reasons, each suit system design was subjected to multiple test repetitions, using a number of different sample suits, volunteer testers, and occasions.

2. LIQUID CHALLENGE/VAPOR PERMEATION TEST (SWATCH TEST)

Three swatches were taken from a minimum of six different areas of the suit or ensemble – at least 18 total swatches per suit design for GB and at least 18 others for HD. The swatches were placed in a test fixture and a predetermined (10 g/m^2) liquid agent challenge, GB or HD, was applied to the top surface of each swatch, and the fixture sealed. Periodically, over 24 hr, gas samples were taken from below the swatches. The amount of agent vapor that permeated the test swatch at each sampling time was measured using a highly sensitive, accurate, miniaturized gas chromatograph and sampling system known as MINICAMS™ (OI Analytical, CMS Field Products Group, Birmingham, AL).

The cumulative mass of agent vapor, which has permeated each of the swatches at each sampling time, divided by the area of the swatch, is defined as the permeation, M_f .

The permeation for each suit design tested was compared with other suit designs. Normally, continuous exposure to chemical agent would not exceed 8 hr (480 min) because the responder needs to be concerned with heat stress and fatigue.

An average cumulative permeation value (M_f) for each suit design and agent combination was calculated by averaging the M_f values for the 18 swatches.

The permeation will typically vary greatly from one area of a suit to the next, because of differences in materials and thickness. A composite average permeation value was calculated by assigning a weighting factor to the permeation value for each swatch, roughly proportional to the actual area on the suit system that the swatch represents. This resulted in a calculated overall permeation for each suit design.

Mustard vapor can produce skin irritation (erythema) at dosages (product of concentration and exposure time) of approximately 100 mg-min/cm³. Sarin vapor can produce incapacitation at dosages of approximately 8000 mg-min/m³. These dosages were set as limits, and the average time to reach each of the limits was calculated using the weighted values of the swatch test results, and this average time was designated the "physiologically-derived breakthrough time" for the suit, under the specific test conditions.

The calculated breakthrough times from all the suit swatches were collected and presented in Table 1.

Table 1. Swatch Test Results for Suits

Test Item	Breakthrough time, minutes	
	GB incapacitation	HD erythema
LANX Chemical Protective Undergarment Ensemble	>480	71
LANX Chemical Protective Overgarment	>480	161
Giat Tactical Operations Multipurpose Protective Suit	>480	342
Giat NBC SWAT Suit	>480	>480
Giat UNISCAPH Undergarment	>480	>480

3. SYSTEM TEST (AEROSOL SIMULANT)

This test measured the leakage of a challenge corn-oil aerosol (physical simulant for biological or chemical aerosol) into a suit ensemble while people were wearing ensembles of different sizes. Volunteers dressed in air-permeable suits with self-contained breathing apparatus (SCBA) entered a chamber with aerosol simulant. Instrumentation measured any aerosol leakage (presumed to be penetration) into the suit through gaps between ensemble components. During the test, the people in the suits performed standardized pre-operational movements.

Eight suits of each design were worn by 12 volunteers on each of two days (not necessarily the same 12 on both days), for a total of at least 22 trials for each suit design. Thus not all of the volunteers or suit replicates were used in equal numbers of trials to accomplish the tests. Only pre-operational routines were run for these suits. See Table 2.

Table 2. Aerosol Test Exercise Routine

Test	Description of Exercise
Pre-Operational – Each exercise performed for 1 min.	1) Standing still, normal breathing
	2) Bending forward and touching toes
	3) Jogging in place
	4) Raising arms above head and looking upward
	5) Bending knees and squatting
	6) Crawling on hands and knees
	7) Torso twists with hands folded on chest
	8) Standing still, normal breathing

Protection Factor (PF) testing of permeable suits was only completed in the pre-operational exercise scenario. From this test a protection factor (PF) is derived. In simplest terms, PF is a measure of the challenge concentration outside the suit divided by the concentration inside the suit ensemble. For example, if the concentration of aerosol inside the suit ensemble is found to be 1/10th the value of the average concentration outside the suit ensemble, the PF is equal to 10. The operational test scenario was not run on these suits due to the low PF values achieved in the pre-operational exercise scenario. Permeable suits are designed to filter and react with chemical agents through absorption by the carbon-impregnated cloth. They are designed to trap agent vapors while allowing moisture to escape.

Samples of aerosol are taken continuously at the neck area and upper arm within the suit and their concentrations are measured by laser photometry, recorded in a computer file and displayed continuously on a computer monitor. These sampling locations were selected as being the most likely locations for aerosol leakage to occur. Therefore the PF is thought to be the worst-case estimation. The PF data are presented based upon predetermined PF pass levels, ranging from 2 to 100,000 (i.e., at each pass level the number of failing and passing suits is recorded). The higher the percentage of test runs that pass at a given PF, the greater the probability that the suit will provide that level of protection in use. These levels are point estimates and are derived from Army requirements. The results are given in Table 3.

Table 3. Summary of Overall Aerosol Test Results

Item	Aerosol PF Pass Rate Per Cent at PF Equal to:		
	2	5	10
	Pre-Operational	Pre-Operational	Pre-Operational
LANX Chemical Protective Undergarment	91	11	0
LANX Chemical Protective Overgarment	91	11	0
Giat Tactical Operations Multipurpose Protective Suit	93	48	0
Giat NBC SWAT Suit	73	34	5
Giat UNISCAPH Undergarment	90	12	0

4. CONCLUSIONS

The test data reveals that the air-permeable charcoal impregnated protective suit materials tested can protect the wearers from liquid CW agents but that the suits only provide minimal protection from a vapor or aerosol threat. Breakthrough times should not be interpreted as the time that a suit can be safely worn, either for HD or GB. Breakthrough times should only be used to compare suit materials. In other words, the suit material does provide limited skin protection, but the suit itself provides little or no skin protection.



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- Leo F. Saubier, Battelle Memorial Institute, Edgewood Operations, Edgewood, MD

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**TEST RESULTS
OF AIR-PERMEABLE CHARCOAL IMPREGNATED SUITS
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BIOLOGICAL WARFARE AGENTS AND SIMULANTS:
SUMMARY REPORT**

1. INTRODUCTION

In 1996, Congress passed Public Law 104-201 (Defense Against Weapons of Mass Destruction Act of 1996), directing the Department of Defense (DoD) to assist other federal, state, and local agencies in enhancing preparedness for terrorist attacks using weapons of mass destruction. The DoD responded by forming the Domestic Preparedness Program that same year. One of the objectives of the Domestic Preparedness Program is to enhance federal, state and local emergency and hazardous material (HAZMAT) response to nuclear, biological and chemical (NBC) terrorism incidents. As part of an effective response, emergency and HAZMAT personnel who are responding to an incident will use personal protective equipment (PPE) to protect them from exposure to chemical agents or biological agents. The specific PPE that would be used by these federal, state and local emergency and HAZMAT personnel would depend upon the situation encountered and what PPE is held in inventory. In some cases, air-permeable charcoal impregnated protective suits may be used to enter a contaminated or potentially contaminated area. Air-permeable charcoal impregnated protective suits are designed to protect the wearer's skin from chemical vapor.

2. OBJECTIVES

This study evaluates some commonly used and commercially available air-permeable charcoal impregnated suits to assess how well they resist vapor permeation from liquid contamination¹ by chemical agents Sarin (GB) and Mustard (HD) and droplet penetration by a corn-oil aerosol used to simulate biological or chemical particulates from 0.4 to 5 μm in diameter (typical military standard for the possible threat). This information is intended for federal, state and local emergency and HAZMAT personnel as an aid in their evaluation (and possible modification) of current work rules regarding specific air-permeable charcoal impregnated suits currently in inventory and as an aid in future procurement of appropriate air-permeable charcoal impregnated suits. This is especially important if these personnel choose to include military chemical agent protection as a criterion for purchase. This information supplements data and information provided by the suits' manufacturers. The suits were tested in new, as-received condition. The effects of aging, temperature extremes, laundering, and other factors are beyond the intended scope of this test program. These tests are conducted to assess percutaneous (i.e. skin) protection² only.

3. TESTING AND DATA ANALYSIS

3.1 Testing Overview

The air-permeable charcoal impregnated suits that were tested in this program are listed in Table 1. Permeation tests of material swatches were conducted to measure the

¹ Throughout this report the term permeation is used even though for some of the tests the precise mechanism of agent transfer is not determined and penetration is likely to be involved also.

² Inhalation and ocular protection are typically provided by the use of a respirator that covers the eyes, nose and mouth.

permeation of both GB and HD through the suit materials. Tests were also conducted to measure the total aerosol leakage into the suits when worn as part of a complete PPE system.

Table 1. Suits Tested

Model	Manufacturer	Address
LANX Chemical Protective Undergarment Ensemble	LANX Fabric Systems	Newark, DE
LANX Chemical Protective Overgarment	LANX Fabric Systems	Newark, DE
Giat Tactical Operations Multipurpose Protective Suit	Centech Group, Inc.	Fairfax, VA
Giat NBC SWAT Suit	Centech Group, Inc.	Fairfax, VA
Giat Uniscaph Undergarment	Centech Group, Inc.	Fairfax, VA

3.2 Liquid Challenge/Vapor Permeation Testing (Agent Swatch Testing)

3.2.1 Liquid Challenge/Vapor Permeation Testing Procedures

This testing was conducted to measure the permeation of chemical agents GB and HD through suit swatches over a 24-hr period. The test was intended to assess how well the suit materials and seams resist agent permeation. The amount of agent applied and duration of exposure do not represent any particular threat that responders may encounter, but they do serve as a common point of reference for all test results.

The test methodology was taken from TOP 8-2-501³ and is described in Appendix A. Air permeability is determined using a Frazier low-pressure air permeability machine, (serial number 961). The minimum air permeability for use of this test procedure is 20 cm³/min/cm². Three swatches were taken from a minimum of six different areas of the suit or ensemble – at least 18 total swatches per suit design for GB and at least 18 others for HD. Undergarment swatches were tested under a swatch of an outer fabric layer (Cloth, Chambray, Cotton (Flame Retardant), MIL-C-24916 (military specification for chambray cloth)) to approximate an actual wear scenario; undergarments are normally worn underneath the outer clothing. In addition, swatches were taken from a Marine Corps Saratoga suit (Suit, Chemical and Biological Protective (Carbon Sphere)), referred to as Saratoga swatches⁴. For each test the six swatches taken from a suit and one Saratoga swatch were placed in test cells; one swatch per test cell. Laboratory personnel applied a predetermined liquid agent challenge (10 g/m²) to the top surface of each swatch. Agent droplets were applied to the surface of the first swatch at time zero. Agent was applied to the surface of each succeeding swatch at 3-min intervals. The convection tower is connected to the upper chamber of each test cell and a flow of air, from the clean air manifold, sufficient to maintain a differential pressure of 0.1 inch of water is drawn through the swatch into the lower test cell chamber. The air then passes through the lower test cell chamber

³ Test Operations Procedure (TOP) 8-2-501, Permeation and Penetration of Air-Permeable, Semipermeable and Impermeable Materials with Chemical Agents or Simulants (Swatch Testing). U.S. Army Dugway Proving Ground, UT. 3 March 1997, UNCLASSIFIED Report (AD A322329).

⁴ Originally, it was intended to use Saratoga swatches as references or controls, but it was soon found that permeation through the Saratoga varied too widely for it to be used for that purpose. Saratoga swatches were used anyway, because they serve as a reliable source of agent vapor to assure the tester that the MINICAMSTTM was responding properly during tests when little or no agent permeates the actual test swatches.

outlet and through Teflon tubing to the sampling tee located prior to the linear mass flow controller and vacuum manifold.

During the 24-hr test period, gas samples are taken on a sequential basis by a laboratory MINICAMS™ (OI Analytical, CMS Field Products Group, Birmingham, AL) with stream selection system (a miniaturized gas chromatograph with flame photometric detector and sampling system) from the air stream at each sampling tee. Gas sampling by the MINICAMS™ begins for the first swatch approximately 3 min following agent application. Subsequent 3-min cycles of the MINICAMS™ are composed of 2 min of desorption of collected agent vapor from the pre-concentrator tube (PCT) onto the miniaturized gas chromatograph (GC) column followed by 1 min of gas sampling (collection of agent vapor in the PCT). Sampling is done sequentially through six swatches (three from one sampling area followed by three from a second sampling area), the Saratoga swatch, and then three blank gas samples are taken from the test cabinet to purge the MINICAMS™ before repeating the sampling sequence. The six swatches, the Saratoga swatch, and three blanks are all sampled for the first time within the first 30 min of the test start. Then the sampling sequence begins anew.

The MINICAMS™ first determines the weight of agent vapor in each gas sample. Using this result, the weight (ng) of the agent vapor present in the air stream that passes through the swatch over the time from the previous gas sample to the current gas sample is determined by the MINICAMS™ permeation software. The calculations assume that the permeation doesn't change with time over 30 minutes. The permeation for each time interval is the average of the permeation rates (flux, ng/cm²/min) for the current and previous gas samples multiplied by 30 min. This amount of agent vapor is presumed to be the amount that has permeated the swatch over that time interval. The cumulative mass of agent permeating the swatch per unit area at any elapsed time during the 24-hr test is defined as M_f . It is based on the mass permeated in the time interval over the effective swatch area, which is the opening in the permeation cell (10 cm²), and is determined by the MINICAMS™ permeation software. Over the 24-hr test period, a series of M_f values is calculated for each swatch.

3.2.2 Liquid Challenge/Vapor Permeation Testing Analysis.

Each suit yielded M_f data for 21 swatches (with the exception of 18 swatches for the LANX overgarment ensemble and 15 swatches for the Giat UNISCAPH undergarment) for each of the two agents over the 24-hr test period. The M_f data were taken for each of the three swatches from one of the seven (six for LANX overgarment and five for Giat UNISCAPH undergarment) sampling areas (see equation 1). For this report, the average (of three swatches) cumulative permeation (M_f) was calculated for each suit area. This average was then presented, at each of the reported elapsed times, as representative of the suit's permeation resistance at that sampling area. The reported elapsed time for each sampling area was the sum of the elapsed times for the three swatches divided by three. For each suit tested, swatches were taken from a single suit.

To estimate M_f at each elapsed time for a suit, the simplifying assumption was that the exposure was uniform over the entire suit. This permitted the use of the weighting factor scheme developed by Belmonte⁵ to determine the weighted average M_f over the entire suit at

⁵ Belmonte, R.B., *Test Results of Level A Suits to Challenge by Chemical and Biological Warfare Agents and Simulants: Summary Report*, ERDEC-TR-513, U.S. Army Edgewood Research, Development and Engineering Center, Aberdeen Proving Ground, MD, August 1998, UNCLASSIFIED Report (AD A353013).

each average elapsed time. The average elapsed time was the sum of the reported elapsed times for all the sampling areas divided by the number of sampling areas. The weighting factors shown in Table 2 were assigned roughly on the basis of surface area assigning a minimum assigned value of 5%. Swatches were not necessarily taken from exactly the same locations for all suits because the suit configurations differed. Note that all suits have the same components. The weighted average M_f at any average elapsed time was calculated using an equation similar to equation 1 (using the LANX Chemical Protective Undergarment Ensemble weighting factors for this example):

$\begin{aligned} \text{Weighted average } M_f = & 0.4(\text{chest area } M_f) + \\ & 0.35(\text{thigh area } M_f) + \\ & 0.05(\text{upper arm seam } M_f) + \\ & 0.05(\text{lower leg seam } M_f) + \\ & 0.05(\text{crotch area } M_f) + \\ & 0.05(\text{glove liner seam } M_f) + \\ & 0.05(\text{boot liner seam } M_f) \end{aligned}$	Equation 1
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The Saratoga swatch data is reported as average M_f , grouped by suit with which the Saratoga swatches were tested.

Table 2. Weighting Factors For Each Sampling Area by Suit

Weighting Factor, Percent, for Each Sampling Area								
Suit Model	Chest Area	Thigh Area	Upper Arm Seam	Lower Leg Seam	Crotch Area	Glove Liner Seam	Boot Liner (Sock) Seam	Glove Seam
LANX Chemical Protective Undergarment Ensemble	40	35	5	5	5	5	5	-
LANX Chemical Protective Overgarment	40	40	5	5	5	-	-	5
Giat TOMPS	40	35	5	5	5	-	5	5
Giat NBC SWAT Suit	40	35	5	5	5	-	5	5
Giat Uniscaph Undergarment	40	40	5	5	10	-	-	-

3.2.3 Relationship Between Liquid Challenge/Vapor Permeation Test Results and Skin Exposure.

The permeation test was designed to distinguish among these material swatches according to their permeation resistance to chemical agents. It was not intended to specifically replicate threat scenarios that may be encountered in actual use. As previously reported by Belmonte⁵, it was instructive to estimate the agent dosage ($C_{i,skin}$) that would result from such a standard agent challenge as a relative indication of possible physiological effects. This was done by converting the weighted average M_f s to equivalent agent dosages. This relationship was developed by Paul Fedele (written communication, Dr. P. Fedele, R&T Directorate, ERDEC, July 1997) and was reported by Belmonte⁵. For suit materials permeable to airflow, the equation is:

$$C_I T_{skin} = \{M_f(P_f + q/A)\} / \{(q/A + q^*/A)(P_f + P_s + q/A)\} \quad \text{Equation 2}$$

where P_f is fabric permeability to agent, q is the airflow through the fabric, q^* is the airflow added beneath the fabric, A is the area of fabric exposed to agent and P_s is the skin permeability to agent. For the convective permeation test, $q^* = 0$. The air flow through the fabric was controlled to maintain a pressure drop of 0.1 in water so q/A is the fabric air permeability (P_a). The equation becomes:

$$C_I T_{skin} = M_f(P_f + P_a) / P_a(P_f + P_s + P_a) \quad \text{Equation 3}$$

P_a must be equal to or greater than 20 cm/min for the convective permeation test to be used. If a fabric provides good protection, P_f is small. P_s is 2.0 cm/min for HD and 0.1 cm/min for GB; small relative to P_a . The equation becomes:

$$C_I T_{skin} = M_f / P_a \quad \text{Equation 4}$$

This approach was reviewed by Fedele and found to be a good approximation (written communication, Dr. P. Fedele, Engineering Dir, ECBC, 29 Mar 00). The agent dosage can then be compared to doses that are known to cause certain levels of toxicity. The simplifying assumption was that skin permeability is constant over all regions of the body.

3.2.4 Evaluation Criteria for Liquid Challenge/Vapor Permeation Test Results.

When analyzing the test results, it is useful to determine whether the data indicate that the air-permeable suit provides percutaneous (i.e. skin) protection over some period of time. Mustard vapor can produce erythema⁶ (reddening of the skin, certain body regions) at dosages of approximately 100 mg-min/m³, and can produce vesication (skin burns and blisters, certain body regions) at 200 mg-min/m³. Sarin vapor can produce incapacitation⁶ (twitching, convulsions or loss of consciousness) at unprotected, percutaneous dosages of approximately 8000 mg-min/m³ and can be lethal at unprotected, percutaneous dosages of 15000 mg-min/m³ where exposed persons are healthy, young, fit, and well-nourished males of approximately 70-kg mass. People, who are smaller, less fit, etc., may exhibit adverse effects at lower doses ($C_{i,skin}$). The simplifying assumption was that the suit was exposed to a uniform liquid GB challenge over its entire surface, resulting in a uniform exposure of all body regions to GB vapor. Therefore, the amount of agent per unit area (weighted average M_f) necessary to permeate the suit to produce a predetermined physiological effect was estimated by using each of the above dosages and that suit's fabric air permeability (P_a). These values are used in the graphs of weighted average M_f versus time given in Appendixes C through H and summarized in Table 3. The critical breakthrough dosages, used to calculate threshold $M_{f,s}$, are considered to be 100 mg-min/m³ for HD (reddening of skin) and 8000 mg-min/m³ for GB (incapacitation – twitching, convulsions, or loss of consciousness). A breakthrough time is the time when the weighted average M_f equals the threshold M_f calculated from equation 4.

⁶ Belmonte, R.B., *Test Results of Level A Suits to Challenge by Chemical and Biological Warfare Agents and Simulants: Summary Report*, ERDEC-TR-513, U.S. Army Edgewood Research, Development and Engineering Center, Aberdeen Proving Ground, MD, August 1998, UNCLASSIFIED Report (AD A353013).

Table 3. Agent Breakthrough Criteria

Suit	Agent	Breakthrough Dosage (mg-min/m ³)	Physiological Effect	Fabric Air Permeability (P _a) at 0.1" water, (cm/min)	Threshold M _t (ng/cm ²)
Cover Fabric/ LANX Undergarment	HD	100	Erythema	101	10100
	HD	200	Vesication	101	20200
	GB	8000	Incapacitation	101	808000
	GB	15000	Lethality	101	1515000
LANX Overgarment	HD	100	Erythema	28	2800
	HD	200	Vesication	28	5600
	GB	8000	Incapacitation	28	224000
	GB	15000	Lethality	28	420000
Giat TOMPS	HD	100	Erythema	225	22500
	HD	200	Vesication	225	45000
	GB	8000	Incapacitation	225	1800000
	GB	15000	Lethality	225	3375000
Giat NBC SWAT Suit	HD	100	Erythema	329	32900
	HD	200	Vesication	329	75800
	GB	8000	Incapacitation	329	3120000
	GB	15000	Lethality	329	4935000
Cover Fabric/Giat Uniscaph Undergarment	HD	100	Erythema	571	57100
	HD	200	Vesication	571	114200
	GB	8000	Incapacitation	571	4568000
	GB	15000	Lethality	571	8565000

Breakthrough time should not be interpreted as the time that a suit can be safely worn, either for HD or GB. Breakthrough times should only be used to compare suit materials.

3.3 System Test (Aerosol Simulant)

3.3.1 Aerosol Simulant Test Procedures.

The testing was conducted to determine leakage of a challenge corn-oil aerosol (physical simulant of a biological or chemical agent aerosol) into a suit ensemble while people were wearing ensembles of different sizes. Volunteers dressed in air-permeable suits with self-contained breathing apparatus (SCBA) entered a chamber with aerosol simulant. Instrumentation measured any aerosol leakage (presumed to be penetration) into the suit through gaps between ensemble components. During the test, the people in the suits performed standardized movements. A brief description of the test and movements made by the people during the test are given in Appendix B. Five different ensembles, listed in Table 1, page 12, were tested. Eight suits of each design were worn by 12 volunteers on each of two days (not necessarily the same 12 on both days), for a total of at least 22 trials for each suit design. Thus not all of the volunteers or suit replicates were used in equal numbers of trials to accomplish the tests. Only pre-operational routines were run for these suits.

Protection Factor (PF) Testing of permeable suits was only completed in the pre-operational exercise scenario. From this test a protection factor (PF) is derived. In simplest terms, PF is a measure of the challenge concentration outside the suit divided by the concentration inside the suit ensemble. For example, if the concentration of aerosol inside the suit ensemble is found to be 1/10th the value of the average concentration outside the suit ensemble, the PF is equal to 10. The operational test scenario was not run on these suits due to the low PF values achieved in the pre-operational exercise scenario. Permeable suits are designed to filter and react with chemical agents through absorption by the carbon-impregnated cloth. They are designed to trap agent vapors while allowing moisture to escape.

3.3.2 Aerosol Simulant Analysis.

Samples of aerosol are taken continuously at the neck area and upper arm within the suit and their concentrations are measured by laser photometry, recorded in a computer file and displayed continuously on a computer monitor. These sampling locations were selected as being the most likely locations for aerosol leakage to occur. Therefore the PF is thought to be the worst-case estimation.

The PF data are presented based upon predetermined PF pass levels, ranging from 2 to 100,000 (i.e., at each pass level the number of failing and passing suits is recorded). The higher the percentage of test runs that pass at a given PF, the greater the probability that the suit will provide that level of protection in use. These levels are point estimates and are derived from Army requirements.

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ACRONYMS and ABBREVIATIONS

A	Surface area of fabric exposed to agent
Ct	Cumulative vapor exposure, product of vapor concentration (mg/m ³) and time (minutes)
C _t _{skin}	Cumulative vapor exposure to skin
cm ²	Square centimeters
CW	Chemical warfare
°F	Temperature in degrees Fahrenheit
delta p	Differential pressure
DoD	Department of Defense
ECBC	U.S. Army Edgewood Chemical Biological Center
ERDEC	U. S. Army Edgewood Research Development and Engineering Center
g	Gram
GB	Sarin, Isopropylmethylphosphonofluoridate
GC	Gas chromatograph
HAZMAT	Hazardous material
HD	Sulfur Mustard; 2,2'-Dichlorodiethylsulfide
L	Liter
M _f	Cumulative mass permeation through the fabric
m ²	Square meters
m ³	Cubic meters
mg	Milligram
μL	Microliter
ng	Nanogram
NBC	Nuclear, Biological and Chemical
PCT	Pre-concentrator tube
PF	Protection factor
PPE	Personal Protective Equipment
P _a	Fabric air permeability
P _f	Fabric agent permeability
P _s	Skin permeability
q	Airflow through fabric, cubic centimeters/min
Q*	Air flow added beneath fabric, cubic centimeters/min
RH	Relative Humidity
SBCCOM	U. S. Army Soldier and Biological Chemical Command
SCBA	Self-contained breathing apparatus
TOMPS	Tactical Operational Multipurpose Protective Suit
TOP	Test Operations Procedure

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Appendix A

Modified Convective Permeation Test Procedure

This test procedure was adapted from Test Operations Procedure (TOP) 8-2-501, Permeation and Penetration of Air-Permeable, Semipermeable and Impermeable Materials with Chemical Agents or Simulants (Swatch Testing). U.S. Army Dugway Proving Ground, UT. 3 March 1997, UNCLASSIFIED Report (AD A322329).

1. Upon receipt of an item, all available information will be recorded; date of manufacture, lot number, serial number, materials of construction, etc. Digital pictures will be taken of the label(s) and packaging (if any).

2. From each overgarment, two six-inch diameter material swatches shall be cut; one from the front chest/abdominal area and one from the front thigh area. These swatches will be tested for air permeability IAW para 3.2 of TOP 8-2-501 and the results averaged. For undergarments, an equal number of like-sized swatches will be cut from the undergarment (same locations as above) and from the clothing (e.g. police uniform, firefighter's bunker gear) worn over the undergarment. Air permeability will then be determined on the outer clothing/undergarment swatch ensemble, layered as worn. The average air permeability must be greater than $20 \text{ cm}^3/\text{min}/\text{cm}^2$ at 0.1-inch water for the convective permeation procedure to be used.

3. From each overgarment, three 1 and 15/16-inch diameter material swatches will be taken from the chest area and 3 like diameter material swatches will be taken from the thigh area, adjacent to the air permeability swatch locations, for HD. The same number of material swatches from the same locations will be taken for GB. Depending upon the overgarment configuration, 3 seam swatches (same diameter) will be taken from the upper arm, 3 seam swatches will be taken from the lower leg and 3 swatches, including at least one seam, will be taken from the crotch area for HD and an equal number for GB. If a hood, socks or gloves are present; 3 seam swatches will be taken from each item for HD and 3 for GB. Each swatch will be placed in an airtight bag and given a unique serial number, which will be placed on the bag. A list of serial numbers will be kept with the swatches. For undergarments, an equal number of like-sized swatches will be cut from the undergarment (same locations as above) and from the clothing worn over the undergarment. The outer clothing/undergarment swatch ensemble will be layered as worn and stored as above.

4. The environmental chamber will be controlled at a temperature of $90 \pm 2^\circ \text{F}$. The temperature will be checked weekly with a calibrated meter. The test cell air will be drawn from a manifold supplied with clean air (flow set at 20-30 L/min, excess vented into the test cabinet) from the Miller-Nelson unit set at 90°F and 80 % RH. There will be no system control and data acquisition system due to budget constraints. The cabinet temperature will be recorded in a computer file. The temperature and RH of the test cell air will be manually recorded.

5. The TOP test cell with convective permeation tower will be used. When assembling, the cell lugs will be tightened by hand to finger tight. The conditioned air will flow from the

manifold into the top of the tower, through each swatch and will exit the bottom of the cell. For each cell, the port on the side of the tower and the tee at the cell exit will be connected to a differential pressure gage. The flow rate from each cell will be controlled with a linear mass flow controller connected to the vacuum manifold. Each flow rate will be set to a value that yields a 0.1-inch water reading on the differential pressure gage. The gage readings will be checked with a calibrated differential pressure meter weekly. Flow rates will be manually recorded.

6. Each test cell will be checked for leaks after assembly by connecting it to the vacuum source and checking that the inlet flow is the same as the outlet flow on the mass flow controller (cell lugs will be retightened if flows don't match).

7. The sample swatches will serve as their own negative controls while being preconditioned for 2 hours prior to agent contamination and monitored by MINICAMS. A Saratoga material swatch will be used as a positive control for each test (6 test swatches and 1 Saratoga swatch). To establish a baseline, at least 2 tests using Saratoga control material only (14 swatches) will be conducted with HD and 2 tests will be conducted with GB prior to commencement of testing.

8. Agents GB and HD will be used. The contamination density will be 10 g/m^2 (eight 1 microliter HD droplets or ten 1 microliter GB droplets). A robotic agent application system is not available due to budget constraints. The agent will be applied using the click/touch method with a Hamilton repeating dispenser. The contamination density will be checked each test day by placing 10 droplets into a pre-weighed flask or vial containing appropriate solvent, weighing the vial or flask on a calibrated balance and calculating the average droplet weight. Alternatively, one droplet may be placed into a vial containing appropriate solvent and the amount of agent in the droplet determined by an appropriate analytical procedure such as gas chromatography.

9. Seven swatches will be tested at once. MINICAMS with stream selection system will monitor vapor permeation with a 3-minute cycle. There will be 3 blank sampling intervals following the positive control swatch. Each swatch will be sampled once every 30 minutes. The MINICAMS will be standardized weekly.

10. The test length will be 10 hours; 2 hours for conditioning and 8 hours after agent contamination. Each swatch shall complete 4 MINICAMS sampling cycles prior to contamination.

11. The test cells and o-rings will be aerated for at least 24 hours between uses. No other cleaning method will be used. O-rings will be completely replaced on a weekly basis.

12. The data to be reported are cumulative permeation (ng/cm^2) versus elapsed time (minutes) and Ct (cumulative mass/flow rate, ng-min/cm^3) versus elapsed time for each swatch. All recorded data will be placed in laboratory notebooks and a technical report will be drafted at the conclusion of this effort.

Appendix B

Aerosol Simulant Test Procedure

To properly test suits with statistical significance, eight suit ensembles of each model are provided to the Mask Fit Test Facility for examination. Each ensemble is new and inspected as received. The suit ensembles include relevant accessory equipment such as respirators that are worn with the suits, gloves, boots, and any other equipment that is necessary for chemical agent use. The suit ensembles are run on at least 12 different subjects with at least 22 trials. The eight suits are reused to achieve the 22 or more trials. Sampling of suits is done at the neck and upper arm for each trial.

Exercise routine for all suits is as follows:

Phase 1 (Pre-Operational):

- 1) standing still, normal breathing
- 2) bending forward and touching toes
- 3) jogging in place
- 4) raising arms above head and looking upward
- 5) bending knees and squatting
- 6) crawling on hands and knees
- 7) torso twists with hands folded on chest
- 8) standing still, normal breathing

Phase 2 (Operational):

- 1) climb step ladder
- 2) move 3 lb boxes from table to floor
- 3) rest
- 4) roll walls and ceiling
- 5) bag clothes
- 6) rest
- 7) loosen bolts
- 8) move 3 lb boxes from floor to table

Note: The phase 1 (pre-operational) exercises are performed for 1 min each for a total of 8 min. The phase 2 (operational) exercises are performed for 4 min each for a total of 40 min.

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Appendix C

LANX Chemical Protective Undergarment Ensemble

Table C - 1. LANX Undergarment Average HD Cumulative Permeation, ng/cm²

Time (min)	Chest Area	Time (min)	Upper Arm Seam	Time (min)	Glove Liner Seam	Time (min)	Crotch Area	Time (min)	Thigh Area	Time (min)	Lower Leg Seam	Time (min)	Boot Liner Seam	Average Time (min)	Weighted Average M _T
5	8	14	191	13	1850	8	14	3	316	12	696	4	218	8	262
35	1451	44	1981	43	10747	38	3027	33	6280	42	5877	34	5007	38	4110
65	4277	74	4760	73	20099	68	9102	63	14024	72	12848	64	10706	68	9495
95	6859	104	7172	103	29420	98	15181	93	21895	102	19879	94	16427	98	14811
125	8731	134	8825	133	38676	128	20116	123	29744	132	26886	124	21984	128	19727
155	9966	164	9857	163	46098	158	23159	153	37202	162	33675	154	27190	158	24006
185	10818	194	10558	193	49360	188	24795	183	43956	192	40014	184	30254	188	27461
215	11459	224	11079	223	50111	218	25826	213	49861	222	45745	214	31100	218	30228
245	11969	254	11484	253	50646	248	26582	243	54973	252	50857	244	31580	248	32586
275	12388	284	11812	283	51088	278	27177	273	59506	282	55380	274	31940	278	34652
305	12741	314	12088	313	51465	308	27664	303	63661	312	59374	304	32226	308	36519
335	13047	344	12326	343	51803	338	28080	333	67504	342	62978	334	32465	338	38228
365	13316	374	12539	373	52121	368	28444	363	71089	372	66276	364	32676	368	39810
395	13556	404	12731	403	52422	398	28766	393	74464	402	69357	394	32868	398	41292
425	13774	434	12904	433	52713	428	29057	423	77667	432	72305	424	33049	428	42694
455	13972	464	13062	463	52996	458	29323	453	80656	462	75003	454	33220	458	43999

Table C - 2. LANX Undergarment Average GB Cumulative Permeation, ng/cm²

Time (min)	Chest Area	Time (min)	Upper Arm Seam	Time (min)	Glove Liner Seam	Time (min)	Crotch Area	Time (min)	Thigh Area	Time (min)	Lower Leg Seam	Time (min)	Boot Liner Seam	Average Time (min)	Weighted Average M _T
5	462	14	1398	5	998	8	1137	5	606	14	1761	14	1476	9	735
35	7742	44	9326	35	14424	38	9421	35	8643	44	10458	44	9503	39	8779
65	14708	74	17161	65	29685	68	17961	65	17858	74	20559	74	17660	69	17285
95	19157	104	22248	95	43497	98	25447	95	25266	104	29363	104	23145	99	23691
125	22251	134	25987	125	54944	128	31803	125	30082	134	36060	134	27324	129	28235
155	24693	164	29051	155	65296	158	37272	155	33813	164	41549	164	30887	159	31914
185	26744	194	31658	185	74808	188	42093	185	36992	194	46296	194	34089	189	35092
215	28536	224	33923	215	83493	218	46340	215	39819	224	50470	224	36993	219	37912
245	30164	254	35941	245	91375	248	50106	245	42362	254	54154	254	39610	249	40452
275	31602	284	37735	275	98478	278	53533	275	44688	284	57566	284	41994	279	42747
305	32897	314	39372	305	104740	308	56674	305	46891	314	60798	314	44112	309	44855
335	34115	344	40916	335	109982	338	59585	335	49030	344	63898	344	45909	339	46821
365	35222	374	42335	365	114290	368	62289	365	51119	374	66882	374	47455	369	48643
395	36227	404	43642	395	117943	398	64787	395	53166	404	69721	404	48814	399	50344
425	37151	434	44844	425	121176	428	67092	425	55158	434	72434	434	50044	429	51945
455	38009	464	45949	455	124145	458	69232	455	57099	464	75044	464	51189	459	53466

Note 1: The time given for each sampling area is the average of the elapsed times for the three swatches tested per sampling area.

Note 2: The average time is the sum of the times given for each sampling area divided by the number of sampling areas.

Note 3: Weighted average M_T = 0.4(chest area M_T) + 0.35(thigh area M_T) + 0.05(upper arm seam M_T) + 0.05(lower leg seam M_T) + 0.05(crotch area M_T) + 0.05(glove seam M_T) + 0.05(boot liner seam M_T).

LANX Chemical Protective Undergarment

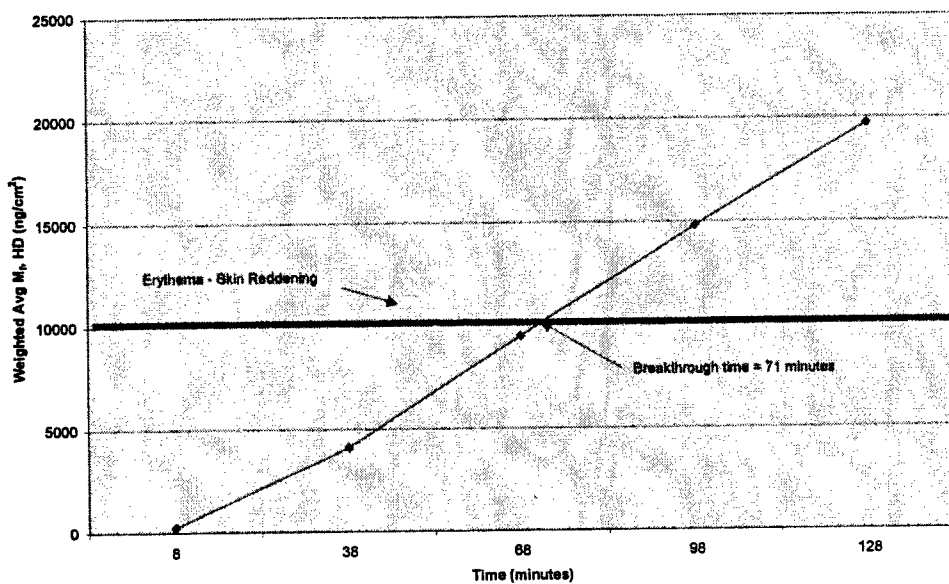


Figure C - 1: LANX Undergarment - Weighted Average HD Permeation

LANX Chemical Protective Undergarment

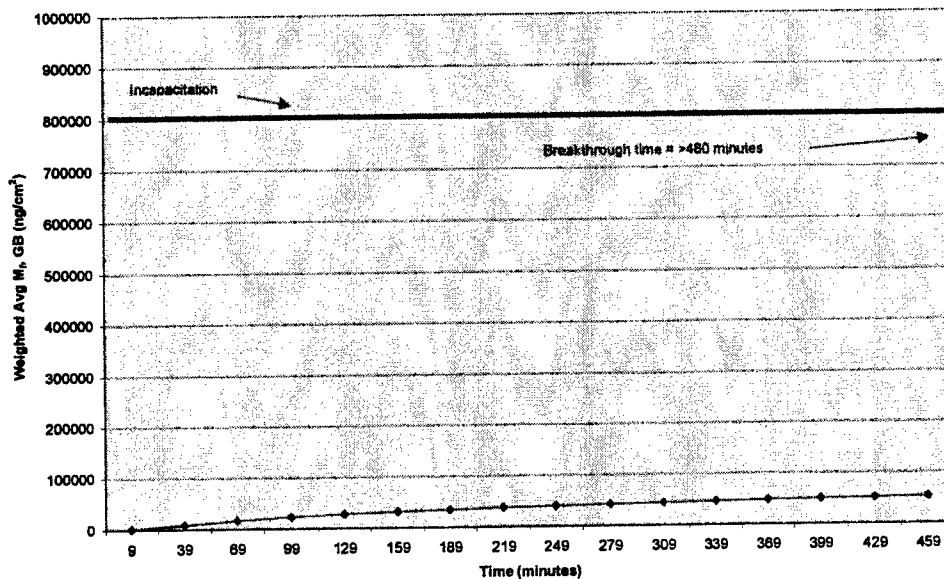


Figure C - 2: LANX Undergarment - Weighted Average GB Permeation

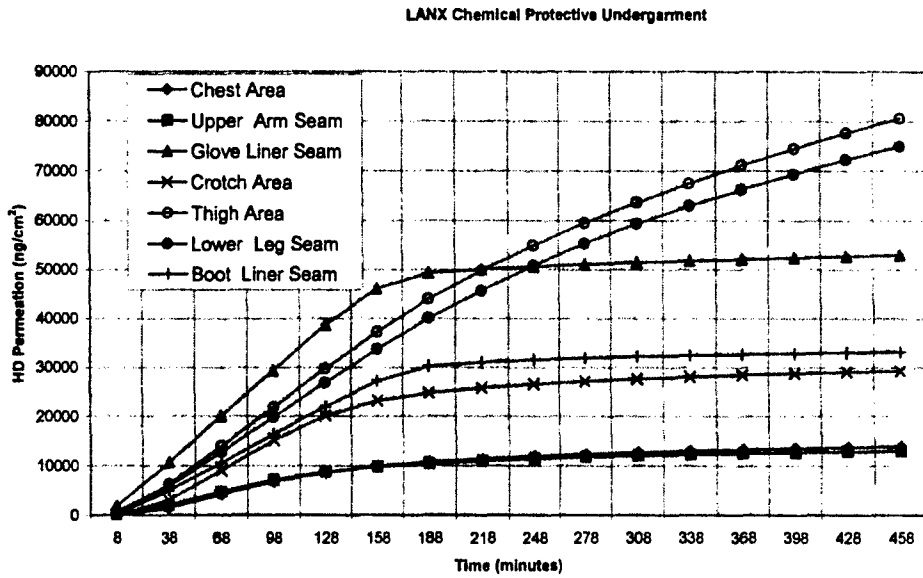


Figure C - 3: LANX Undergarment: HD Permeation by Sampling Area

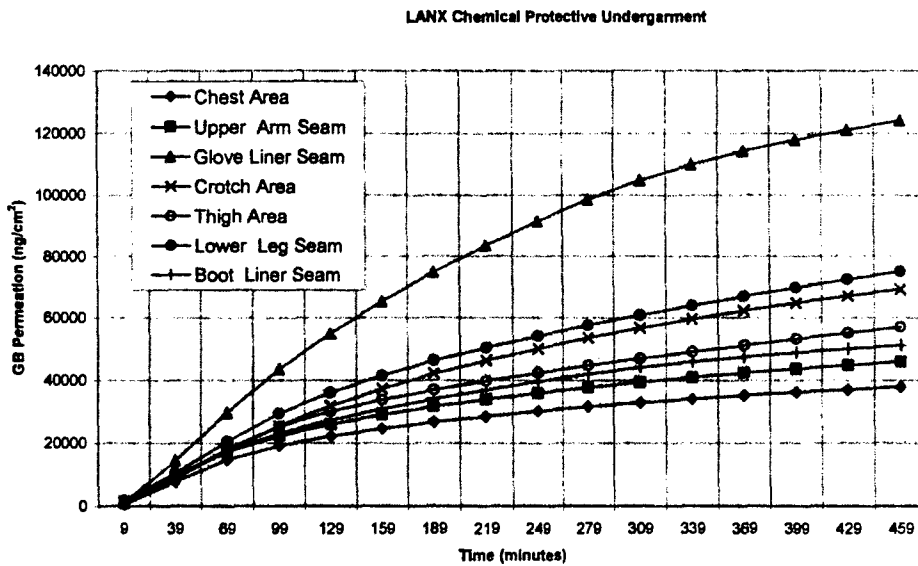


Figure C - 4: LANX Undergarment: GB Permeation by Sampling Area

Table C - 3. LANX Undergarment System Test (Aerosol Simulant) Results

PF Range	Neck Region and Upper Arm, Combined					
	Pre-Operational Exercises			Operational Exercises		
	No. of Occasions in Range	Cumulative Rate, Percent	Cumulative Pass Rate, Percent	No. of Occasions in Range	Cumulative Rate, Percent	Cumulative Pass Rate, Percent
0	0	0.00	100.00	-	-	-
2	6	9.38	90.63	-	-	-
5	51	89.06	10.94	-	-	-
10	7	100.00	0.00	-	-	-
50	0	100.00	0.00	-	-	-
100	0	100.00	0.00	-	-	-
150	0	100.00	0.00	-	-	-
500	0	100.00	0.00	-	-	-
1000	0	100.00	0.00	-	-	-
1667	0	100.00	0.00	-	-	-
2000	0	100.00	0.00	-	-	-
5000	0	100.00	0.00	-	-	-
6667	0	100.00	0.00	-	-	-
10000	0	100.00	0.00	-	-	-
20000	0	100.00	0.00	-	-	-
50000	0	100.00	0.00	-	-	-
100000	0	100.00	0.00	-	-	-
No. of Trials	64			-		

Table C - 4. LANX Undergarment Overall Test Results

Breakthrough Time (minutes)		Aerosol PF Pass Rate at PF Equal to:			Exercise Phase
Incapacitation	Erythema	2	5	10	
GB	HD	2	5	10	Pre-Operational Operational
>480	71	91	11	0	
		-	-	-	

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Appendix D
LANX Chemical Protective Overgarment

Table D - 1. LANX Overgarment Average HD Cumulative Permeation, ng/cm²

Time (min)	Chest Area	Time (min)	Upper Arm Seam	Time (min)	Glove Seam	Time (min)	Crotch Area	Time (min)	Thigh Area	Time (min)	Lower Leg Seam	Average Time (min)	Weighted Average M _t
5	4	14	97	7	1	7	0	4	1	13	1	8	7
35	731	44	1039	37	124	37	32	34	19	43	34	38	361
65	2162	74	2612	67	521	67	162	64	67	73	132	68	1063
95	3487	104	4193	97	1079	97	403	94	149	103	329	98	1754
125	4478	134	5515	127	1537	127	695	124	263	133	617	128	2314
155	5203	164	6524	157	1843	157	966	154	417	163	946	158	2762
185	5921	194	7266	187	2069	187	1177	184	605	193	1267	188	3199
215	6913	224	7826	217	2271	217	1340	214	843	223	1558	218	3752
245	8174	254	8336	247	2452	247	1482	244	1164	253	1817	248	4439
275	9541	284	8861	277	2593	277	1624	274	1595	283	2060	278	5211
305	10968	314	9386	307	2707	307	1781	304	2174	313	2306	308	6066
335	12432	344	9856	337	2801	337	1972	334	2962	343	2575	338	7018
365	13890	374	10256	367	2886	367	2218	364	3997	373	2880	368	8067
395	15312	404	10603	397	2963	397	2523	394	5298	403	3235	398	9210
425	16693	434	10910	427	3035	427	2888	424	6827	433	3647	428	10432
455	18031	464	11188	457	3105	457	3305	454	8437	463	4097	458	11672

Table D - 2. LANX Overgarment Average GB Cumulative Permeation, ng/cm²

Time (min)	Chest Area	Time (min)	Upper Arm Seam	Time (min)	Glove Seam	Time (min)	Crotch Area	Time (min)	Thigh Area	Time (min)	Lower Leg Seam	Average Time (min)	Weighted Average M _t
4	70	13	384	13	861	4	225	4	191	13	493	9	202
34	1335	43	2188	43	5039	34	2996	34	2661	43	2588	39	2239
64	2529	73	4345	73	9430	64	5155	64	5334	73	4347	69	4309
94	3750	103	6844	103	13758	94	6875	94	8178	103	5765	99	6433
124	5036	133	9366	133	18061	124	8418	124	11098	133	7000	129	8596
154	6397	163	11738	163	22325	154	9875	154	14051	163	8116	159	10782
184	7811	193	13878	193	26510	184	11269	184	17025	193	9142	189	12975
214	9272	223	15812	223	30588	214	12613	214	20015	223	10100	219	15170
244	10760	253	17595	253	34438	244	13916	244	23007	253	10997	249	17354
274	12259	283	19234	283	38053	274	15184	274	25981	283	11839	279	19511
304	13761	313	20741	313	41404	304	16416	304	28929	313	12629	309	21635
334	15263	343	22138	343	44431	334	17610	334	31830	343	13376	339	23715
364	16760	373	23447	373	47192	364	18769	364	34674	373	14081	369	25748
394	18254	403	24685	403	49653	394	19833	394	37476	403	14751	399	27738
424	19729	433	25859	433	51847	424	20790	424	40219	433	15388	429	29673
454	21183	463	26977	463	53785	454	21678	454	42913	463	15995	459	31560

Note 1: The time given for each sampling area is the average of the elapsed times for the three swatches (six swatches for chest area and upper arm seam) tested per sampling area.

Note 2: The average time is the sum of the times given for each sampling area divided by the number of sampling areas.

Note 3: Weighted average M_t = 0.4(chest area M_t) + 0.4(thigh area M_t) + 0.05(upper arm seam M_t) + 0.05(lower leg seam M_t) + 0.05(crotch area M_t) + 0.05(glove seam M_t).

LANX Chemical Protective Overgarment

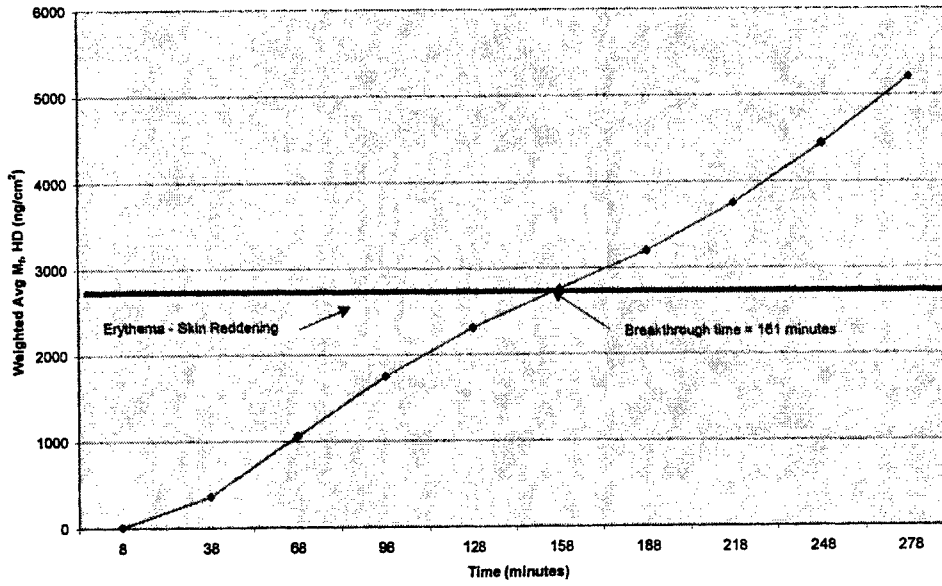


Figure D - 1: LANX Overgarment - Weighted Average HD Permeation

LANX Chemical Protective Overgarment

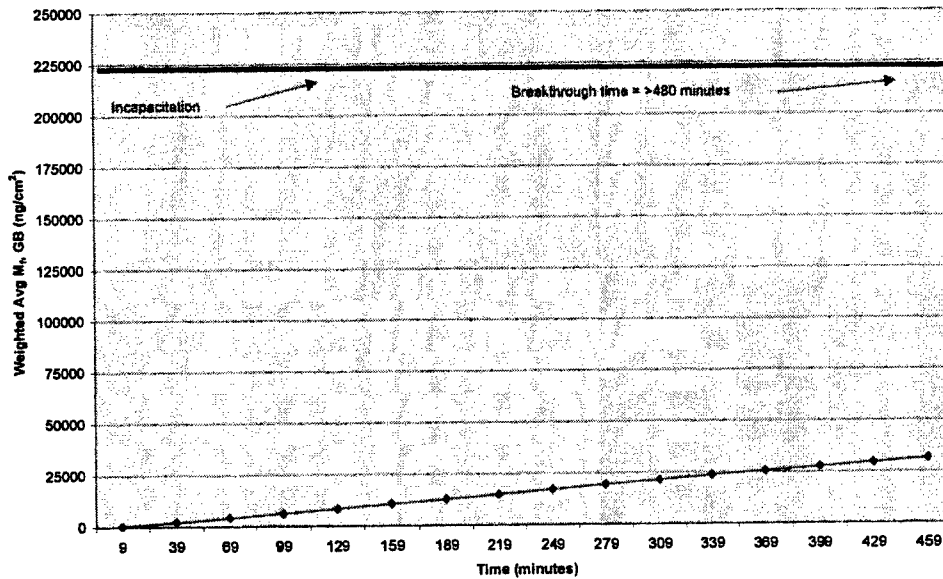


Figure D - 2: LANX Overgarment - Weighted Average GB Permeation

LANX Chemical Protective Overgarment

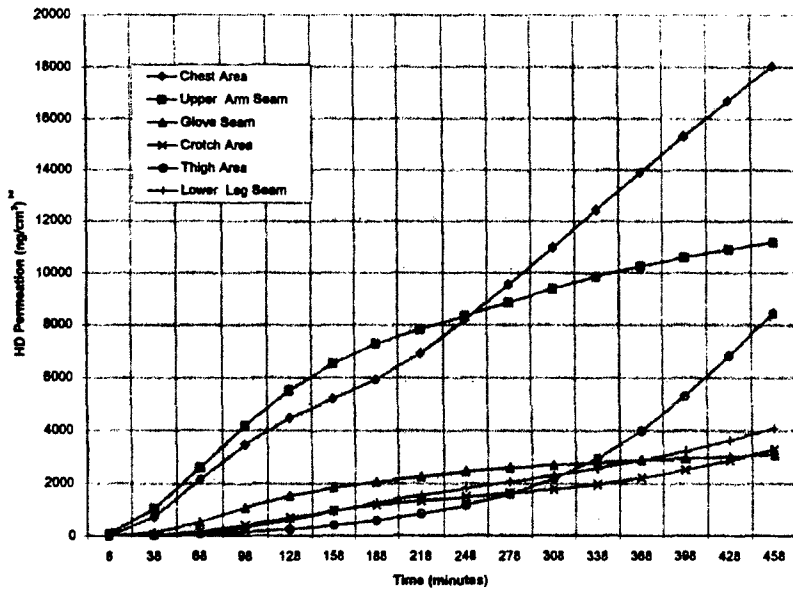


Figure D - 3: LANX Overgarment: HD Permeation by Sampling Area

LANX Chemical Protective Overgarment

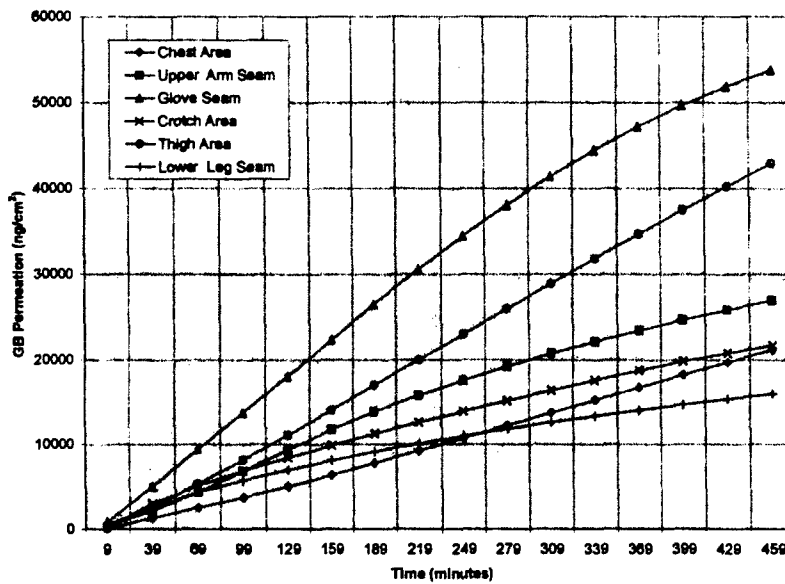


Figure D - 4: LANX Overgarment: GB Permeation by Sampling Area

Table D - 3. LANX Overgarment System Test (Aerosol Simulant) Results

PF Range	Neck Region and Upper Arm, Combined					
	Pre-Operational Exercises			Operational Exercises		
	No. of Occasions in Range	Cumulative Rate, Percent	Cumulative Pass Rate, Percent	No. of Occasions in Range	Cumulative Rate, Percent	Cumulative Pass Rate, Percent
0	0	0.00	100.00	-	-	-
2	6	9.38	90.63	-	-	-
5	51	89.06	10.94	-	-	-
10	7	100.00	0.00	-	-	-
50	0	100.00	0.00	-	-	-
100	0	100.00	0.00	-	-	-
150	0	100.00	0.00	-	-	-
500	0	100.00	0.00	-	-	-
1000	0	100.00	0.00	-	-	-
1667	0	100.00	0.00	-	-	-
2000	0	100.00	0.00	-	-	-
5000	0	100.00	0.00	-	-	-
6667	0	100.00	0.00	-	-	-
10000	0	100.00	0.00	-	-	-
20000	0	100.00	0.00	-	-	-
50000	0	100.00	0.00	-	-	-
100000	0	100.00	0.00	-	-	-
No. of Trials	64			-		

Table D - 4. LANX Overgarment Overall Test Results

Breakthrough Time (minutes)		Aerosol PF Pass Rate at PF Equal to:			Exercise Phase
Incapacitation	Erythema	2	5	10	
GB	HD	2	5	10	
>480	161	91	11	0	Pre-Operational
		-	-	-	Operational

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Appendix E

Giat Tactical Operations Multipurpose Protective Suit (TOMPS)

Table E - 1. Giat TOMPS Average HD Cumulative Permeation, ng/cm²

Giat Tactical Operations Multipurpose Protective (TOMPS) Suit															
Time (min)	Chest Area	Time (min)	Upper Arm Seam	Time (min)	Glove Seam	Time (min)	Crotch Area	Time (min)	Thigh Area	Time (min)	Lower Leg Seam	Time (min)	Boot Liner Seam	Average Time (min)	Weighted Average M _f
4	0	13	2	14	1	9	1	3	1	12	0	5	0	9	1
34	91	43	188	44	436	39	600	33	95	42	448	35	1904	39	249
64	583	73	1348	74	1433	69	2308	63	487	72	1660	65	5698	69	1026
94	1761	103	3227	104	2628	99	4398	93	1429	102	3127	95	9489	99	2348
124	3532	133	4973	134	3926	129	6323	123	3176	132	4454	125	13283	129	4172
154	5716	163	6728	164	5272	159	8199	153	5720	162	5655	155	17066	159	6435
184	8327	193	8596	194	6645	189	10037	183	8733	192	6726	185	20851	189	9030
214	11245	223	10467	224	8018	219	11785	213	11907	222	7647	215	24608	219	11792
244	14218	253	12217	254	9361	249	13417	243	15035	252	8450	245	28265	249	14535
274	17126	283	13823	284	10831	279	14955	273	18033	282	9196	275	31922	279	17198
304	19927	313	15225	314	12438	309	16394	303	20957	312	9899	305	35654	309	19786
334	22610	343	16376	344	14006	339	17729	333	23782	342	10525	335	39354	339	22267
364	25087	373	17284	374	15505	369	18969	363	26369	372	11050	365	42944	369	24551
394	27270	403	17994	404	16921	399	20150	393	28621	402	11467	395	46402	399	26572
424	29256	433	18629	434	18238	429	21291	423	30566	432	11794	425	49752	429	28386
454	31123	463	19221	464	19458	459	22397	453	32290	462	12067	455	53019	459	30059

Table E - 2. Giat TOMPS Average GB Cumulative Permeation, ng/cm²

Giat Tactical Operations Multipurpose Protective (TOMPS) Suit															
Time (min)	Chest Area	Time (min)	Upper Arm Seam	Time (min)	Glove Seam	Time (min)	Crotch Area	Time (min)	Thigh Area	Time (min)	Lower Leg Seam	Time (min)	Boot Liner Seam	Average Time (min)	Weighted Average M _f
5	0	5	3	14	2	8	5	14	0	14	5	5	2	9	1
35	2249	35	3755	44	2460	38	4367	44	2825	44	4384	35	4763	39	2875
65	6876	65	13479	74	7732	68	13568	74	8753	74	14148	65	15351	69	9028
95	11822	95	25756	104	13335	98	22942	104	15123	104	24536	95	27206	99	15710
125	17071	125	38244	134	18771	128	31372	134	21795	134	34082	125	38966	129	22528
155	22527	155	50476	164	23883	158	38881	164	28692	164	42609	155	50205	159	29356
185	28264	185	62240	194	28555	188	45815	194	35741	194	50114	185	60636	189	36183
215	34184	215	73398	224	32754	218	52257	224	42851	224	56754	215	69907	219	42925
245	40069	245	83787	254	36542	248	58173	254	49922	254	62617	245	78053	249	49459
275	45431	275	93403	284	39949	278	63837	284	56799	284	67824	275	85255	279	55565
305	50424	305	102151	314	43069	308	69298	314	63405	314	72512	305	91529	309	61289
335	55417	335	110021	344	46017	338	74138	344	69818	344	76777	335	97107	339	66806
365	60167	365	117107	374	48804	368	78387	374	75955	374	80615	365	102221	369	72008
395	64664	395	123371	404	51461	398	82196	404	82496	404	84061	395	106952	399	77141
425	69098	425	128900	434	54038	428	85582	434	89183	434	87151	425	111545	429	82214
455	72360	455	133761	464	56544	458	88512	464	93261	464	89938	455	116065	459	85827

Note 1: The time given for each sampling area is the average of the elapsed times for the three swatches tested per sampling area.

Note 2: The average time is the sum of the times given for each sampling area divided by the number of sampling areas.

Note 3: Weighted average M_f = 0.4(chest area M_f) + 0.35(thigh area M_f) + 0.05(upper arm seam M_f) + 0.05(lower leg seam M_f) + 0.05(crotch area M_f) + 0.05(glove seam M_f) + 0.05(boot liner seam M_f).

Giat TOMPS Suit

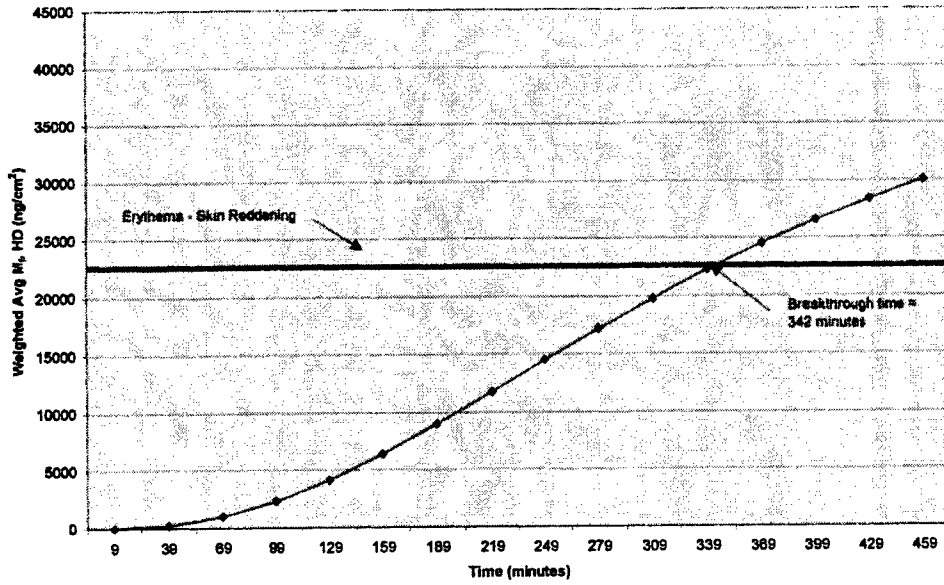


Figure E - 1: Giat TOMPS - Weighted Average HD Permeation

Giat TOMPS Suit

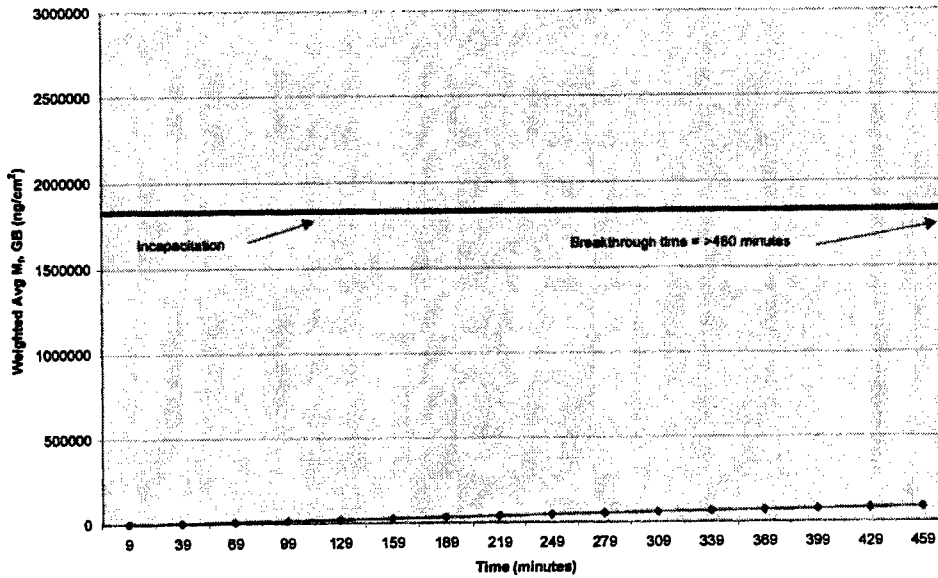


Figure E - 2: Giat TOMPS - Weighted Average GB Permeation

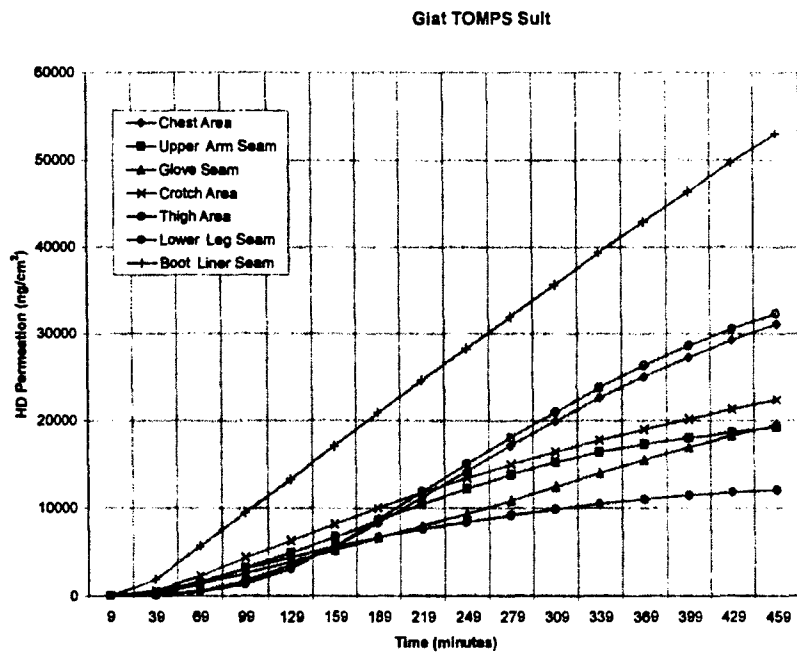


Figure E - 3: Giat TOMPS - HD Permeation By Sampling Area

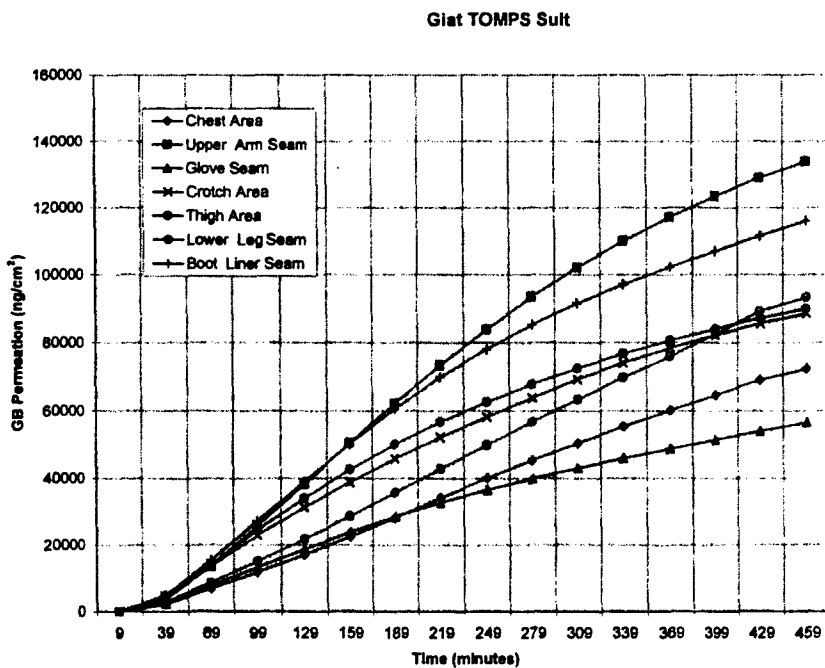


Figure E - 4: Giat TOMPS GB Permeation By Sampling Area

Table E - 3. Giat TOMPS System Test (Aerosol Simulant) Results

PF Range	Neck Region and Upper Arm, Combined					
	Pre-Operational Exercises			Operational Exercises		
	No. of Occasions in Range	Cumulative Rate, Percent	Cumulative Pass Rate, Percent	No. of Occasions in Range	Cumulative Rate, Percent	Cumulative Pass Rate, Percent
0	0	0.00	100.00	-	-	-
2	3	6.82	93.18	-	-	-
5	20	52.27	47.73	-	-	-
10	21	100.00	0.00	-	-	-
50	0	100.00	0.00	-	-	-
100	0	100.00	0.00	-	-	-
150	0	100.00	0.00	-	-	-
500	0	100.00	0.00	-	-	-
1000	0	100.00	0.00	-	-	-
1667	0	100.00	0.00	-	-	-
2000	0	100.00	0.00	-	-	-
5000	0	100.00	0.00	-	-	-
6667	0	100.00	0.00	-	-	-
10000	0	100.00	0.00	-	-	-
20000	0	100.00	0.00	-	-	-
50000	0	100.00	0.00	-	-	-
100000	0	100.00	0.00	-	-	-
No. of Trials	44			-		

Table E - 4. Giat TOMPS Overall Test Results

Breakthrough Time (minutes)		Aerosol PF Pass Rate at PF Equal to:			Exercise Phase
Incapacitation	Erythema	2	5	10	
GB	HD	2	5	10	Pre-Operational Operational
>480	342	93	48	0	
		-	-	-	

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Appendix F
Giat NBC SWAT Suit

Table F - 1. Giat NBC SWAT Average HD Permeation, ng/cm²

Time (min)	Chest Area	Time (min)	Upper Arm Seam	Time (min)	Glove Seam	Time (min)	Crotch Area	Time (min)	Thigh Area	Time (min)	Lower Leg Seam	Time (min)	Boot Liner Seam	Average Time (min)	Weighted Average M _r
5	1	14	6	14	0	7	0	5	0	14	0	5	0	9	1
35	510	44	758	44	767	37	86	35	875	44	1716	35	2716	39	813
65	4062	74	4774	74	2980	67	2079	65	4943	74	7002	65	8194	69	4607
95	8958	104	10597	104	6118	97	7489	95	10575	104	14175	95	13733	99	9890
125	11903	134	14495	134	9539	127	13895	125	14524	134	20940	125	19186	129	13747
155	13752	164	16688	164	13064	157	18241	155	16703	164	25920	155	24328	159	16259
185	15087	194	18148	194	16803	187	20620	185	17674	194	29180	185	28961	189	17906
215	16171	224	19263	224	20857	217	22277	215	18215	224	31744	215	33003	219	19201
245	17099	254	20184	254	25064	247	24042	245	18663	254	33782	245	36417	249	20346
275	17903	284	20982	284	29209	277	26140	275	19074	284	35474	275	39297	279	21392
305	18625	314	21675	314	33209	307	28137	305	19458	314	36919	305	41824	309	22349
335	19275	344	22288	344	37100	337	29903	335	19810	344	38223	335	44057	339	23222
365	19856	374	22846	374	40873	367	31479	365	20136	374	39424	365	46109	369	24027
395	20394	404	23353	404	44117	397	32935	395	20438	404	40514	395	48041	399	24759
425	20903	434	23820	434	46717	427	34260	425	20714	434	41522	425	49784	429	25416
455	21376	464	24257	464	48905	457	35388	455	20976	464	42452	455	51311	459	26008

Table F - 2. Giat NBC SWAT Average GB Permeation, ng/cm²

Time (min)	Chest Area	Time (min)	Upper Arm Seam	Time (min)	Glove Seam	Time (min)	Crotch Area	Time (min)	Thigh Area	Time (min)	Lower Leg Seam	Time (min)	Boot Liner Seam	Average Time (min)	Weighted Average M _r
5	0	5	1	13	3	8	0	14	0	14	3	4	1	9	1
35	2886	35	2061	43	3659	38	3845	44	3561	44	2005	34	3407	39	3150
65	8127	65	6116	73	10614	68	11833	74	10890	74	6049	64	10277	69	9307
95	12612	95	10361	103	17651	98	20050	104	18459	104	10250	94	17748	99	15309
125	16711	125	14978	133	25103	128	28058	134	25966	134	14598	124	26039	129	11
155	20522	155	19755	163	32483	158	35728	164	33239	164	19077	154	34790	159	26934
185	24515	185	24534	193	39744	188	43041	194	40506	194	23698	184	43197	189	32694
215	28863	215	29164	223	44329	218	50027	224	47750	224	28352	214	49026	219	38303
245	33217	245	33652	253	45592	248	56610	254	54677	254	32918	244	51458	249	43435
275	37310	275	38015	283	46339	278	62774	284	60733	284	37055	274	52551	279	48017
305	40970	305	41275	313	47147	308	68498	314	66240	314	40301	304	53544	309	52110
335	44382	335	43290	343	47821	338	73822	344	72017	344	43069	334	54440	339	56081
365	47706	365	44867	373	48453	368	78741	374	77890	374	44799	364	55274	369	59951
395	50986	395	45821	403	49062	398	83175	404	83677	404	45334	394	56064	399	63654
425	54231	425	46277	433	49655	428	87214	434	89348	434	45765	424	56814	429	67250
455	57417	455	46661	463	50233	458	90908	464	94934	464	46186	454	57537	459	70770

Note 1: The time given for each sampling area is the average of the elapsed times for the three swatches tested per sampling area.

Note 2: The average time is the sum of the times given for each sampling area divided by the number of sampling areas.

Note 3: Weighted average M_r = 0.4(chest area M_r)+0.35(thigh area M_r)+0.05(upper arm seam M_r)+0.05(lower leg seam M_r)+0.05(crotch area M_r)+0.05(glove seam M_r)+0.05(boot liner seam M_r).

Giat NBC SWAT Suit

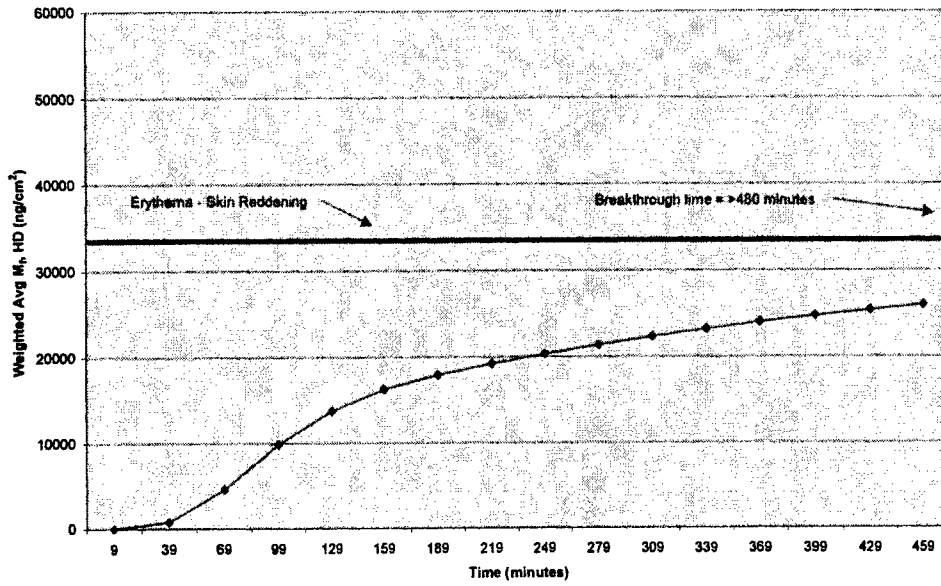


Figure F - 1: Giat NBC SWAT Suit - Weighted Average HD Permeation

Giat NBC SWAT Suit

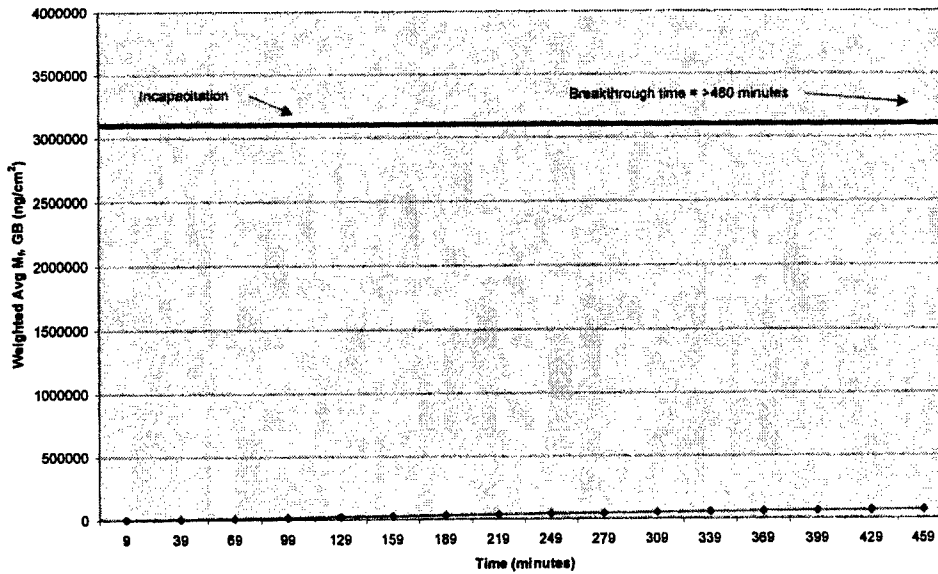


Figure F - 2: Giat NBC SWAT Suit - Weighted Average GB Permeation

Giat NBC SWAT Suit

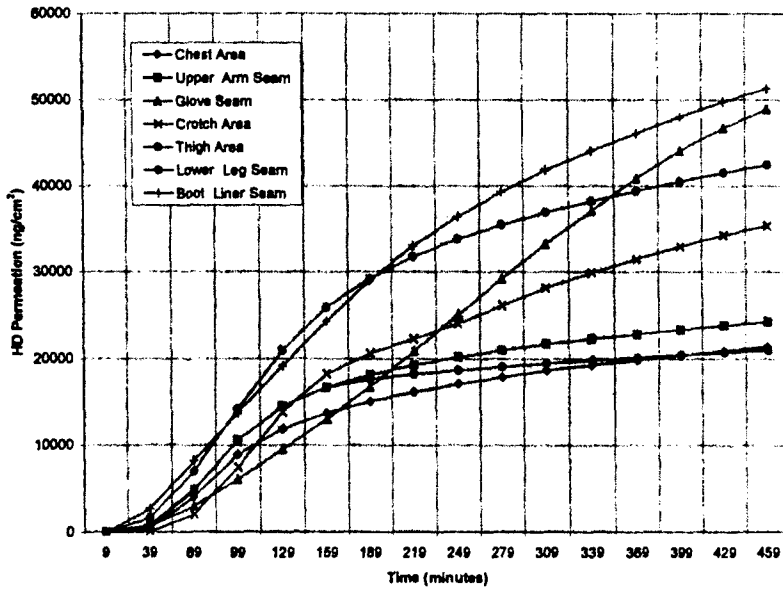


Figure F - 3: Giat NBC SWAT Suit - HD Permeation by Sampling Area

Giat NBC SWAT Suit

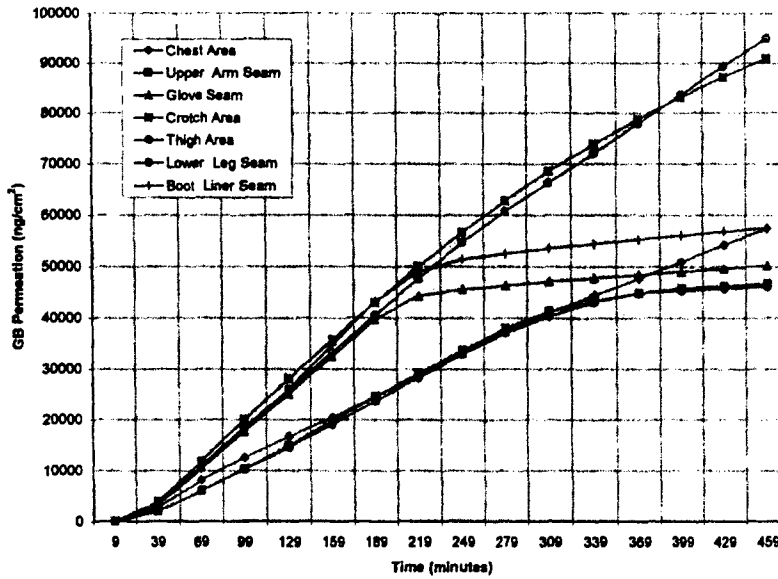


Figure F - 4: Giat NBC SWAT Suit - GB Permeation by Sampling Area

Table F - 3. Giat NBC SWAT System Test (Aerosol Simulant) Results

PF Range	Neck Region and Upper Arm, Combined					
	Pre-Operational Exercises			Operational Exercises		
	No. of Occasions in Range	Cumulative Rate, Percent	Cumulative Pass Rate, Percent	No. of Occasions in Range	Cumulative Rate, Percent	Cumulative Pass Rate, Percent
0	0	0.00	100.00	-	-	-
2	17	26.56	73.44	-	-	-
5	25	65.63	34.38	-	-	-
10	19	95.31	4.69	-	-	-
50	3	100.00	0.00	-	-	-
100	0	100.00	0.00	-	-	-
150	0	100.00	0.00	-	-	-
500	0	100.00	0.00	-	-	-
1000	0	100.00	0.00	-	-	-
1667	0	100.00	0.00	-	-	-
2000	0	100.00	0.00	-	-	-
5000	0	100.00	0.00	-	-	-
6667	0	100.00	0.00	-	-	-
10000	0	100.00	0.00	-	-	-
20000	0	100.00	0.00	-	-	-
50000	0	100.00	0.00	-	-	-
100000	0	100.00	0.00	-	-	-
No. of Trials	64			-		

Table F - 4. Giat NBC SWAT Overall Test Results

Breakthrough Time (minutes)		Aerosol PF Pass Rate at PF Equal to:			Exercise Phase
Incapacitation	Erythema	2	5	10	
GB	HD	2	5	10	Pre-Operational Operational
>480	>480	73	34	5	
		-	-	-	

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Appendix G

Giat Uniscaph Undergarment

Table G - 1. Giat UNISCAPH Average HD Permeation, ng/cm²

Time (min)	Chest Area	Time (min)	Thigh Area	Time (min)	Upper Arm Seam	Time (min)	Lower Leg Seam	Time (min)	Crotch Area	Average Time (min)	Weighted Average M _r
5	2	4	2	14	3	13	1	7	0	9	2
35	2389	34	2495	44	2536	43	2147	37	3311	39	2519
65	7115	64	7477	74	8350	73	6542	67	9896	69	7571
95	11840	94	12510	104	14693	103	10778	97	16067	99	12620
125	16523	124	17420	134	20298	133	14352	127	21337	129	17444
155	21034	154	22016	164	24725	163	17162	157	25578	159	21872
185	25278	184	26227	194	27988	193	19311	187	29001	189	25867
215	29279	214	29962	224	30473	223	20978	217	31930	219	29462
245	33082	244	33273	254	32492	253	22332	247	34476	249	32731
275	36630	274	36284	284	34197	283	23469	277	36720	279	35721
305	39923	304	39031	314	35665	313	24459	307	38740	309	38462
335	42987	334	41543	344	36951	343	25360	337	40578	339	40985
365	45793	364	43972	374	38097	373	26204	367	42270	369	43348
395	48374	394	46370	404	39139	403	27007	397	43815	399	45586
425	50792	424	48634	434	40123	433	27763	427	45248	429	47690
455	53117	454	50756	464	41062	463	28473	457	46605	459	49686

Table G - 2. Giat UNISCAPH Average GB Permeation, ng/cm²

Time (min)	Chest Area	Time (min)	Thigh Area	Time (min)	Upper Arm Seam	Time (min)	Lower Leg Seam	Time (min)	Crotch Area	Average Time (min)	Weighted Average M _r
5	1	4	0	14	2	13	1	6	1	8	1
35	2036	34	1186	44	2341	43	2006	36	1683	38	1675
65	7527	64	4385	74	8255	73	6816	66	4828	68	6001
95	14347	94	8652	104	15418	103	12272	96	7493	98	11334
125	20169	124	13210	134	21566	133	17239	126	9651	128	16257
155	24706	154	17803	164	26337	163	21569	156	11438	158	20543
185	28703	184	22373	194	30505	193	25812	186	13018	188	24548
215	32347	214	26948	224	34248	223	30212	216	14443	218	28385
245	35869	244	31482	254	37843	253	34401	246	15759	248	32129
275	39430	274	35891	284	41692	283	38333	276	16990	278	35829
305	43149	304	40209	314	45652	313	42133	306	18141	308	39546
335	46951	334	44496	344	49645	343	45832	336	19390	338	43292
365	50622	364	48675	374	53739	373	49372	366	20680	368	46942
395	54266	394	52693	404	57773	403	52779	396	21886	398	50500
425	57850	424	56585	434	61617	433	56080	426	23125	428	53971
455	61240	454	60328	464	65391	463	59274	456	24385	458	57299

Note 1: The time given for each sampling area is the average of the elapsed times for the three swatches tested per sampling area.

Note 2: The average time is the sum of the times given for each sampling area divided by the number of sampling areas.

Note 3: Weighted average M_r = 0.4(Chest Area M_r) + 0.4(Thigh Area M_r) + 0.05(Upper Arm Seam M_r) + 0.05(Lower Leg Seam M_r) + 0.1(Crotch Area M_r).

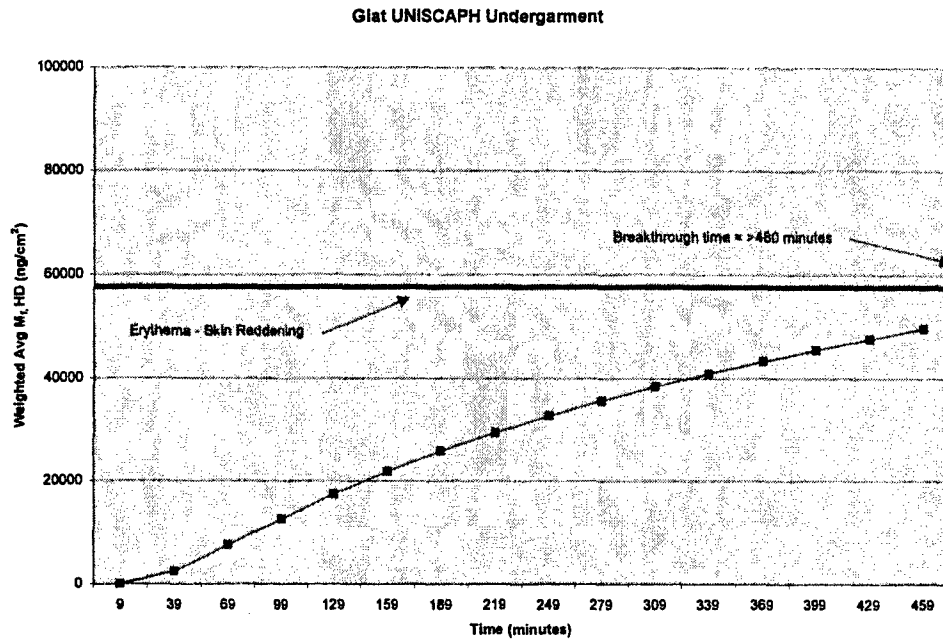


Figure G - 1: Giat UNISCAPH Undergarment - Weighted Average HD Permeation

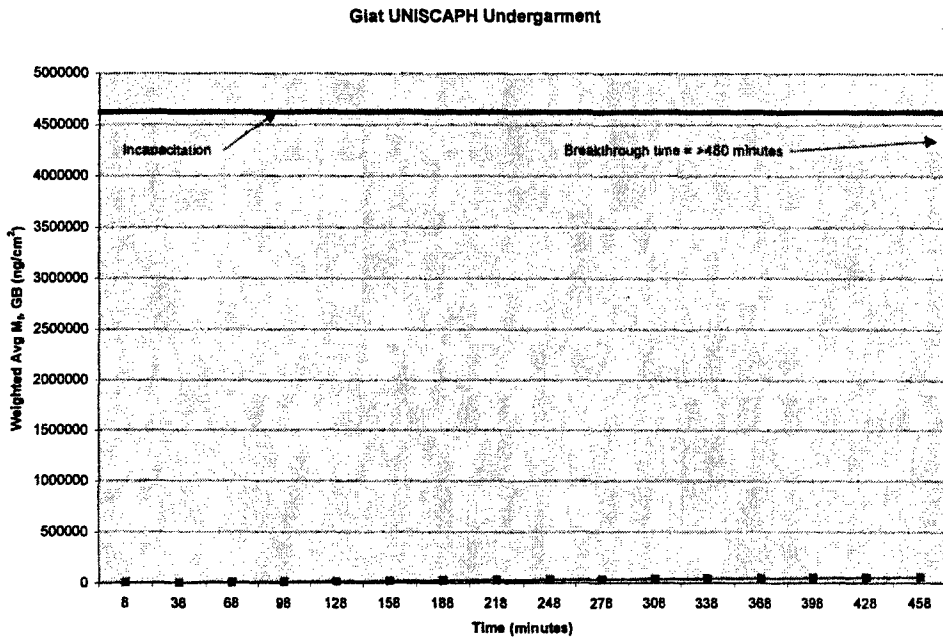


Figure G - 2: Giat UNISCAPH Undergarment - Weighted Average GB Permeation

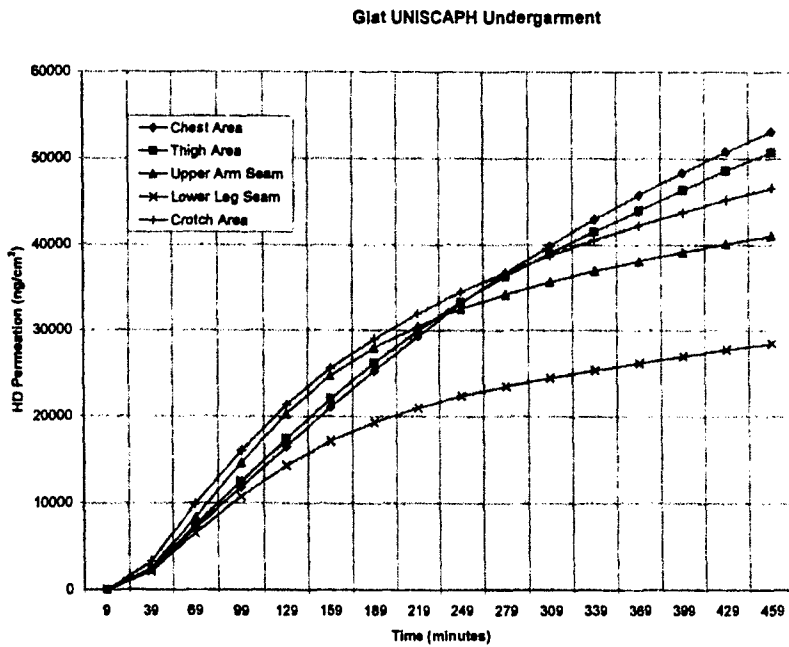


Figure G - 3: Giat UNISCAPH Undergarment: HD Permeation by Sampling Area

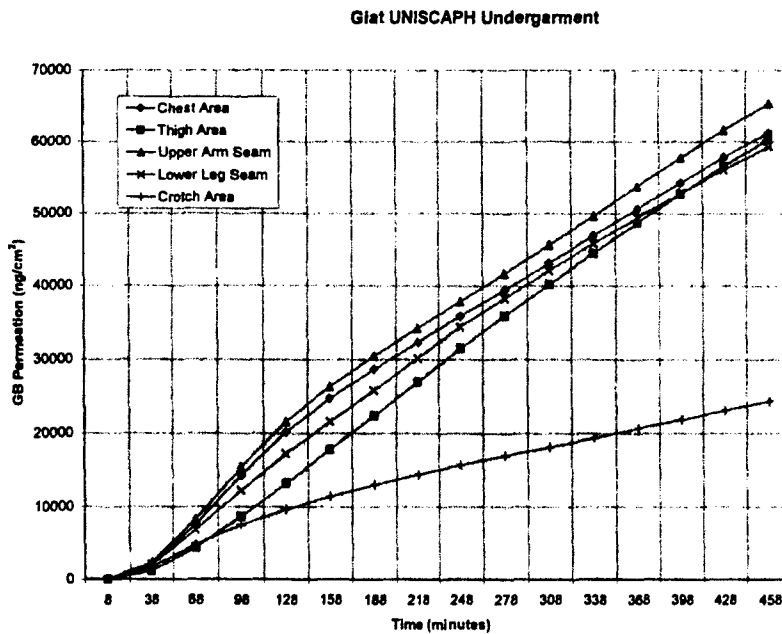


Figure G - 4: Giat UNISCAPH Undergarment: GB Permeation by Sampling Area

Table G - 3. Giat UNISCAPH System Test (Aerosol Simulant) Results

PF Range	Neck Region and Upper Arm, Combined					
	Pre-Operational Exercises			Operational Exercises		
	No. of Occasions in Range	Cumulative Rate, Percent	Cumulative Pass Rate, Percent	No. of Occasions in Range	Cumulative Rate, Percent	Cumulative Pass Rate, Percent
0	0	0.00	100.00	-	-	-
2	6	10.00	90.00	-	-	-
5	47	88.33	11.67	-	-	-
10	7	100.00	0.00	-	-	-
50	0	100.00	0.00	-	-	-
100	0	100.00	0.00	-	-	-
150	0	100.00	0.00	-	-	-
500	0	100.00	0.00	-	-	-
1000	0	100.00	0.00	-	-	-
1667	0	100.00	0.00	-	-	-
2000	0	100.00	0.00	-	-	-
5000	0	100.00	0.00	-	-	-
6667	0	100.00	0.00	-	-	-
10000	0	100.00	0.00	-	-	-
20000	0	100.00	0.00	-	-	-
50000	0	100.00	0.00	-	-	-
100000	0	100.00	0.00	-	-	-
No. of Trials	60			-		

Table G - 4. Giat UNISCAPH Overall Test Results

Breakthrough Time (minutes)		Aerosol PF Pass Rate at PF Equal to:			Exercise Phase
Incapacitation	Erythema	2	5	10	
GB	HD	2	5	10	Pre-Operational Operational
>480	>480	90	12	0	
		-	-	-	

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Appendix H
Saratoga Swatch Data

Table H - 1. Saratoga Swatch Average HD Permeation, ng/cm²

Time (min)	LANX Over-garment*	Time (min)	LANX Under-garment*	Time (min)	Giat TOMPS*	Time (min)	Giat SWAT*	Time (min)	Giat Under-garment*
19	83	19	360	19	1	20	2	19	1
49	671	49	2656	49	357	50	606	49	1003
79	1792	79	6194	79	1204	80	2812	79	3197
109	3176	109	9526	109	2180	110	6248	109	5322
139	4687	139	12444	139	3152	140	9788	139	6962
169	6426	169	14679	169	4161	170	12896	169	8289
199	8817	199	16361	199	5357	200	15996	199	9538
229	12427	229	18002	229	6866	230	19662	229	11020
259	17096	259	19018	259	8575	260	23687	259	13073
289	22107	289	19344	289	10323	290	27762	289	15603
319	26800	319	19551	319	12044	320	31436	319	18218
349	30962	349	19720	349	13656	350	34527	349	20774
379	34869	379	19869	379	15102	380	37042	379	23226
409	38683	409	20005	409	16360	410	38876	409	25542
439	42282	439	20133	439	17375	440	40209	439	27575
469	45553	469	20254	469	18171	470	41216	469	29260

Table H - 2. Saratoga Swatch Average GB Permeation, ng/cm²

Time (min)	LANX Over-garment*	Time (min)	LANX Under-garment*	Time (min)	Giat TOMPS*	Time (min)	Giat SWAT*	Time (min)	Giat Under-garment*
19	1943	20	2172	20	5	20	2	19	1
49	7547	50	8042	50	3418	50	3125	49	1632
79	12099	80	12405	80	9683	80	9257	79	5119
109	15743	110	15655	110	15123	110	15346	109	8241
139	18910	140	18426	140	20108	140	21563	139	10453
169	21714	170	20806	170	24830	170	27718	169	12284
199	24210	200	22914	200	29331	200	33766	199	14036
229	26468	230	24860	230	33571	230	39112	229	15750
259	28539	260	26663	260	37558	260	43562	259	17375
289	30446	290	28312	290	41353	290	47451	289	18937
319	32220	320	29817	320	44989	320	50842	319	20490
349	33869	350	31174	350	48394	350	54020	349	21998
379	35411	380	32382	380	51532	380	56793	379	23514
409	36871	410	33465	410	54765	410	59198	409	25087
439	38248	440	34454	440	57770	440	61496	439	26629
469	39541	470	35360	470	59981	470	63700	469	28116

Note: Each time and M_f is the average for three or four swatches.

*Headers refer to test series during which Saratoga swatches were run at the same time. See note 4 on page 12.

Appendix I
Digital Images of Tested Chemical Protective Items



Figure I - 1: LANX Chemical Protective Undergarment Ensemble - Jacket



Figure I - 2: LANX Chemical Protective Undergarment Ensemble – Glove Liners



Figure I - 3: LANX Chemical Protective Undergarment Ensemble - Drawers

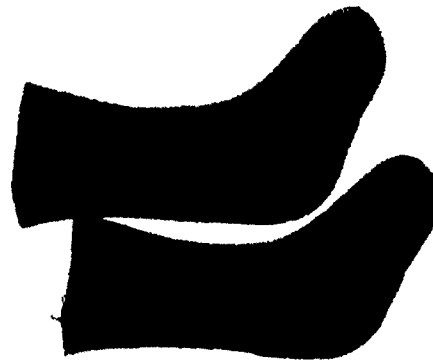


Figure I - 4: LANX Chemical Protective Undergarment Ensemble – Boot Liners



Figure I - 5: LANX Chemical Protective Overgarment - Jacket



Figure I - 6: LANX Chemical Protective Overgarment - Pants



Figure I - 7: LANX Chemical Protective Overgarment - Gloves



Figure I - 8: Giat Tactical Operations Multipurpose Protective Suit - Jacket

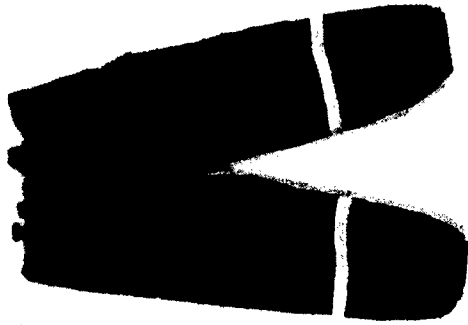


Figure I - 9: Giat Tactical Operations Multipurpose Protective Suit - Pants

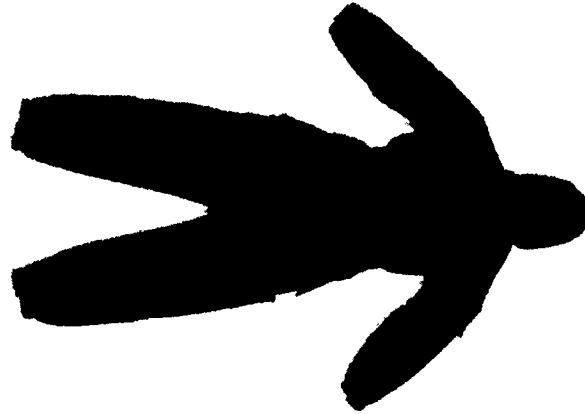


Figure I - 10: Giat NBC SWAT Suit

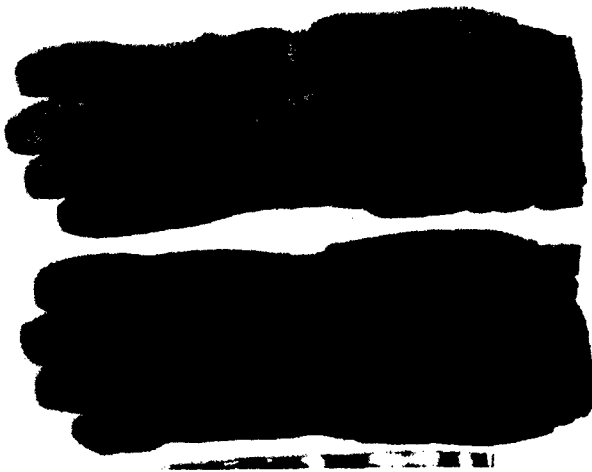


Figure I - 11: Giat NBC SWAT Suit - Gloves

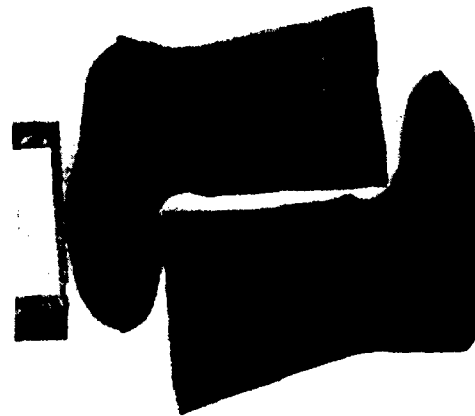


Figure I - 12: Giat NBC SWAT Suit - Boot Liners

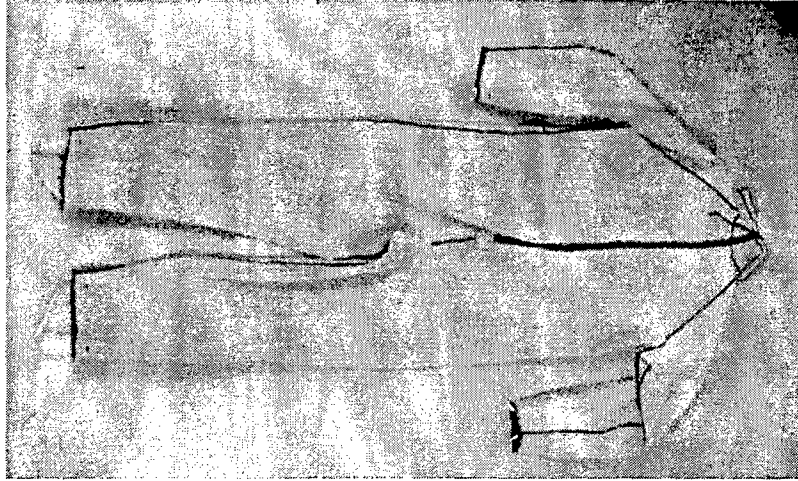


Figure I - 13: Giat UNISCAPH Undergarment

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Appendix J
Overall Test Results

Summary of HD Permeation Results

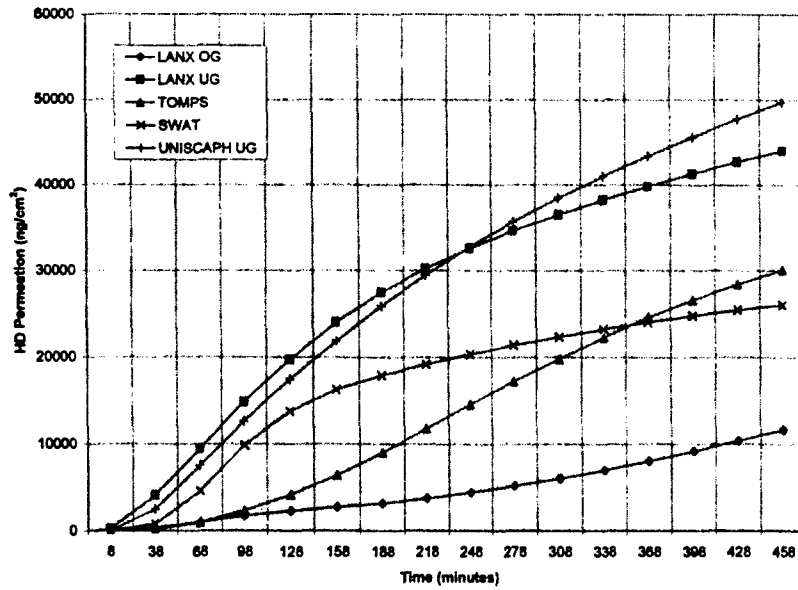


Figure J - 1: Weighted Average HD Permeation

Summary of GB Permeation Results

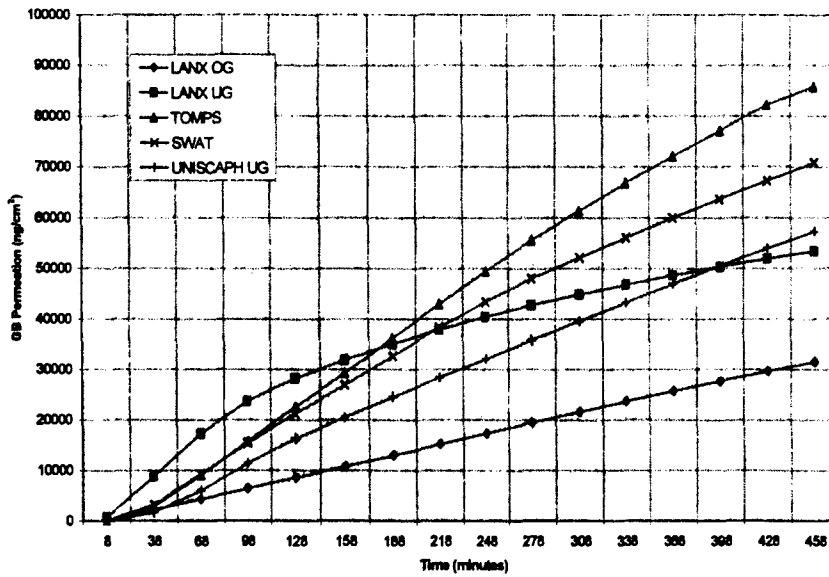


Figure J - 2: Weighted Average GB Permeation

Table J - 1. Summary of Overall Results for All Suits

Test Item	Breakthrough Time (minutes)		Aerosol PF Pass Rate at PF Equal to:			Exercise Phase
	Incapacitation	Erythema	2	5	10	
	GB	HD				
LANX Chemical Protective Undergarment Ensemble	>480	71	91	11	0	Pre-Operational
			-	-	-	Operational
LANX Chemical Protective Overgarment	>480	161	91	11	0	Pre-Operational
			-	-	-	Operational
Giat Tactical Operations Multipurpose Protective Suit	>480	342	93	48	0	Pre-Operational
			-	-	-	Operational
Giat NBC SWAT Suit	>480	>480	73	34	5	Pre-Operational
			-	-	-	Operational
Giat UNISCAPH Undergarment	>480	>480	90	12	0	Pre-Operational
			-	-	-	Operational