ERDEC-TR-

Test Results of Level A Suits to Challenge By Chemical and Biological Warfare Agents and Simulants: Summary report

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EXECUTIVE SUMMARY

As part of the Domestic Preparedness Program, twelve Occupational Safety and Health Level A* suit designs were tested in Phase 1 to assess their capability to protect in a chemical agent or biological agent environment. Each suit design was tested for resistance to chemical agent permeation for both Sarin (GB) and mustard agent (HD). From these tests, it was possible to determine a breakthrough time when a defined amount of agent per unit area permeated through representative swatches of material from the suit. The breakthrough criterion for each agent tested is based upon when sufficient agent would permeate the suit material to cause a minimal physiological effect in a person wearing the suit. Each suit design was also tested for its overall protection factor in a simulant aerosol (corn oil) environment (may be representative of a chemical or biological agent) and six of twelve were tested in a HD simulant vapor environment. These protection factors give the ratio between the challenge concentration outside the suit to the measured concentration inside the suit. The tests and results for determining the breakthrough times and overall protection factors are presented.

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* Level A protection consists of a completely encapsulating, gas/vapor proof chemical resistant suit; a self-contained breathing apparatus (SCBA) or positive-pressure supplied-air respirator with escape SCBA, chemical-resistant gloves and boots.

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PREFACE

The work described in this report was authorized under the Expert Assistance (Equipment Test) Program for the CBDCOM Program Director for Domestic Preparedness.

The use of either trade or manufacturers' names in this report does not constitute an official endorsement of any commercial products. This report may not be cited for purposes of advertisement.

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The Panel reviewed and commented on the test procedures, instrumentation, data analysis and presentation. Their guidance was a valuable element in the development of clear and adequate descriptions of the concepts and procedures used in these tests.

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TEST RESULTS OF LEVEL A SUITS FOR CHEMICAL AND BIOLOGICAL PROTECTION: SUMMARY REPORT

1. INTRODUCTION

In 1996, Congress passed Public Law 104 - 201, 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. DoD responded by forming the Domestic Preparedness Program that same year. One of the objectives of the Domestic Preparedness Program is to enhance emergency and hazardous material response to Nuclear, Biological and Chemical (NBC) terrorism incidents. As part of an effective response, people who are responding to an incident will use personal protective equipment to protect them from exposure to chemical agents or biological agents. The specific personal protective equipment that will be used depends upon the situation that they encounter and what they have on hand. In some cases, Level A protective suits are required to enter a contaminated or potentially contaminated area. Level A suits are totally encapsulated suits that protect the wearer from liquid, vapor and gaseous chemicals and particulates. Air is supplied by self-contained breathing apparatuses or supplied airlines. Appendix A has a list of the Level A suits that are tested in this test program.

2. OBJECTIVES

This study evaluates some commonly used Level A suits to assess how well they resist penetration or permeation[1] by chemical agents GB and HD, the HD simulant methyl salicylate (MS) and a corn-oil aerosol used to simulate biological or chemical particulates greater than 0.4 microns in diameter. This information is intended for emergency responders as an aid in evaluating Level A suits when they choose to include chemical and biological agent protection as a criterion. The information supplements data and information provided by the suits' manufacturers. The suits are 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 protection only[2].

3. TESTING AND DATA ANALYSIS

3.1 Testing Overview.

Testing Level A suits includes a permeation test of material swatches (up to 6 locations) to measure the permeation of both Sarin (GB) and Mustard (HD) through the swatches over 24 hours. The test is intended to assess how well the suit materials and interfaces resist agent permeation. The amount of agent applied and duration of exposure

[1] Throughout this report the terms permeation and penetration are used interchangeably.
[2] Inhalation and ocular protection are typically provided by the use of a self-contained breathing apparatus or air-supplied respirator that covers the eyes, nose and mouth.

does not represent any particular threat that responders may encounter, but it does serve as a common point of reference for all test results. As another point of comparison, 24 swatches of 25-mil chemical agent protective gloves (MIL-G-43976, "Glove Set, Chemical Protective) were tested in a similar manner with each agent. These butyl rubber gloves are commonly used when contact with agent is a possibility and are considered effective protection. System tests are also conducted to measure the total leakage into the suits, when people, as part of a complete personal protective equipment (PPE) system wear them. A system test using volunteers dressed in a Level A suits in a chamber with aerosol simulant is conducted to measure any aerosol leakage into the suit. During the test, the people in the suits are moving in ways that mimic responder movements. The aerosol test is also used to assess protection against biological particulates greater than 0.4 microns. A brief description of the test and movements made by the people during the test are in Appendix C. A second system test, using volunteers wearing the suits in a chamber filled with methyl salicylate (mustard agent simulant) vapor, is used to measure any vapor leakage into the suit. This test was conducted on six suits – one from each manufacturer. The system test (vapor simulant) is described in Appendix D. In simplest terms, protection factor is a measure of challenge outside the suit divided by the concentration inside the suit ensemble. That is the concentration of chemical inside the suit ensemble is expected to be the value of PF times lower than the concentration outside the suit ensemble.

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

3.2.1 Liquid Challenge/Vapor Penetration Testing Procedures.

This testing is conducted to measure the actual permeation of chemical agents GB and HD through swatches taken from the suits. The test methodology is described in appendix B. Three swatches are taken from each of six different areas of the suit – 18 total swatches per suit design for GB and 18 more for HD. Each of the three swatches is placed in a test cell (six material swatches per test and one indicator swatch). Laboratory personnel apply a predetermined liquid agent challenge (10 g/m^2 – a very severe challenge) to the top surface of each swatch. The upper chamber of each test cell is sealed and a 1.0 liter/minute flow of air, from the test chamber, is maintained in the lower test cell chamber beneath each swatch. During the 24-hour test period, gas samples are taken by a MINICAMS from the 1.0 liter/minute airstream beneath each swatch on a sequential basis. A gas sample is taken every 3 minutes by the MINICAMS which determines the amount of agent vapor in each gas sample. By calculation, the MINICAMS determines the amount (nanograms) of agent vapor present in the 1.0 liter/minute airstream for each swatch over the time from the previous gas sample to the current gas sample. This amount of agent vapor is presumed to be the amount of agent vapor that has permeated the swatch over that time interval. A MINICAMS is a miniaturized gas chromatograph and sampling system. With these measurements and knowing the area of the test swatches, it is possible to determine the nanograms per square centimeter (ng/cm^2) that permeate each of the three swatches taken from the six areas of the suit over a 24-hour period. Agent droplets are applied to the surface of the first swatch at time zero. Agent is then applied to the surface of each succeeding swatch at 3-minute intervals. Gas sampling by the MINICAMS begins for the first swatch approximately 3

minutes following agent application. The MINICAMS 3-minute cycle is composed of 2 minutes of desorption of collected agent vapor from the pre-concentrator tube (PCT) onto the column followed by 1 minute of gas sampling (collection of agent vapor in the PCT). Sampling is done sequentially through the six swatches (3 from one sampling area followed by 3 from a second sampling area), the silicone indicator and then three blank gas samples are taken from the test chamber to purge the sampling line prior to beginning the sampling sequence again. The six samples, the indicator swatch, and three blanks are all sampled for the first time within the first 30 minutes. Then the sampling sequence begins anew. For ease of comparison and analysis, the data for each suit is presented at an average elapsed time that the sample is taken for all seven samples in a test. The first average elapsed time is 12 minutes (3+6+9+12+15+18+21 divided by 7 = 12). The average elapsed times presented in the Tables and Figures are: 12 minutes, 42 minutes, 72 minutes, 102 minutes, 6 hours (360 minutes), 12 hours (720 minutes), 18 hours (1080 minutes), 24 hours (1440 minutes).

3.2.2 Liquid Challenge/Vapor Penetration Testing Analysis. Each suit has permeation data for 18 swatches and two agents over a 24-hour period. Data are taken for each of the three swatches from one sampling area tested with one of the agents. For this report, the average permeation (M_f - the cumulative mass of agent penetrating the swatch per unit area during an elapsed time) of the three samples is presented at each of the reported elapsed times to represent the suit's permeation resistance. A sample table with average cumulative permeation at elapsed times is shown as Table 1 and a corresponding graph, plotted for each of the suits, is shown in Figure 1. The weighting factors shown for each swatch location were assigned roughly on the basis of surface area with all values greater than 5%.

A graph containing only the data for the first 480 minutes[3] (8 hours or 1 standard workday) is shown as Figure 2.

While Figures 1 and 2 provide useful information about permeation at different locations on the ensemble, it is difficult to use these charts. One can create a composite graph by assigning a weighting factor to each of the six swatch locations. With this technique, a composite weighted permeation is derived and one can easily compare the results of one suit to another. The weighting factors shown in Table 2 were assigned roughly on the basis of surface area with all values greater than 5%. A sample composite graph for 480 minutes is shown in Figure 3.

[3] Generally, breakthrough times that exceed 480 minutes are shown as ">480 min" in Tables of breakthrough values in manufacturers' material data sheets. See paragraph 3.2.4 for additional information related to breakthrough time and breakthrough criteria.

Table 1. Suit XXXX - Illustrative Average Agent (GB or HD) Permeation
(Nanograms/cm^2)

Time (min)	suit mat'l 50%	visor mat'l 15%	glove 10%	suit seam 15%	suit/visor 5%	zipper seam 5%	Cumulative Weighted Average
12	3.33	45.7	44.2	11.33	100.7	49.33	22.1
42	6.40	120.3	80.5	14.87	153.9	72.50	46.1
72	14.7	120.3	105.3	19.50	193.7	112.3	54.6
102	45.7	120.3	160.3	60.33	276.7	200.7	93.2
360	456.7	345.7	1504	482.0	692.0	4514	768
720	1287	360.3	3514	635.0	1483.3	14597	1948
1080	1424	360.3	5773	791.3	1909.7	25630	2839
1440	1568	360.3	8908	903.7	2539.7	35650	3772

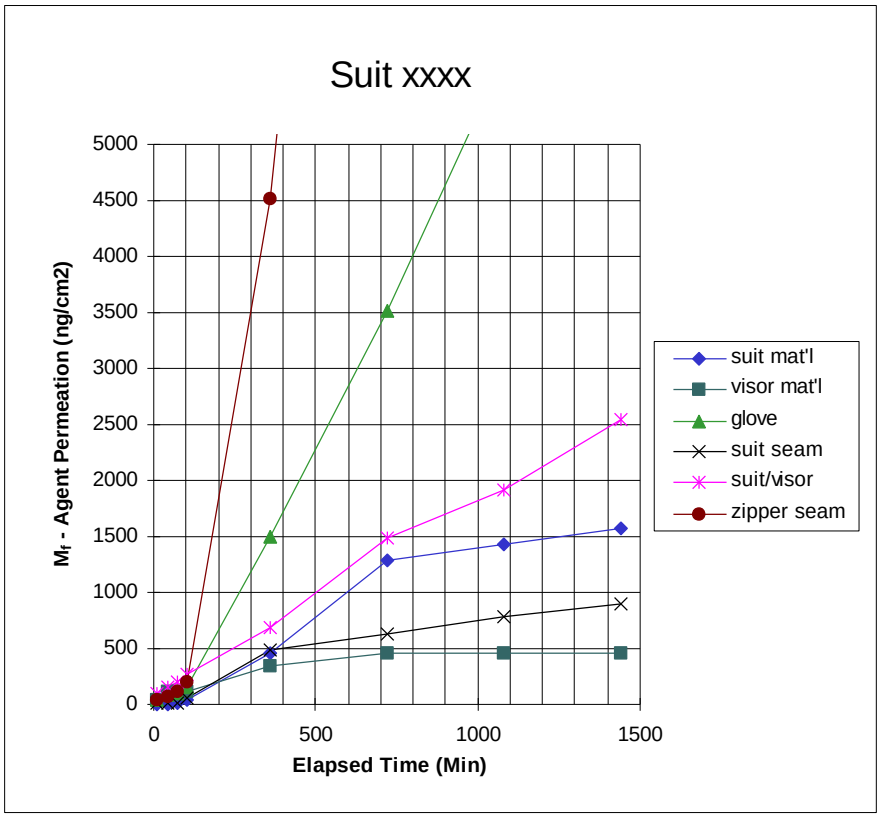

Figure 1. Illustrative Liquid Challenge/Vapor Penetration Test Results

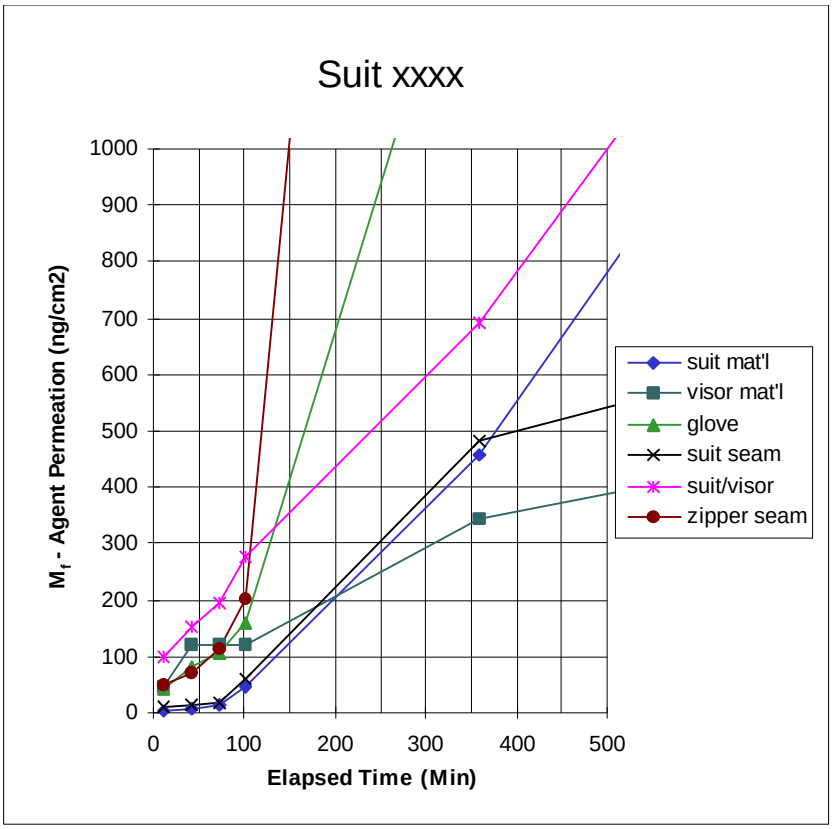

Figure 2. Illustrative Liquid Challenge/Vapor Penetration Test Results (480 Minutes Only)

Table 2. Weighting Factors For Each Swatch Location

Suit material	50%	Visor material	15%
Seam material	15%	Glove material	10%
Visor/suit interface	5%	Zipper/material seam	5%

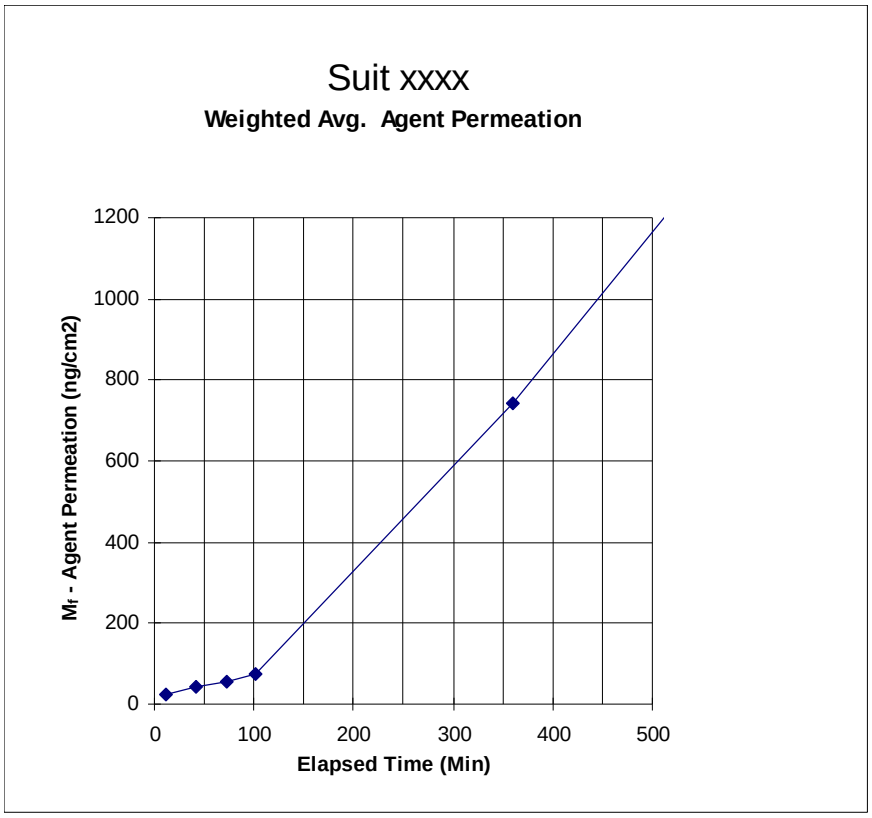

Figure 3. Illustrative Composite Liquid Challenge/Vapor Penetration Test Results

3.2.3 Correlation between Liquid Challenge/Vapor Penetration Test Results and Skin Exposure.

Liquid challenge testing is performed by placing a significant amount (10 g/m^2) of liquid agent on one side of material swatches. MINICAMS are used to measure the amount that permeates through the material at regular time intervals over a 24-hour period. The test is designed to distinguish among the permeation resistances of these materials to chemical agents. It's not intended to specifically replicate threat scenarios that may be encountered in actual use. This is a very severe challenge for a long period of time. Nonetheless, it is instructive to determine the agent dosage that would result from such a standard agent challenge as a relative indication of possible physiological effects. The first step is in correlating the measured test results to equivalent agent dosages. A complete derivation of the relationship is provided in Appendix E. For suit materials impermeable to airflow, the correlation is:

$$\text{Agent Dosage (mg-min/m}^3\text{)} = \frac{\text{Measured test results (ng/cm}^2\text{)}}{\text{Skin permeation (cm/min)}}$$

where skin permeation is 2 cm/min for HD and 0.1 cm/min for GB.

3.2.4 Test Criteria for Liquid Challenge/Vapor Penetration Testing.

When analyzing the test results it is useful to determine whether the data indicate that the Level A suit provides percutaneous protection over some period of time[4]. HD vapors can produce erythema (reddening of the skin) at dosages of approximately 100 mg-min/cm^3, and can produce vesication (skin burns and blisters) at 200 mg-min/m^3. GB vapors can produce incapacitation at dosages of approximately 8000 mg-min/m^3 and can cause lethality at dosages of 15000 mg-min/m^3 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 Cts. Using these values and applying the skin permeation factor yields a value that can be used on the agent permeation charts to show how much agent per unit area would have to penetrate the suit to produce a predetermined physiological effect. These values are summarized in Table 3. The breakthrough criteria are considered 100 mg-min/cm^3 for HD (reddening of skin) and 8000 mg-min/m^3 for GB (incapacitation – twitching, convulsions or loss of consciousness). A breakthrough time is the time when M_f (for the weighted composite of all six swatch types for an agent) equals the breakthrough dosage criterion. Illustrative charts depicting the breakthrough criteria and breakthrough times for agents HD and GB of Suit XXXX are shown in Figures 4 and 5.

Table 3. Agent Breakthrough Criteria

Agent	Dosage (mg-min/m^3)	Physiological Effect	Skin Permeation Rate (cm/min)	Breakthrough Criteria (ng/cm^2)
HD	100[i]	Erythema	2	200
HD	200[i]	Vesication	2	400
GB	8000[ii]	Incapacitation	0.1	800
GB	15000[ii,iii]	Lethality	0.1	1500

[4] Inhalation and ocular protection are provided by the proper use of self-contained breathing apparatus that seals around the eyes, nose and mouth.

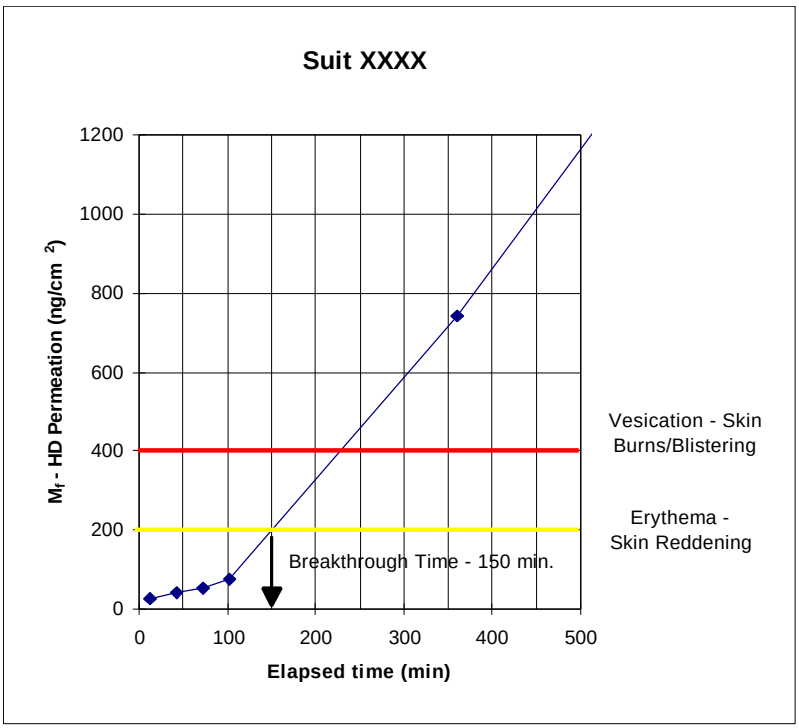

Figure 4. Illustrative Composite Liquid Challenge/Vapor Penetration HD Results for Suit XXXX

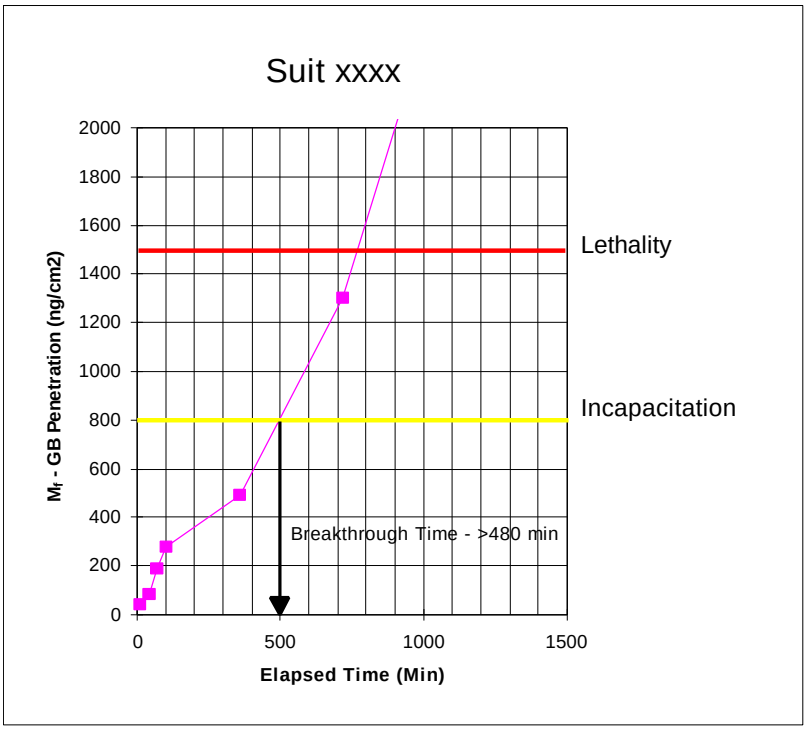

Figure. 5: Illustrative Composite Liquid Challenge/Vapor Penetration GB Results for Suit XXXX

Standard 25-mil, thick butyl rubber, chemical protective gloves are also tested with both GB and HD. Twenty-four swatches of material are tested with each agent for cumulative agent permeation and the average cumulative agent shown in Figure 6. Since these gloves are approved for Army use, it's useful to compare the permeation test results for both agents of the Level A suits and the standard chemical protective gloves. These gloves might also be used with any suits that do not have integral gloves. A sample chart is provided as Figure 7.

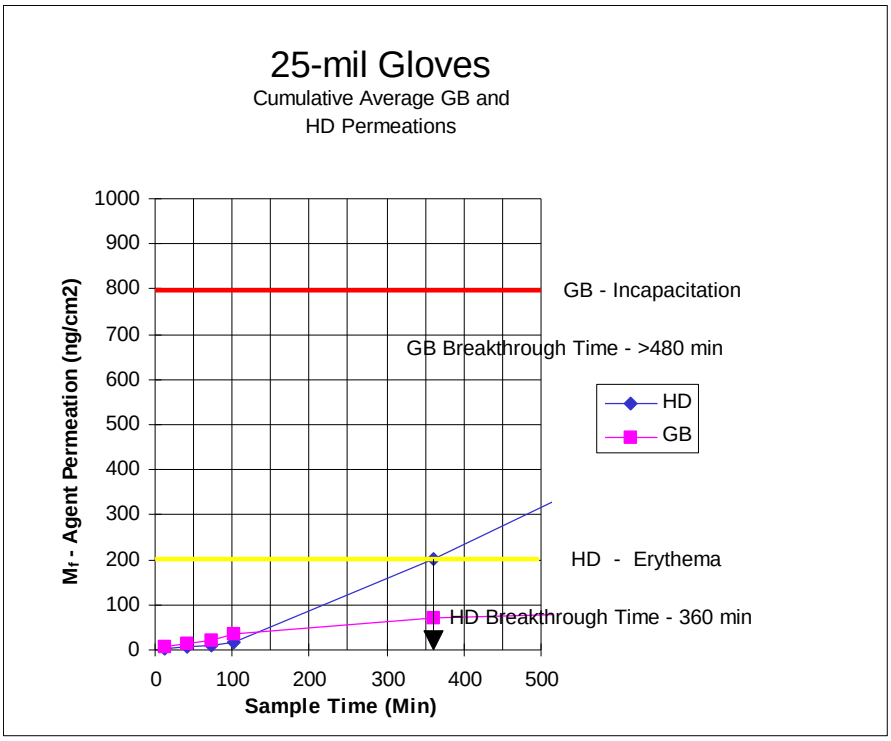

Figure 6. Cumulative Agent Permeation of GB and HD Through 25-Mil Chemical Protective Glove

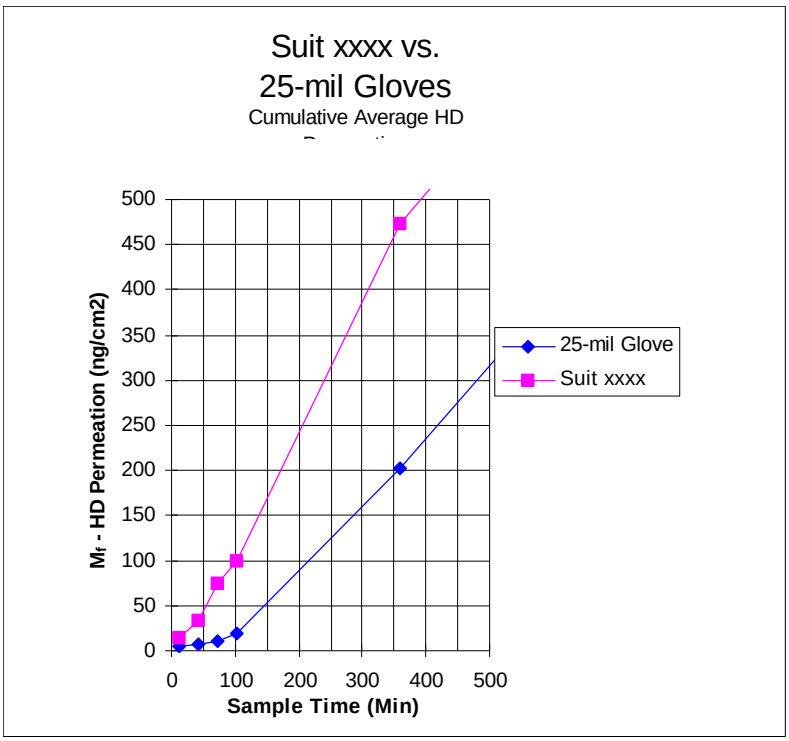

Figure 7. Illustrative Composite Liquid Challenge/Vapor Permeation HD Results for Suit XXXX Liquid

3.3 System Test (Aerosol Simulant)

3.3.1 System Test (Aerosol Simulant) Test Procedures.

The testing is conducted to determine leakage of a challenge corn-oil aerosol (physical simulant of a biological agent aerosol) into a suit ensemble using people and ensembles of different sizes[iv]. Eight different ensembles are tested when worn by people using a self-contained breathing apparatus performing prescribed pre-operational and operational exercises. These exercises are described in Appendix C. Samples are taken continuously at the visor and upper arm within the suit and are measured, recorded and displayed continuously on a computer monitor. The raw protection factor (PF) data are analyzed using a binomial comparison based on predetermined protection factor pass levels. These predetermined PF levels range from 10 to 100,000. At each of the predetermined PF levels, a percentage of the suits that have passed that PF level is calculated and presented.

3.3.2 System Test (Aerosol Simulant) Analysis.

This report presents results such as that shown in Table 4 for each suit ensemble tested. The sample table shows what percentage of suits exceeds a given PF value. The higher percentage that passes at a given PF, the more protection (less leakage) provided by the suit. A complete technical report will be or has been prepared for each suit ensemble containing all system test (aerosol simulant) results.

Table 4. Suit XXXX - Illustrative System Test (Aerosol Simulant) Results

Pre-Operational Exercises Visor Region/Upper Arm Combined				**Operational Exercises Visor Region/Upper Arm Combined**			
PF	*Frequency*	*Cumulative %*	Pass %	*PF*	*Frequency*	*Cumulative %*	Pass %
10	0	0	100	10.0	0	0	100
50	2	8	100	50.0	0	0	100
100	2	16	100	100.0	0	0	100
500	2	24	100	500.0	0	0	100
1000	0	24	76	1000.0	0	0	100
1667	2	32	68	1667.0	0	0	100
2000	2	40	60	2000.0	2	8	92
5000	10	80	20	5000.0	1	12	88
6667	3	92	8	6667.0	4	28	72
10000	2	100	0	10000.0	11	72	28
20000	0	100	0	20000.0	7	100	0
50000	0	100	0	50000.0	0	100	0
100000	0	100	0	100000.0	0	100	0
	25				25		

3.4 System Test (Vapor Simulant)

3.4.1 System Test (Vapor Simulant) Test Procedures.

These tests were conducted to determine the protection provided by a complete protective garment/mask/ boot/glove ensemble against chemical warfare agents through the use of non-toxic simulants (methyl salicylate - MS). The test analysis procedures are based on the Body Region Hazard Analysis (BRHA) process developed by Fedele and Nelson[v]. This analysis uses actual skin adsorption data on agents and simulants and is modelled to predict the Minimum Required Exposure Dosage (MRED) to which an individual must be exposed to in order to produce end-point reactions in the body for systemic (nerve agent) and localized (mustard) exposure to agents. These reactions are headache and miosis for GB and erythema (reddening of the skin) for HD. The MREDs provide an indication of the concentration of agent needed outside the suit to produce an endpoint effect at the skin area listed, which may be used to calculate a stay time for a wearer of the suit (only valid if exact measurements of the agent are known). The range of overall protection factor is determined for each suit model. No other specific protection factor criterion for suit ensembles besides the BRHA Process exists. A complete description of the test procedures is provided in Appendix D.

The tests were conducted by placing diffusive dosimeter samples on 10 different skin locations of the test subjects, dressing them up in the Level A suit ensembles, and exposing them to the MS vapors in a controlled chamber environment. Fourteen different ensembles were tested when worn by people using a self-contained breathing apparatus performing prescribed exercises. Samples were removed and analyzed to determine how much methyl salicylate was adsorbed at each sample location. The mass from each sample was divided by the product of the sampler flow rate and the effective sample time to yield a concentration that was present at that skin region during the test. The concentration was multiplied by the exposure time to yield the exposure dosage, and this value was divided into the net challenge exposure dosage to produce a Protection Factor (PF) for that skin region. The BRHA process uses these PF values, along with skin area-dosage factors (amount of agent that must be adsorbed at a specific skin region to cause end-point effects multiplied by the area of skin at that region) to calculate an Overall PF for the suit ensemble. The Overall PF is based upon 27 skin regions and performs a summation of all the dosages that are adsorbed at each region to produce a 'skin area weighted' average PF for the suit. This Overall PF is the relative protection the suit ensemble provides the wearer when compared to an exposed individual who is not wearing the suit.

The Systemic MRED for each suit tested was calculated by multiplying the Overall PF by the dosage of agent that must be adsorbed by the body in order to incur an end-point affect. The generally accepted value of 10 mg-min/m^3 for the nerve agent VX (which is the nerve agent that the BRHA model is based on for systemic reactions) was used. This is a conservative value that is generally believed to be the dosage at which miosis or headache occurs, but was still used to provide a safety factor into the values given to the general public.

The localized MRED was calculated straight from the BRHA process. These values were obtained by multiplying the skin region PF by a factor that represents the dosage of mustard that has been shown to cause erythema at that skin region. These values are different from those listed in Table 3; the values listed there are an average value for the entire body. The values used in the BRHA process are derived specifically from each skin area's sensitivity and measured adsorption rate of mustard.

3.4.2 System Test (Vapor Simulant) Results Presentation.

This report presents system test (vapor simulant) results such as that shown in Table 5 for each suit ensemble tested. A complete technical report will be or has been prepared for each suit ensemble that will include all system test (vapor) results. Summary overall test results for each suit model are presented as shown in Table 6. For tables containing the summary results, the aerosol simulant data is presented for PFs of 100, 1000 and 2000 only for both pre-operational and operational exercises. For the vapor simulant test, the table contains the minimum, maximum and median PF values. For both vapor and aerosol simulant tests, we felt these PFs would be of most interest to potential users of the suits.

Table 5: Suit XXXX: Illustrative System Test (Vapor Simulant) Results

Suit	Overall PF	Systemic MRED (mg-min/m^3)	Localized MRED (mg-min/m^3)	Skin Area Affected
1	2754	27540	244900	Chin & Neck
2	2361	23610	38160	Back
3	2312	23120	98960	Abdomen
4	2037	20370	108100	Arm
5	3093	30930	35390	Leg
6	1501	15010	20460	Groin
7	3750	37500	267500	Popliteal Space
8	2691	26910	128500	Arm
9	4446	44460	48810	Groin
10	1651	16510	16920	Abdomen
11	2131	21310	74010	Chin & Neck
12	2683	26830	66780	Groin
13	3493	34930	268400	Chin & Neck
14	6017	60170	429300	Chin & Neck

Overall PF (Median)	Overall PF (Minimum)	Overall PF (Maximum)	Average Systemic MRED	Average Localized MRED
2723	1501	6017	18230	113800

Table 6. Suit XXXX - Illustrative Overall Test Results

Breakthrough time (minutes)		Aerosol PF Pass Rate at PF equal to:				Overall Vapor PF		
incapacitation	erythema							
GB	HD	100	1000	2000		Min	Median	Max
>480	130	91.5	87.2	78.7	(Pre-op)	1501	2723	6017
		100	95.6	86.8	(Operational)			

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ACRONYMS

C - concentration
cm – centimeters
DoD – Department of Defense
F – flow
f – flux
g - grams
GB – Sarin
HD – Mustard agent
JSLIST - Joint Services Lightweight Integrated Suit Technology
m – meters
M_f - the cumulative mass of agent penetrating the swatch sample per unit area during an elapsed sampling time
mg – milligrams
MIST – Man-in-Simulant Test
MRED - minimum required exposure dose
MS – methyl salicylate (HD simulant)
NBC – Nuclear, Biological and Chemical
NFPA – National Fire Protection Association
ng – nanograms
PF – Protection Factor
PPE – Personal Protective Equipment
q – volume flow into fabric
RH – Relative Humidity

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Appendix A: Level A Suits Chosen for Testing and Their Characteristics

Table A-1. Level A Suits Tested

Model	Manufacturer
Kappler Suit Model 42483 Kappler Ensemble Model 50660	Kappler Protective Apparel and Fabrics
Tychem 10,000 Package Style No. 12645 Tychem 10,000 Package Style No. 11645	Lakeland Industries, Inc.
Commander Ultrapro Suit, Style 79102 Commander Brigade Ensemble, Style 10000 F91	MAR-MAC Manufacturing, Inc.
Ready 1 Limited Use Suit: Model 91 Chemturion Suit: Model 13	ILC Dover, Inc.
First Team XE HazMat suit Chempruf II BETEX suit	Mine Safety Appliances Co.
Trellchem HPS suit Trellchem TLU suit	Trelleborg Viking, Inc.

Table A-2. Level A Suit Characteristics

Model	Multiple uses	NFPA Certified
Kappler Suit Model 42483	Yes	No
Kappler Ensemble Model 50660	Yes	Yes
Tychem 10,000 Package Style No. 12645	Yes	Yes
Tychem 10,000 Package Style No. 11645	Yes	Yes
Commander Ultrapro Suit, Style 79102	Yes	Yes
Commander Brigade Ensemble, Style 10000 F91	Yes	Yes
Ready 1 Limited Use Suit: Model 91	No	No
Chemturion Suit: Model 13	Yes	No
First Team XE HazMat suit	Yes	Yes
Chempruf II BETEX suit	Yes	No
Trellchem HPS suit	Yes	Yes
Trellchem TLU suit	No	No

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MODIFIED STATIC DIFFUSION TEST

This test procedure was adapted from the "Semipermeable and Impermeable Materials Static Diffusion Penetration Testing (Liquid Agent Challenge/Vapor Penetration; delta p = 0, Single Flow Test) given in TOP 8-2-501 dated 03/03/97.

The following procedure will be used:

1.Upon receipt of a suit, all available information concerning the suit will be recorded; date of manufacture, lot number, serial number, materials of construction, etc.

2. From each suit, 3 ea 1 and 15/16-inch diameter material swatches will be taken for HD and a like number taken for GB. Depending upon the suit configuration, 3 seam swatches (same diameter) will be taken plus triplicate swatches of other flat components such visor, gloves, suit/visor interface and zipper/material interface for HD and an equal number 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. Alternatively, the swatches for each day's test will be cut from the suit and placed in the environmental chamber for conditioning. Sample identification will accompany each swatch.

3. The environmental chamber will be controlled at a temperature of 90 +/- 2 deg F and the maximum achievable relative humidity without occurrence of condensation (50% +/- 10% RH). The temperature and RH readings will be checked weekly with a calibrated meter. The test cell air will be drawn from the chamber air. There will be no system control and data acquisition system. The temperature and RH will be recorded in a computer file. Flow rates will be manually recorded. There will be no differential pressure monitoring since differential pressure gages of sufficient sensitivity are not available.

4. The TOP test cell will be used. When assembling, the cell lugs will be tightened by hand to finger tight. The flow rate beneath each swatch will be 1 liter/minute, which will be controlled by a linear mass flow controller. The flows will be checked with a calibrated test meter weekly. 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. If the flows don't match; the test cell will be disassembled, adjustments made, the test cell reassembled and flows rechecked.

5. Negative controls will not be used. The swatches will be preconditioned for at least 2 hours and will be monitored by MINICAMS for at least one cycle prior to agent application. Eighty mil silicone will be used as a reference material for each test (6 suit swatches and 1 silicone swatch).

6. Agents GB and HD will be used. The contamination density will be 10 g/m2 (8 ea 1 microliter HD droplets or 10 ea 1 microliter GB droplets). A robotic agent application system is not available. The agent will be applied using the click/touch method with a Hamilton repeating dispenser.

7. Seven swatches will be tested at once. MINICAMS with stream selection system will monitor vapor penetration with a 3-minute cycle. There will be 3 sampling intervals following the silicone where chamber air will be sampled. Each swatch will be sampled once every 30 minutes. The MINICAMS will be standardized weekly with a range of agent standards; concentrations will normally range from 1 nanogram/microliter to 100 nanograms/microliter.

8. The test length will be 24 hours.

9. The test cells and o-rings will be aerated between uses. No other cleaning method will be used.

10. The data to be reported are cumulative penetration (ng/cm2) versus elapsed time (minutes) for each swatch. The elapsed time is the time from agent contamination for each swatch plus 30 minutes (one MINICAMS cycle prior to agent contamination). All recorded data will be placed in laboratory notebooks and one technical report per suit will be drafted at the conclusion of this effort.

11. For entry into the DP database, the data for each swatch will be reported as cumulative penetration for the first 4 sampling intervals (approximately 12, 42, 72 and 102 minutes), at approximately 6 hours, 12 hours, 18 hours and 24 hours.

APPENDIX B

Appendix C: System Test (Aerosol Simulant)

In order to properly test suits with statistical significance, 8 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 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 10 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:

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 3lb. boxes from table to floor
3) rest
4) roll walls and ceiling
5) bag clothes
6) rest
7) loosen bolts
8) move 3lb boxes from floor to table

Note: The phase 1 (pre-operational) exercises are performed for 1 minute each for a total of eight minutes. The phase 2 (operational) exercises are performed for four minutes each for a total of 40 minutes.

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Appendix D. System Test (Vapor Simulant) - [Man In Simulant Test (MIST) Protection Factor Testing of Individual Protection Equipment Suit Ensembles]

D-1 Introduction and Scope of Testing.

This testing was conducted according to guidelines set forth by the Joint Services Lightweight Integrated Suit Technology (JSLIST) working group, specifying test methods capable of accurately measuring a protection factor (PF) greater than 1,000. The maximum PF that could accurately be measured in this testing was around 10,000. This involved the use of passive sampling devices mounted beneath the clothing of the test subjects to sample the vapors at a rate consistent with the body's uptake rate of agent, as determined in the JSLIST research study on passive sampling devices[vi]. The sizes used for this testing were matched to the size of the test subject, a total of fourteen suits were used for each suit tested. The testing conducted was similar to that performed on the Kappler First Responder© suit in July of 1995[2] when this suit was evaluated for possible use by emergency personnel in the event of a chemical agent release from the Tooele Army Depot's demilitarization facility.

In each of four trials, four test subjects dressed in the protective ensemble and were exposed to a high concentration of methyl salicylate (MS) vapor. The JSLIST working group selected this simulant for the agent mustard (HD) for use in testing under the JSLIST program. Each trial exposed the test subjects to an MS concentration of 50 mg/m^3 in a chamber for a total of 30 minutes. The test subjects performed a series of exercises while exposed to the MS vapors. Vapor concentrations were measured at several locations beneath the suit with passive sampling devices (PSDs). The PSDs contained the solid adsorbent Tenax, which the JSLIST working group had chosen as the best adsorbent for use with MS[vii].

The configuration of the protective suit ensemble tested was as follows. The test subjects wore shorts and t-shirts underneath the suit ensemble. PSDs were affixed directly on skin areas or on the underclothing. Self-Contained Breathing Apparatus was put on and then the suit was donned and sealed up according to the manufacturer's specifications. All subjects were trained in the use of the suit according to the manufacturer’s use instructions prior to testing.

D-2. **TEST EQUIPMENT AND PROCEDURES**

D-2.1 **<u>Test Facility</u>**.

The tests were conducted in the MIST test facility in building E5354 in the Edgewood Area of Aberdeen Proving Ground, MD. The exposure chamber is 40 ft by 20 ft by 14 ft high and contains an evaporative-blower vapor generator controlled by a data acquisition system (DAS) with feedback concentration readings generated by a Foxboro Miniature Infra-Red Gas Analyzer (MIRAN©). The challenge concentration in the chamber was measured during the exposure period with two MIRAN©s. The location of the MIRAN©’s sampling point were as follows: one sample was taken in the front of the chamber right in the area where the subjects performed the exercises, the other sample point was in the rear of the chamber. All MIRAN© readings were recorded by the DAS and the average of the two was used in the data analysis. A layout of the test area and apparatus is shown in Figure D-1.

A four-stage clean-room was erected in a bay area adjacent to the exposure chamber and was occupied by test subjects during application and removal of the sampling devices. This clean-room consisted of two airlocks and two 16-ft enclosures of the U.S. Army M28 shelter system. The enclosures, made of a chemically resistant plastic material, were pressurized with filtered air from Nuclear, Biological, and Chemical (NBC) filter units of the M28. A 600-cfm unit was used to pressurize the clean room area (Enclosure 4 of Figure D-1), and two 200-cfm units were used to pressurize the doffing room area (Enclosure 2 of Figure D-1), for a total clean airflow of 1000 cfm.

APPENDIX D

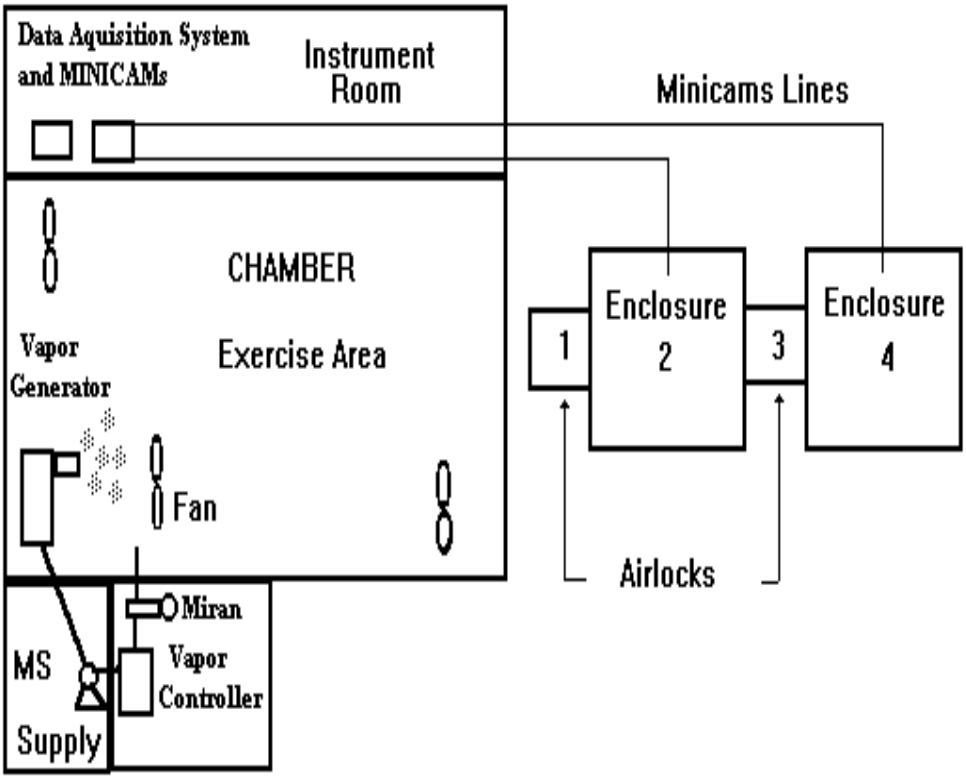

Figure D-1. Chamber and Clean-Room Layout

D-2.2 **Air Sampling Devices for Measuring Concentration Inside Suit.**

PSDs developed by the Natick Research, Development and Engineering Center (NRDEC) were used to sample for MS vapors beneath the suit. The Natick sampler is the passive sampler used in this testing and has been approved by the JSLIST committee for sampling individual protective equipment suits. This PSD contains the solid adsorbent material Tenax**Ò** TA in a small plastic pouch and samples air by capturing the MS vapors onto the adsorbent material. This device samples the air beneath the suit by diffusion (molecular transport) with the rate of diffusion into the adsorbent controlled by the exposed layer of polyethylene film. The sampling rate for the lot of PSDs used in this testing was determined experimentally; the average rate was found to be 14.60 ml/min with a standard deviation of 0.13 ml/min. The adsorption velocity, or uptake rate, of the PSDs is very similar to the skin's adsorption rate of chemical agents.

The PSDs were handled with specific procedures to minimize the potential for contamination. The filter units that pressurized the clean room areas were run overnight to make sure that no trace levels of MS were present during the testing. The concentration in the clean room where the PSDs were applied to the subjects was monitored throughout the entire test period. Test technicians who worked in the clean room area washed their hands prior to handling any PSDs and were not allowed to come into any contact with the MS vapor generation equipment. They were applied to test subjects in the fourth stage of the clean-air room as the subjects put on the suit and were also removed in the fourth stage at the completion of each trial. After

removing the PSD, the plastic pouch of the patch samplers was cut with a razor knife (on one end), and a sorbent tube connected to a vacuum pump was used to remove the adsorbent. The adsorbent was then packed in with a screen after removal from the PSD sampler and sealed. The tube ID was recorded to ensure accurate PSD sample identification. The tubes were then analyzed with a flame ionization detector (FID) on the Perkin Elmer Autosystems Gas Chromatograph (GC) and the ATD-400 thermal tube desorber according to guidelines determined in the JSLIST research study[viii]. Background samples were also analyzed.

D-2.3 **Applying PSDs to Test Subjects**.

The PSDs were placed at 10 locations beneath the suit of each test subject, as listed below and depicted in Figure D-2. They were placed either directly on the skin at these locations or on the inside of the underclothing (T-shirts and shorts).

(1) Center of back, between shoulder blades

(2) Center of chest (3 duplicate PSDs used at this location)

(3) Center of back, lumbar, at upper buttocks

(4) Left axillae, on ribs

(5) Right upper arm, outer dorsum

(6) Right lower arm, outer dorsum

(7) Center of abdomen, low, into the groin area

(8) Mid-right, outer thigh

(9) Mid-right, outer lower leg

(10) Neck

The following procedures were used to apply the PSDs to test subjects to ensure minimum potential for contamination and allow measurement of the background levels of simulant during the analysis.

Dressing took place in the fourth (cleanest) stage of the clean room enclosure. Subjects operated in pairs during the testing; this was performed due to the limitation of having no more than two people in the airlock at one time during purge operations upon re-entry to the clean room areas. Test subjects dressed in gym shorts and T-shirts before entering the clean room. When they entered the clean room, they were given new suits, SCBA mask, and overboots (which had been pre-positioned in the clean room). The PSDs, sealed in appropriate containers, and data forms were also pre-positioned. The PSDs were removed from the storage containers and placed on the subjects at the 10 designated locations. The PSDs, which have adhesive backing, were applied directly to the skin, or to the inside of the gym shorts or T shirt (if worn). The identification number of each PSD was recorded for each location.

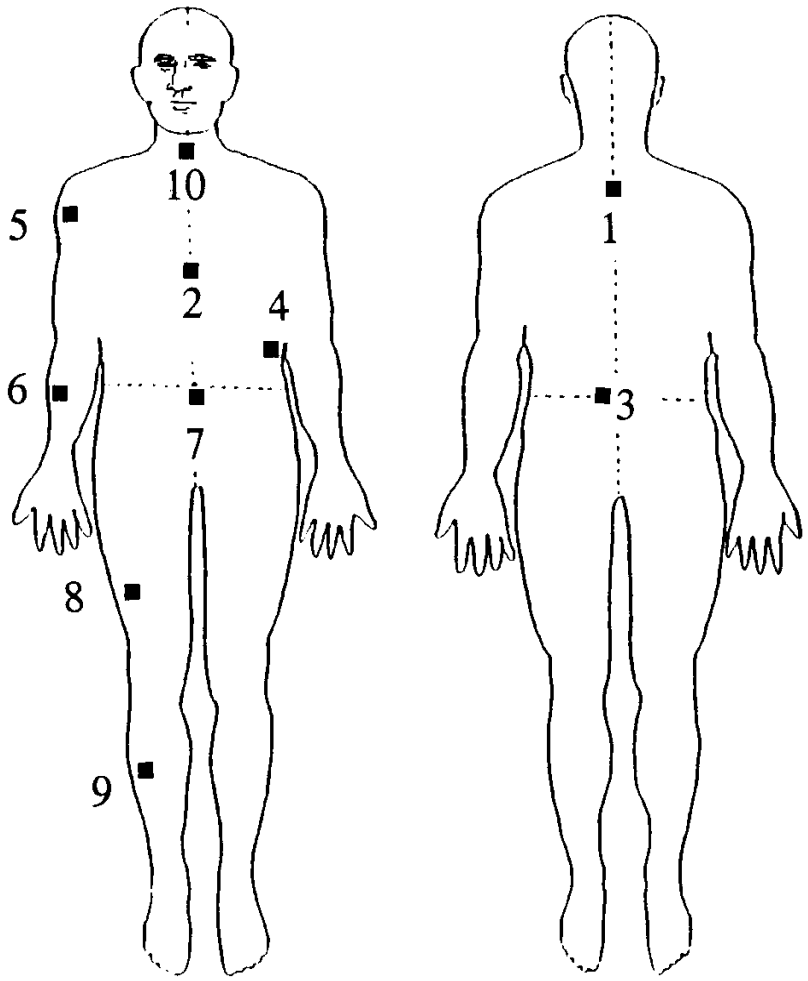

Figure D-2. PSD Sample Locations.

Once initiated, the application of the PSDs was completed as rapidly as possible. Normal application of samplers took about two minutes. Then the SCBA mask was donned, a one-hour tank for the SCBA was worn on the back, and the suit was donned and sealed completely. Each subject was checked to ensure proper closure and fit of all of the gastight zipper closures. The subjects then proceeded out the airlock and entered the exposure chamber. This total procedure generally took between five and ten minutes.

D-2.4 **Procedure for Challenging the Suit**.

The test involved a controlled sequence of steps performed to keep the samplers free of background contamination and ensure accuracy of the results. The procedure is described below.

Subjects were briefed on the test procedures and entered the clean room, enclosure 4 in Figure D-1, to have the passive samplers applied and don the suit ensemble. Once dressed, the subjects passed through the transition airlock (enclosure 3 of Figure D-1), doffing room (enclosure 2 of Figure D-1)

and exited through the entry/exit airlock (enclosure 1 of Figure D-1). A test technician escorted the subjects into the chamber and recorded the time of entry. The chamber was prepared by bringing the MS concentration to 50 mg/m^3 before the subjects exited the clean room. Temperature and concentration readings in the chamber and in both clean-air rooms were recorded on the DAS. Once inside the chamber, subjects performed the activities listed in Table D-1. Each of these exercises was performed twice during the 30-minute exposure interval. Subjects rested for about one minute after each exercise.

Table D-1. Exercise Regimen

Stationary run	1 minute
Jumping jacks	2 times
Trunk twister	2 times
Bend and reach	2 times
Back stretcher	2 times
Bent knee leg lifts (left and right)	10 times
Vertical reach and grasp (left and right)	1 minute
Lifting box from ground to table and return	1 time
Squat down, kneel on one knee	3 times

3.5 **Procedures for Removing PSDs**.

Because the outer garments desorb significant amounts of MS in a clean area after prolonged exposure to high concentrations of vapor, doffing took place in stages in the clean room with the following procedures.

After completing the 30 minute exercise, the subjects were escorted from the chamber and processed into the clean room in four stages (see Figure D-1):

- **Stage 1** -- Entry/exit airlock. The subjects exited the chamber, entered the airlock (enclosure 1), and set the purge timer for 5 minutes. They remained fully dressed while airflow through the airlock purged any vapor brought in with them. This period also allowed for some desorption of MS vapor from the outer surfaces of the ensemble.

- **Stage 2** - Once inside the doff room (enclosure 2), each subject removed their ensemble with the assistance of a technician. Suits, overboots, and masks were placed in plastic bags to minimize the quantity of MS introduced. The subjects proceeded without delay to the next stage for removal of the PSDs. This process was completed in approximately 2 minutes.

- **Stage 3** - Transition airlock. In this airlock (enclosure 3), the subjects proceeded without delay to the final stage to remove the PSD samplers.

- **Stage 4** - In this clean-room shelter area (enclosure 4), the PSDs were removed from the subjects and placed on data sheets according to their position on the body of the subject. The subjects then exited the clean room through the transition airlock. Adsorbent was transferred from the passive samplers to individually numbered sorbent tubes. The sorbent tubes were capped to preserve each sample for analysis.

D-2.6 **Procedures for Analyzing Samples**.

Sorbent tube PSDs were analyzed on the Perkin Elmer Autosystem GC system, which includes the Automatic Thermal Tube Desorber (ATD-400) and the Turbochrom data acquisition system. The detector used in the GC for analysis of the samples was a Flame Ionization Detector (FID). The Turbochrom computer data acquisition system integrated the area beneath the peaks to determine the mass of each individual component in terms of Fg. The Turbochrom system was calibrated with chemical standards injected onto cleaned sorbent tubes (analyzed on the ATD-400/Autosystems GC system). Quality Control checks were performed each test day to ensure that the GC was functioning properly. Injections of standards were made throughout the mass range that was anticipated to be analyzed. Tubes were not analyzed if the QC checks showed a deviation greater than 10% from the mass injected.

D-2.7 **Quality Assurance/Quality Control Procedures**.

Tenax sorbent provided to the manufacturer of the PSDs was purified and certified clean by an independent laboratory at Pennsylvania State College. The purification process involved supercritical liquid extraction followed by heating and purging with carrier gas. The adsorbent was then sampled and analyzed by gas chromatograph analysis to ensure adequacy of the cleaning; strict purity protocol requirements were followed. Following receipt of the samplers from the manufacturer, the sorbent from a PSD sampler was checked again at the ERDEC lab to determine sampling rate and residual levels of MS. The MIRAN© used to control the level of MS vapor in the chamber was also calibrated before the testing and checked for proper zero level.

During each pre- and post-trial period in which the PSDs were being mounted, removed, and transferred to sorbent tubes in clean room area, three PSDs designated as "open blanks", were removed from their storage containers and exposed to the clean-room environment. These samples were analyzed to measure background levels of MS present during instrumentation, dressing, doffing, and removal of samplers and not related to the exposure in the chamber (these levels were generally very low).

D-3. **METHOD OF ANALYSIS**

D-3.1 **PSD Concentrations and Protection Factors**.

The concentration of MS (C_{ms}) sampled by each interior PSD was calculated by dividing the total mass of MS on each PSD measured in the GC analysis (☞g) by the product of the sampling rate of the PSDs (in ☼/min) multiplied by the total sampling time of each PSD (in minutes) (see equation D-1). The averaged mass from the open background PSD samples was subtracted from each samples' mass before calculating the concentration to correct for incidental exposure of the PSDs during donning, doffing, transfer, and storage. The PSD concentration for each body area was calculated using the following equation:

$$C_{ms} = \frac{\text{Mass of MS from PSD - Mass of MS from Background}}{\text{Sampling Rate of PSD x Exposure Time}} \qquad \text{(D-1)}$$

Each PSD concentration was converted to a dosage by multiplying by the exposure time. The concentration of MS in the chamber was averaged from the MIRAN© data file and the total exposure dosage during each trial was calculated by multiplying by the exposure time. This value was used in the calculations of the protection factor (PF) at each body area.

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Individual body region PFs were determined by dividing the exposure dosage by the dosage detected inside the suit at each location. The PF calculation is expressed mathematically in equation D-2:

$$PF = \frac{\text{Average Exterior Concentration x Time}}{\text{Average Concentration Inside Suit x Time}} = \frac{\text{Exterior Dosage}}{\text{Dosage Inside Suit}} \qquad \text{(D-2)}$$

The PF values were tabulated for each different body area.

The mass analyzed from each PSD was examined to determine if it was significantly different from the mass of the averaged background samples. This process was performed by subtracting the averaged background mass plus one standard deviation (of the average) from the mass of each PSD and determining if the result was greater than zero. If the resulting mass was greater than zero, then the analysis methods outlined above were performed. If the resulting mass was less than zero, then the PSD was considered not to have sampled any MS during the exposure period and the maximum PF for that test was assigned for that PSD sample. The maximum PF for each test was determined by dividing the challenge dosage that the test subjects were exposed to by the minimum dosage capable of being analyzed by the gas chromatograph.

The smallest detectable amount of MS that can be measured with the combined PSD/gas chromatograph system during these tests was determined by measuring the variability of analyzed samples. This variability was measured in a study that determined the overall background mass of MS on 25 unopened, unused PSDs. In this study, 25 unused PSDs were packed in sample tubes and analyzed. There was very little difference between the readings obtained in this background sample study and the average background masses determined in the MIST tests. The average background mass on these samples was 113.46 ng with a standard deviation of only 3.60 ng. The standard deviation of these samples is the value that was used as the smallest detectable mass of MS on the PSD/GC system. Based upon an average challenge concentration of 50 mg/m^3, a 30-minute exposure period, and a PSD sampling rate of 14.6 cm^3/min, the equations listed above yield a maximum detectable PF of around 8000. This value varied from test to test depending on the total exposure dosage each subject was exposed to. The range of maximum PFs calculated in these tests was between 6500 to 10000.

D-3.2 **Calculation of Overall Protection Factors.**

The overall PF of the suit was determined by using the Body Region Hazard Analysis (BRHA) process developed by Fedele and Nelson[v], which is based upon the amount of agent that must be absorbed percutaneously (through the skin) in each of 23 different body areas to produce mean, end-point reactions. In the model, the mean end-point reaction is taken as the first significant symptom that occurs as a result of exposure to the agent. For nerve agent (O-ethyl S-[2-diisopropylaminoethyl] methylphosphono-thiolate - VX) or GB systemic exposure, it is generally headache or miosis (constriction of the pupil) that occurs first. Reddening of the skin (similar to severe sunburn) is the mean, end-point reaction for exposure to blister agent mustard (Bis[2-chloroethyl] sulfide - HD). This model applies data obtained from adsorption studies on human skin with pesticides[ix] and the nerve agent VX[x]. A weighting factor is assigned to each of these values based on the dose and the total percentage of that skin area.

The overall PF for nerve and blister agents requires separate calculations. For nerve agent, the overall PF is based on a weighted average of the PF measurements from all individual body areas. This approach is used because nerve agents produce a systemic rather than a localized response in the individual. When the overall PF for nerve agents is multiplied by 10 mg-min/m^3 (which is the minimum dosage of the nerve agent VX that an unprotected individual must adsorb through their skin to develop end-point reactions) the systemic Minimum Required Exposure Dosage (MRED) value is obtained.

The initial effects of blister agent are localized to specific body areas. Furthermore, the skin in each body area has a different level of sensitivity. Consequently, the overall PF for the blister agent HD is expressed as a localized MRED. This is calculated by multiplying a local exposure dosage, which quantifies the sensitivity of the skin at a particular body region, by the PF measured at that region. The *lowest* calculated localized MRED value is applied in evaluating the suit and is reported (along with the skin area affected) in evaluating the protective capability of the suit and areas of susceptibility.

A detailed description of both of these methods and equations that is used to calculate overall PF using the Fedele BRHA process is contained below.

D-3.2.1 **Systemic Effect - Nerve Agent (VX).**

The BRHA process quantifies the dosage required to cause a systemic nerve agent effect (end-point reaction) for each body area. These dosages are listed in Table D-2 and are divided into the skin area to calculate the area/dosage (A/D) factor. The A/D factor equals the percentage of skin area divided by mass required to be absorbed at that area to produce the end-point reaction. The overall PF of the suit is determined by dividing the sum of the A/D factors by the sum of the A/(D*PF) factors (A/D factor divided by PF at each area). The equations used to perform each of these calculations are as follows:

$$(A/D)_i = A_i \div D_i \qquad \text{(D-3)}$$

$$(A/(D*PF))_i = A_i \div (D_i * PF_i) \qquad \text{(D-4)}$$

$$\text{Overall PF} = \frac{\sum (A/D)_i}{\sum A/(D*PF)_i} \qquad \text{(D-5)}$$

where PF_i is the protection factor measured at location i = 1, 2,... 23, and PF is the overall protection factor summed over i = 1, 2, ... 23 body areas. Because this portion of the Fedele model was developed using data taken from controlled human exposure to the nerve agent VX, the overall PF was then multiplied by the minimum dosage of VX that an unprotected individual must be exposed to in order to develop end-point reactions (headache or miosis occurs first in systemic exposures). That dosage is 10 mg-min/m^3. The same factor is used for GB. This factor is called the Systemic MRED, and is used to predict dosage exposure required for systemic nerve agent effects.

D-3.2.2 Localized Effect - Blister Agent (HD).

A second data set from the BRHA process was used to determine what exposure dosages are required to cause end-point reactions when the suit wearer is exposed to HD vapor (reddening of the skin occurs first, similar to severe sunburn). Since the effects of HD are not cumulative and generally affect only localized body regions, the model predicts MREDs for each body region (based upon the individual PF values); and the lowest value of all these dosages is used to predict the lowest response dosage for people using the Responder. Listed in Table D-2 are the local exposure dosages for HD provided by the model. The local exposure dosage column in Table D-2 contains values of agent dosages (LEDs) to which each individual skin area must be exposed to in order to attain a localized skin reaction. These values were multiplied by the appropriate PF value to obtain the MRED required to cause localized skin reactions at each body location.

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Table D-2. Model Parameters used to Calculate the Overall Protection Factor

Sample Region	PSD Sample Number	Skin Area (cm2)	VX Dose mg/ind	A/D Factor	Local Exposure Dosage for HD mg-min/m3
1 - Chin & Neck	10	200	0.36	556	129
2 - Ears	10	50	0.46	109	164
3 - Cheeks & Neck	10	100	0.48	208	171
4 - Nape	10	100	1.72	58	614
5 - Scalp	10	350	0.76	461	271
6 - Abdomen	2,4	2858	2.23	1282	796
7 - Back	1,4	2540	2.65	958	946
8 - Buttocks	3	953	4.26	224	1521
9 - Arms(lower, volar)	6	487	2.8	174	1000
10 - Arms(upper, volar)	5	488	2.8	174	1000
11 - Elbows (back)	5	50	2.25	22	804
12 - Arms (lower, dorsum)	6	706	6.57	107	2346
13 - Arms (upper, dorsum)	5	706	6.57	107	2346
14 - Legs (plantar, lower)	9	948	2.8	339	1000
15 - Legs (plantar, upper)	8	1422	4.26	334	1521
16 - Legs (dorsum, lower)	9	1897	6.57	289	2346
17 - Legs (dorsum, upper)	8	2845	6.57	433	2346
18 - Knees (front)	9	200	7.14	28	2550
19 - Groin	7	200	0.11	1818	39
20 - Groin	7	300	1.22	246	436
21 - Axillae	4	200	2.07	97	739
22 - Popliteal Space	9	100	2.09	48	746
23 - Elbowfold	6	50	2.09	24	746
		17750		8095	

Thus, the localized MRED for the suits was calculated using the following equation:

$$\text{Localized MRED} = (LED_i * PF_i) \quad \text{(D-6)}$$

where LED is the localized exposure dosage for skin area i=1,2,...23, and PF is the protection factor measured at skin area i=1, 2,...23. The site with the lowest value is used in the evaluation of the data for the tests, i.e., the site with the smallest MRED value was the area least protected by the individual suit.

Appendix E: A Description of Agent Penetration Analysis for Impermeable Fabrics by Paul D. Fedele, Physical Scientist, US Army ERDEC, July 1997

We perform agent permeation and penetration tests on materials of personal protective equipment (PPE) to determine if, or when, agent permeation and penetration of PPE materials may **create** a cumulative hazard beneath the PPE materials. To do this, we need an indication of what agent exposure levels create hazards, or toxicological endpoints. We use various values of such endpoints to place the test results into perspective. We also need measurements of agent transport (permeation and penetration) through materials. We perform these measurements at Edgewood.

Although these fabric tests do not **completely address** the adequacy of PPE systems, they give some qualitative indication of the effectiveness of PPE materials in reducing agent hazards. Material permeation and penetration tests involve exposing the outside of the material to agent in some form and at some concentration, and measuring the cumulative mass of agent transported through the material over time.

The tests are conducted in laboratory test cups, which hold the material and allow one side to be exposed to a chemical agent. Figure 1 shows a general laboratory test configuration. It shows many of the possible transport processes used in testing both barriers and fabrics. It includes absorption by skin beneath the protective barrier or fabric.

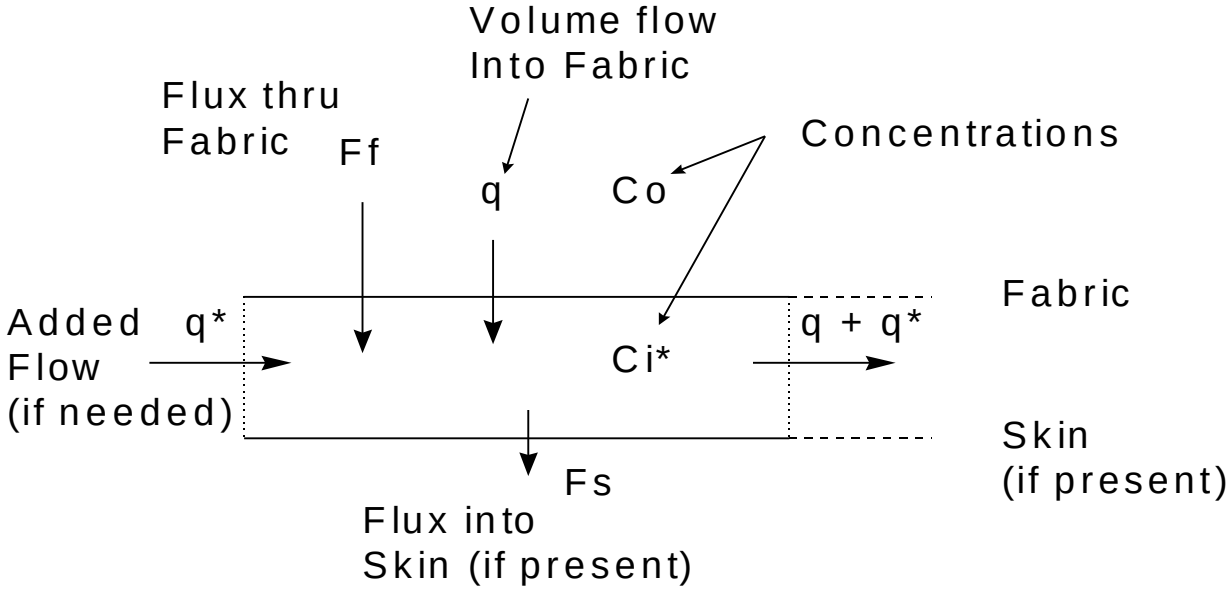

Figure E-1. Agent Transport through Fabric and into Skin.

APPENDIX E

Flow through the fabric, q, is zero when the material is impenetrable to airflow. Specific values of the illustrated transport processes occur during tests, depending on the physical characteristics of the material being tested. When skin is beneath the fabric, a flux into the skin exists, created by the skin's permeability to the agent vapor. For example, skin permeability to HD is 2 cm min^{-1}, for HD [5]. Skin, or a skin simulant, is not present in the test

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[5] References for the skin permeability of HD and for our estimate of the skin permeability of GB are given below.

Max Bergmann, Joseph S. Fruton, Calvin Golumbic, Stephen M. Nagy, Mark A. Stahmann and William H. Stein, "Formal Progress Report on the Penetration of Vesicant Vapors into Human Skin", The Rockefeller Institute for Medical Research, February 1, 1945, Division 9, National Defense Research Committee of the Office of Scientific Research and Development, OSRD Report Number 4855, March 24, 1945.

F. C. Henriques, A. R. Moritz, H. S. Breyfogle, and L. A. Patterson, "The Mechanisms of Cutaneous Injury by Mustard Gas. An Experimental Study Using Mustard Prepared With Radioactive Sulfur", Division 9, National Defense Research Committee of the Office of Scientific Research and Development, Formal Progress Report dated November 10, 1943, OSRD Report Number 3620, May 9, 1944.

Kazuo K. Kimura, Bernard P. McNamara and Van M. Sim, "Intravenous Administration of VX in Man", US Army CRDL Technical Report, CRDLR 3017, July 1960.

V. M. Sim and Jane L. Stubbs, "VX Percutaneous Studies in Man", US Army CRDL Technical Report, CRDLR 3015, August 1960.

Van M. Sim, "Variability of Different Intact Human-Skin Sites to the Penetration of VX", US Army CRDL Technical Report, CRDLR 3122, February 1962.

The skin permeability value for GB is determined from the ratio of toxicities for GB and VX through the inhalation and the percutaneous routes.

We consider:

1) A lethal(50%) intravenous dose (IVLD) (delivered over a proper time interval) is collected into the blood from a respiratory lethal CT (RLCT). Call the transfer rate R (respiratory). It has units of volume per time and when multiplied by the respiratory RLCT(50%) gives mass transferred into the blood.

$$IVLD = R \times RLCT$$

2) Similarly, a lethal(50%) intravenous dose (again delivered over the proper time interval) is collected into the blood from a lethal(50%) cutaneous exposure. Call the transfer rate C (cutaneous). It again has units of volume per time and equals the average skin absorption velocity, v, times an appropriate skin surface area, A.

$$IVLD = v \times A \times CLCT$$

Solving for v, we obtain

$$v = \frac{R \times RLCT}{A \times CLCT}$$

Taking the ratio for GB to VX, we get

$$\frac{v(GB)}{v(VX)} = \frac{R(GB) \times RLCT(GB) \times A \times CLCT(VX)}{A \times CLCT(GB) \times R(VX) \times RLCT(VX)}$$

The area of the body, A, is the same for both agents, so the A's cancel. When the mass transfer rate, R, is largely determined by external mass transfer resistance, the molecular diffusion rates largely will determine R and values will be similar for different molecular species, like GB and VX. Thus to within some approximation, we also can cancel the R's.

cup because it restricts convective penetration in the dual-flow cup geometry. Skin does restrict convective penetration for full PPE systems.

The flow under the fabric is used to carry the agent to a measurement system that requires a minimum flow for operation. When the fabric has limited, or zero, air flow penetrability, clean air is added beneath the material to accommodate measurements.

We summarize the hazard to skin as C_iT, or the exposure measured in mg min m^{-3} beneath the fabric. In the general case illustrated in Figure 1, the relation between the mass penetrating the fabric and the exposure to skin beneath the fabric is obtained using a steady-state approximation. By equating the fluxes into and out of the region between the fabric and the skin, the exposure can be shown to be

$$C_iT_{skin} = \frac{M_f \{ P_f + q/A + q^*/A \}}{\{ q/A + q^*/A \} \{ P_f + P_s + q/A \}} \qquad (1)$$

C_iT_{skin} is exposure to skin, M_f is the cumulative mass permeation through the fabric, per unit area, T is the total time after the exposure, P_f is the fabric permeability, P_s is the permeability of skin to vapor absorption, q^* is the volume flow rate beneath the fabric, q is the volume flow rate through the fabric, and A is the area of the fabric.

For impenetrable fabrics, q is zero, and we have

This gives

$$v(GB) = \frac{RLCT(GB) \times CLCT(VX)}{RLCT(VX) \times CLCT(GB)} \times v(VX)$$

The absorption data gives v(VX) = 2 cm/min. We take toxicity estimates for GB and VX from the US Army Field Manual, FM 3-9. Applying the mild activity estimate for inhalation median lethal exposure for GB, or 70 mg min m-3, the mild activity inhalation median lethal exposure for VX, or 30 mg min m-3, and the nude cutaneous median lethal exposure for GB, 12000 mg min m-3, and the mid point of the range of the bare skin cutaneous median lethal exposure of VX, 180 mg min m-3, we obtain

$$v(GB) = \frac{70 \times 180}{30 \times 12000} \times 2 = 0.07 \text{ cm/min}$$

Note that a tendency to over, or under, estimate effects CT's for any particular agent will cancel if the tendency is uniformly applied to determining effective lethal exposures for both the respiratory and the cutaneous routes of entry. Since the margin of error for the bare skin cutaneous median lethal exposure of VX is from 6 to 360, the value is taken to be approximately 0.1 cm min-1, as applied in the assessment.

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$$C_{iT_{skin}} = \frac{M_f \{ P_f + q^*/A \}}{\{ q^*/A \} \{ P_f + P_s \}} \qquad (2)$$

A fabric that provides agent protection must have an agent permeability much smaller that the absorptive permeability of skin, P_s, which we approximate as 2 cm min^{-1} for HD. Thus, for any protective fabric, P_f must be negligible with respect to P_s in the denominator of Eq (2). Further, the airflow requirement, q*, for sampling is 200 cm^3 min^{-1}. Over 20 cm^2, this is a linear flow velocity of 10 cm min^{-1}, which is, itself, much greater than the permeability of skin and thus also much greater than the permeability of a reasonable protective fabric. Thus, we also can safely neglect P_f, in the numerator of Eq (2). With this, we have

$$C_{iT_{skin}} = \frac{M_f}{P_s} \qquad (3)$$

Eq (3) shows that, for any protective material that offers a reasonable amount of protection (beyond skin alone) we can approximate the exposure of the skin by the cumulative mass permeation, M_f, divided by the permeability of skin, P_s. Thus, from the laboratory measurement of agent permeation of impenetrable materials, we determine the hazard presented to skin by dividing the cumulative mass penetration per unit area, M_f, by the permeability of skin. For example, with mustard, we approximate skin permeability to 2 cm min^{-1}.

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We consider materials to offer protection as long as the exposure remains less than what is considered hazardous, depending on the agent. Naturally, as the permeation rate increases with time, exposures and associated hazards continue to increase.

These material tests do not **completely** indicate that a protective system made of the material will protect against the chemical agent. However, they do gives an indication of how long the material itself will delay hazardous amounts of agent penetration and they indicate the time that a protective system made with the material might provide protection against the reactions indicated.

APPENDIX E

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Test Results

Appendix F: Kappler Model 42483

Figure F-1: Kappler 42483 - Front View

Figure F-2: Kappler 42483 - Side View

Appendix F: Kappler Model 42483

Table F-1. Kappler Model 42583 - Average HD Permeation

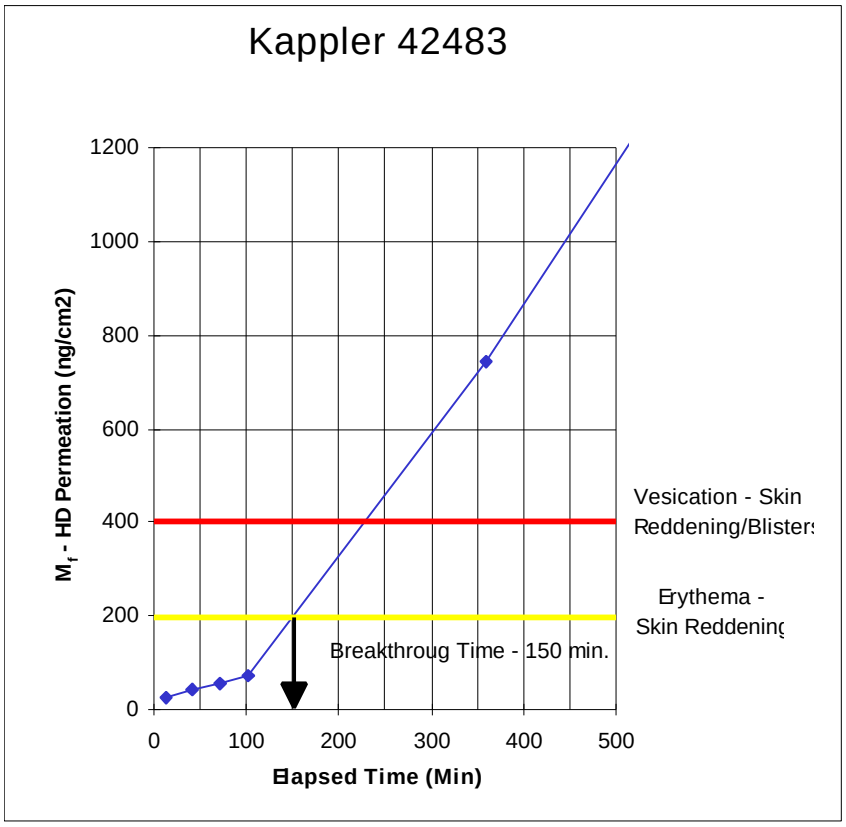
	Swatch Material Source (Weighting Factor) (Nanograms/cm2)						
Time (min)	suit mat'l	visor mat'l	glove	suit seam	suit/visor	zipper mat'l	Cum Perr Wei
	(50%)	(15%)	(10%)	(15%)	(5%)	(5%)	
12	3.70	66.07	53.67	9.23	90.67	40.60	
42	6.40	120.33	78.93	14.93	153.93	72.47	
72	14.60	120.33	105.33	19.50	193.67	112.37	
102	34.73	120.33	140.33	29.40	233.67	180.33	
360	638.67	301.67	1147.57	331.00	682.00	3579.00	7
720	1181.67	360.00	3191.33	635.00	1235.33	14161.00	18
1080	1424.33	360.33	5773.00	791.33	1909.67	25634.67	28
1440	1568.33	360.33	8908.33	903.67	2539.67	35648.67	37

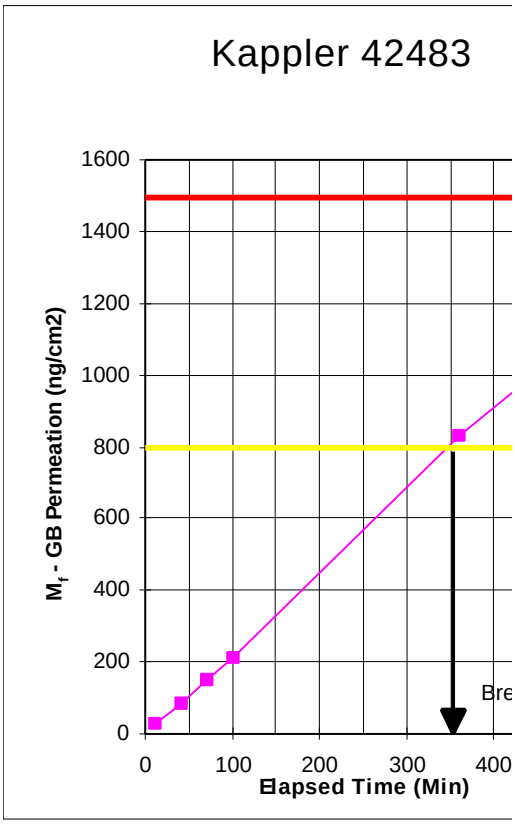
Appendix F: Kappler Model 42483

Table F-2. Kappler Model 42483 - Average GB Permeation

	Swatch Material Source (Weighting Factor) (Nanograms/cm2)						
Time (min)	suit mat'l	visor mat'l	glove	suit seam	suit/visor	zipper mat'l	Cum Perr Wei
	(50%)	(15%)	(10%)	(15%)	(5%)	(5%)	
12	2.09	16.17	1.71	6.12	391.33	32.93	
42	12.27	61.00	7.27	25.33	1178.00	114.00	
72	29.73	116.33	15.50	49.00	1954.50	217.00	1
102	47.43	173.33	26.37	68.03	2696.67	335.67	2
360	195.33	726.00	226.33	220.00	7814.50	3517.67	8
720	328.33	1240.33	464.00	245.00	11536.50	10735.33	15
1080	411.00	1537.67	623.33	261.00	13597.00	16123.67	20
1440	425.00	1667.50	708.33	261.67	14639.00	19104.00	22

Appendix F: Kappler Model 42483

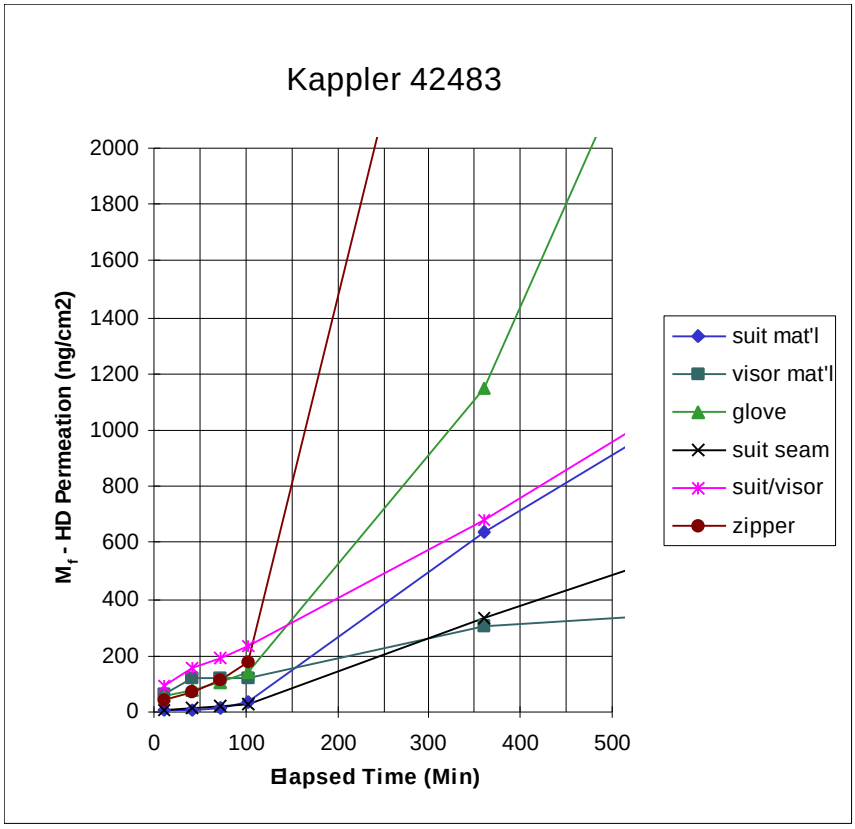




Appendix F: Kappler Model 42483

Figure F-3: Kappler 42483 - Cumulative Weighted Average HD Permeation

Figure F-4: Kappler 42483 - Cumulative Weighted Average GB Permeation



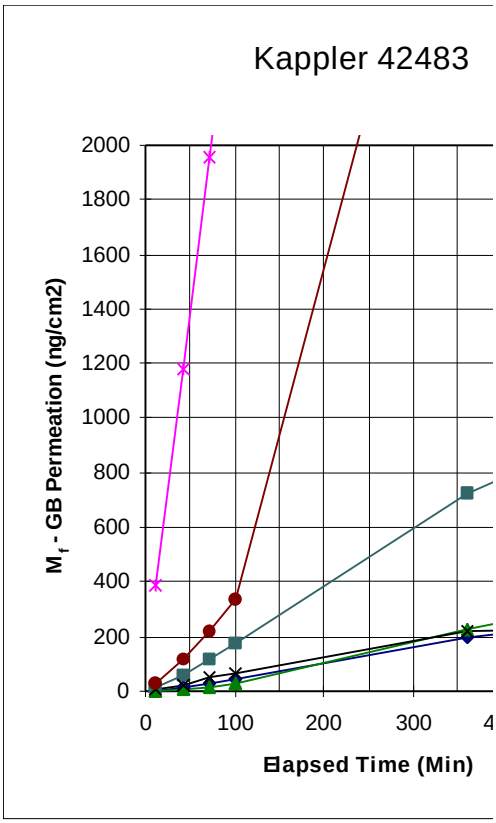


Figure F-5: Kappler Model 42483: HD Permeation by Swatch Location

Figure F-6: Kappler Model 42483: GB Perme

Appendix F: Kappler Model 42483

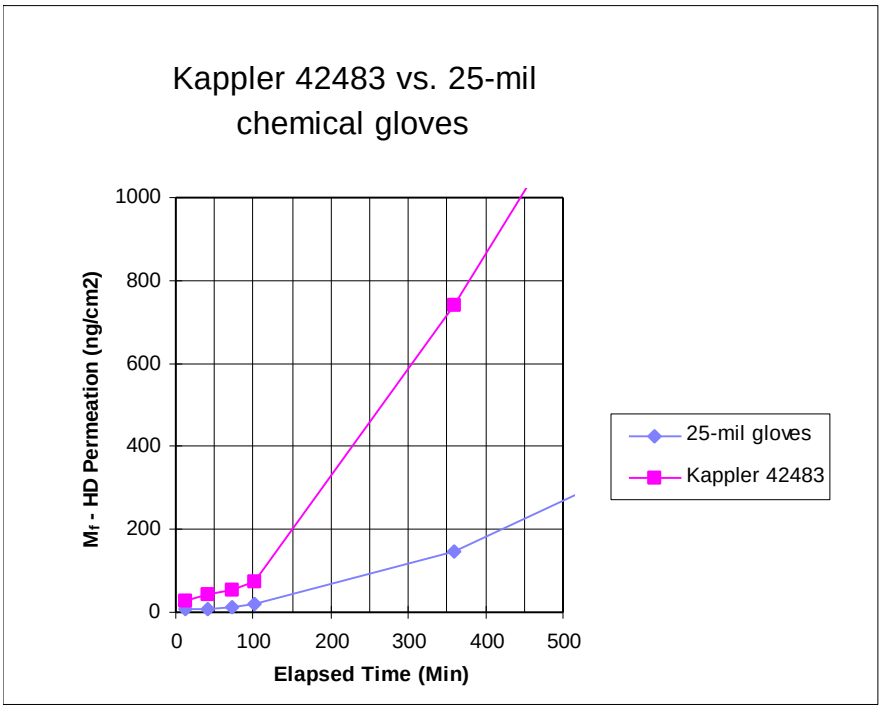


Figure F-7: Kappler 42483 - Cumulative Weighted Average HD Permeation vs. 25-Mil Chemical Protective Glove HD Permeation

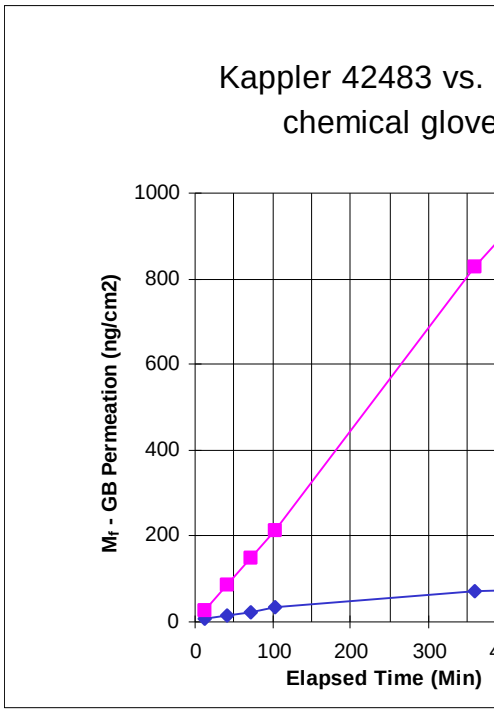


Figure F-8: Kappler 42483 - Cumulativ
Permeation vs. 25-Mil Chemical Protect

Table F-3: Kappler 42483: System Test (Vapor Simulant) Results

Suit	Overall PF	Systemic MRED (mg-min/m^3)	Localized MRED (mg-min/m^3)	Skin Area Affected
1	1654	16540	134900	Chin & Neck
2	1261	12610	27160	Groin
3	1212	12120	87960	Groin
4	937	9373	97070	Groin
5	1993	19930	24390	Groin
6	401	4008	9460	Groin
7	2650	26500	256500	Popliteal Space
8	1591	15910	117500	Arm
9	3346	33460	37810	Groin
10	551	5506	5920	Groin
11	1031	10310	63010	Chin & Neck
12	1583	15830	55780	Groin
13	2393	23930	257400	Chin & Neck
14	4917	49170	418300	Chin & Neck

Overall PF (Median)	Overall PF (Minimum)	Overall PF (Maximum)	Average Systemic MRED	Average Localized MRED
1582	401	4917	18230	113800

Table F-4. Kappler 42483 – System Test (Aerosol Simulant) Results

Pre-Operational Exercises Visor Region/Upper Arm Combined				**Operational Exercises Visor Region/Upper Arm Combined**			
PF	*Frequency*	*Cumulative %*	Pass %	*PF*	*Frequency*	*Cumulative %*	Pass %
10	1	2.2	97.8	10	2	4.3	95.7
50	1	4.3	95.7	50	0	4.3	95.7
100	0	4.3	95.7	100	0	4.3	95.7
500	16	39.1	60.9	500	16	39.1	60.9
1000	7	54.3	45.7	1000	7	54.3	45.7
1667	9	73.9	26.1	1667	7	69.6	30.4
2000	3	80.4	19.6	2000	2	73.9	26.1
5000	9	100	0	5000	9	93.4	6.6
6667	0	100	0	6667	1	95.7	4.3
10000	0	100	0	10000	1	97.8	2.2
20000	0	100	0	20000	1	100	0
50000	0	100	0	50000	0	100	0
100000	0	100	0	100000	0	100	0
	46				46		

Table F-5. Kappler Model 42483 - Overall Test Results

Breakthrough time (minutes)		Aerosol PF Pass Rate at PF equal to:				Overall Vapor PF	
incapacitation	erythema						
GB	HD	100	1000	2000		Min	Median
350	150	95.7	45.7	19.6	(Pre-operational)	401	1582
		95.7	45.7	26.1	(Operational)		

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Appendix G: TYCHEM 12645

Figure G-1: Tychem 12645 - Front View

Figure G-2: Tychem 12645 - Side V

Appendix G: TYCHEM 12645

Table G-1. TYCHEM Pkg 12645 Suit - Average HD Permeation

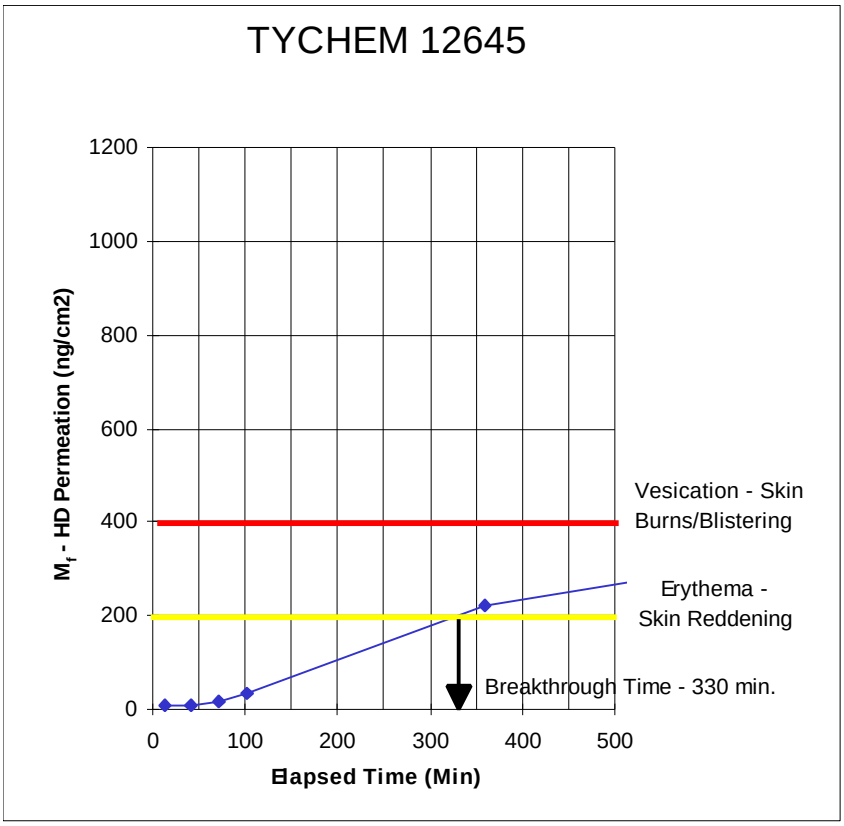
	Swatch Material Source (Weighting Factor) (Nanograms/cm2)						
Time (min)	suit mat'l	visor mat'l	glove	suit seam	suit/visor	zipper mat'l	Cum Perr Wei
	(50%)	(15%)	(10%)	(15%)	(5%)	(5%)	
12	5.33	0.00	30.33	0.00	0.00	14.33	
42	5.33	0.00	59.67	0.00	0.00	32.00	
72	13.33	0.00	78.67	0.00	0.00	53.67	
102	38.33	0.00	99.33	0.00	0.00	79.00	
360	322.00	65.00	303.00	5.33	0.00	377.00	2
720	435.00	219.00	521.00	5.33	0.00	716.67	3
1080	435.00	334.67	720.00	5.33	0.00	1019.33	3
1440	435.00	347.00	868.67	5.33	0.00	1238.67	4

Appendix G: TYCHEM 12645

Table G-2. TYCHEM Pkg 12645 Suit - Average GB Permeation

	Swatch Material Source (Weighting Factor) (Nanograms/cm2)						
Time (min)	suit mat'l	visor mat'l	glove	suit seam	suit/visor	zipper mat'l	Cum Perr Wei
	(50%)	(15%)	(10%)	(15%)	(5%)	(5%)	
12	0.00	51.33	20.00	18.33	43.67	11.33	
42	4.67	106.33	63.33	72.67	115.33	51.00	
72	16.33	162.67	110.00	145.33	169.00	111.33	
102	28.00	205.67	155.00	216.00	204.00	175.33	1
360	85.33	406.67	446.67	540.33	308.33	857.33	2
720	85.33	494.00	707.00	700.00	308.33	1846.00	4
1080	85.33	494.00	809.33	777.67	315.00	2621.67	4
1440	85.33	494.00	860.00	793.67	308.33	3136.00	4

Appendix G: TYCHEM 12645



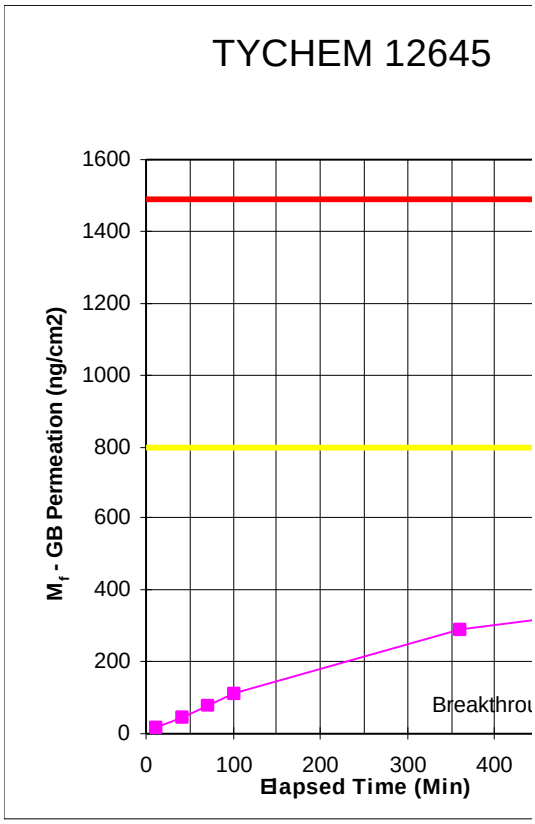


Figure G-3: TYCHEM 12645 - Cumulative Weighted Average HD Permeation

Figure G-4: TYCHEM 12645 - Cumulative Wei

Appendix G: TYCHEM 12645

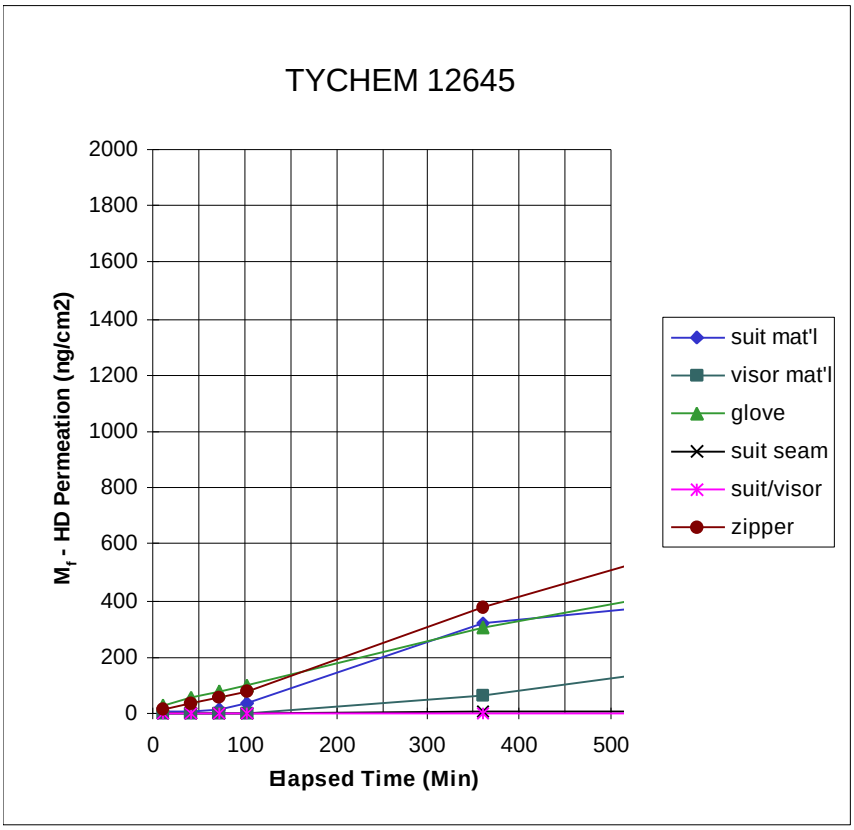


Figure G-5: TYCHEM 12645: HD Permeation by Swatch Location

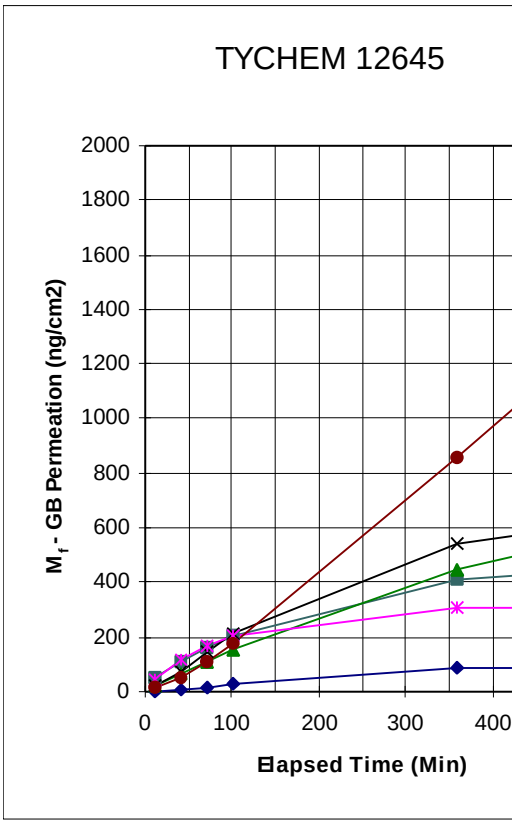


Figure G-6: TYCHEM 12645: GB Permeatior

Appendix G: TYCHEM 12645

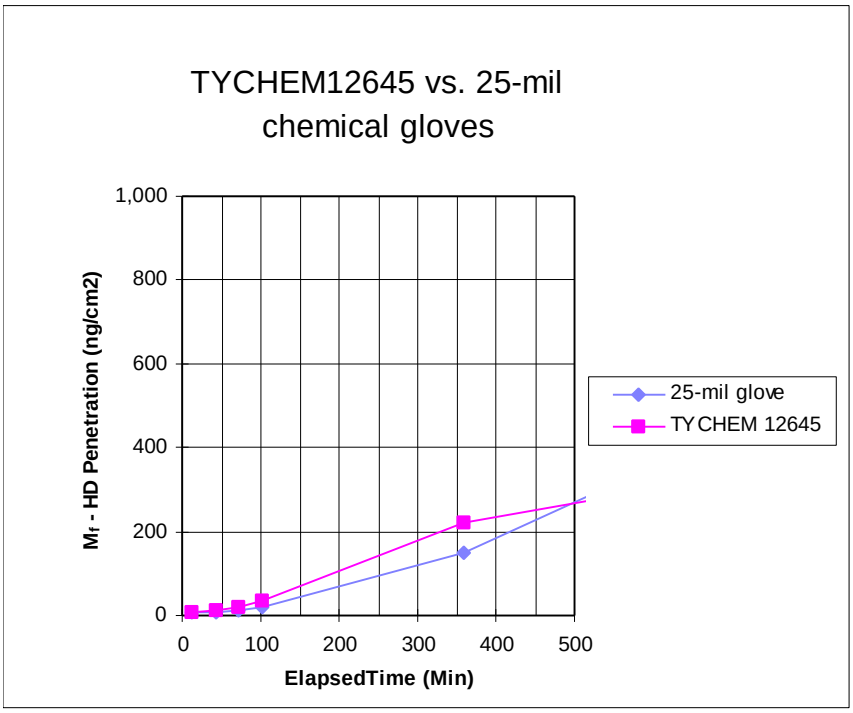


Figure G-7: TYCHEM12645 - Cumulative Weighted Average HD Permeation vs. 25-Mil Chemical Protective Glove HD Permeation

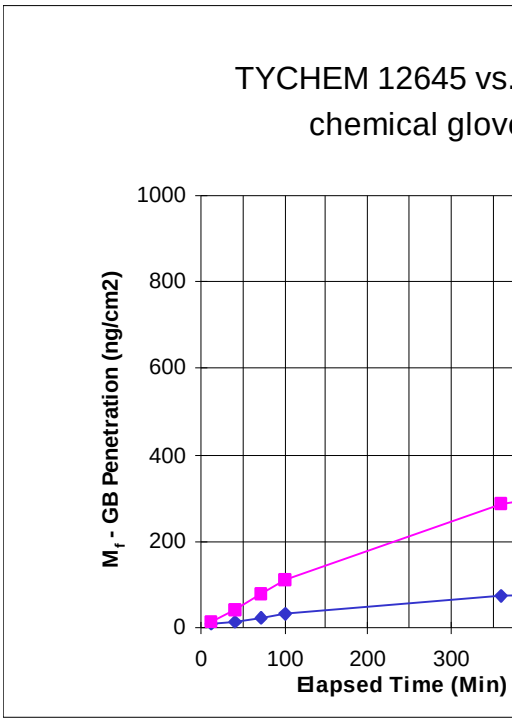


Figure G-8: TYCHEM12645 - Cumulative W
Permeation vs. 25-Mil Chemical Protective G

Appendix G: TYCHEM 12645

Table G-3. TYCHEM 12645- System Test (Vapor Simulant) Results

	Overall PF	Systemic MRED (mg-min/m^3)	Localized MRED (mg-min/m^3)	Skin Area Affected
1	1961	19610	83900	Groin
2	567	5673	10930	Groin
3	773	7728	71710	Chin & Neck
4	836	8358	15060	Groin
5	363	3625	7285	Groin
6	2478	24780	125700	Groin
7	193	1933	14330	Chin & Neck
8	5257	52570	246000	Groin
9	1971	19770	125200	Chin & Neck
10	1331	13310	253800	Groin
11	429	4290	57920	Chin & Neck
12	363	3634	28740	Groin
13	1476	14760	174800	Chin & Neck
14	657	6571	20700	Groin

Overall PF (Median)	Overall PF (Minimum)	Overall PF (Maximum)	Average Systemic MRED	Average Localized MRED
804	193	5257	13330	88280

Table G - 4. TYCHEM 12645 – System Test (Aerosol Simulant) Results

Pre-Operational Exercises Visor Region/Upper Arm Combined				**Operational Exercises Visor Region/Upper Arm Combined**			
PF	*Frequency*	*Cumulative %*	Pass %	*PF*	*Frequency*	*Cumulative %*	Pass %
10	0	0	100	10	1	2.1	97.9
50	0	0	100	50	3	8.5	91.5
100	3	6.2	93.8	100	7	23.4	76.6
500	20	47.9	52.1	500	14	53.2	46.8
1000	17	83.3	16.7	1000	17	89.4	10.6
1667	5	93.8	6.2	1667	5	100	0
2000	1	95.8	4.2	2000	0	100	0
5000	2	100	0	5000	0	100	0
6667	0	100	0	6667	0	100	0
10000	0	100	0	10000	0	100	0
20000	0	100	0	20000	0	100	0
50000	0	100	0	50000	0	100	0
100000	0	100	0	100000	0	100	0
	48				47		

Table G-5. TYCHEM 12645 - Overall Test Results

Breakthrough time (minutes)		Aerosol PF Pass Rate at PF equal to:				Overall Vapor PF	
GB incapacitation	HD erythema	100	1000	2000		Min	Mec
>480	330	93.8	16.7	4.2	(Pre-operational)	193	804
		76.6	10.6	0.0	(Operational)		

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Appendix H: Trellchem HPS Suit

Figure H-1: Trellchem HPS Suit - Front View

Figure H-2: Trellchem HPS Suit - Side View

Appendix H: Trellchem HPS Suit

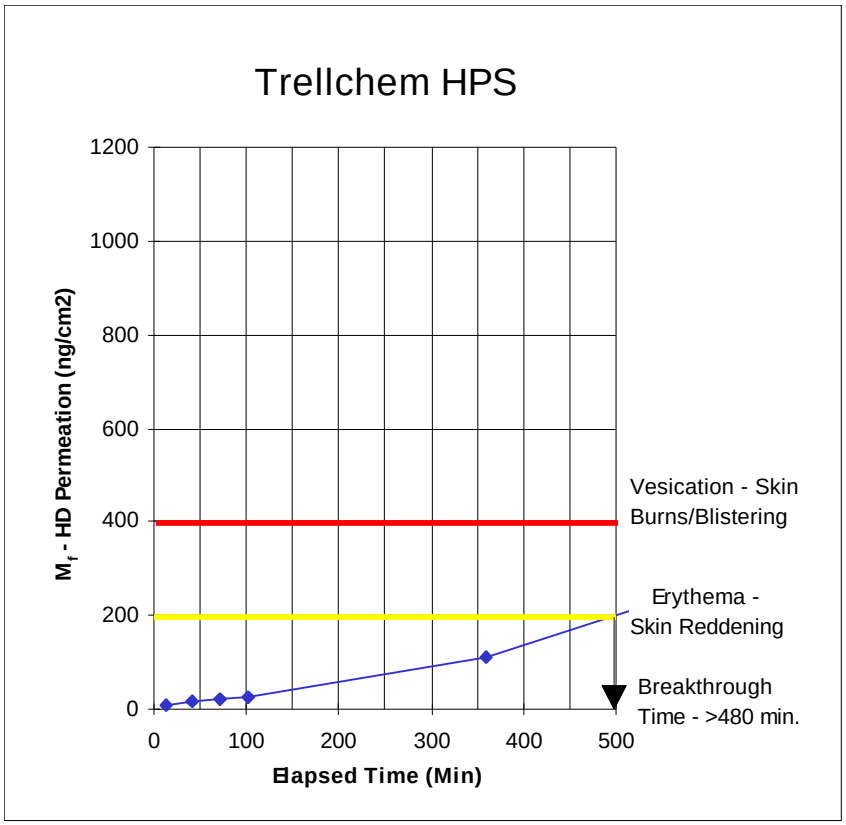
Table H-1. Trellchem HPS - Average HD Permeation

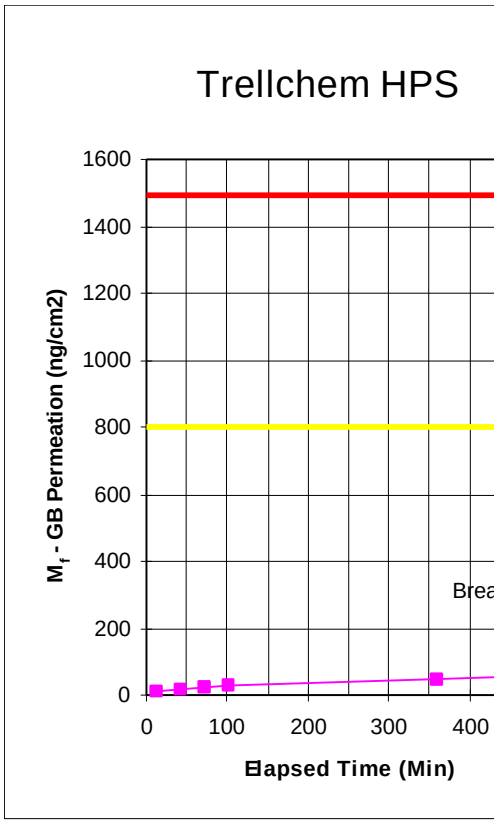
	Swatch Material Source (Weighting Factor) (Nanograms/cm2)						
Time (min)	suit mat'l	visor mat'l	glove	suit seam	suit/visor	zipper mat'l	Cum Perr Wei
	(50%)	(15%)	(10%)	(15%)	(5%)	(5%)	
12	7.00	12.67	0.00	24.00	0.00	0.00	
42	14.00	12.67	0.00	50.67	0.00	0.00	
72	14.00	12.67	0.00	76.33	0.00	0.00	
102	14.00	12.67	0.00	105.67	0.00	0.00	
360	31.00	12.67	0.00	387.67	0.00	745.00	1
720	96.00	12.67	0.00	387.67	0.00	4640.00	3
1080	160.67	12.67	0.00	1124.00	0.00	9205.67	7
1440	204.33	12.67	0.00	1406.33	0.00	12845.33	9

Table H-2. Trellchem HPS - Average GB Permeation

	Swatch Material Source (Weighting Factor) (Nanograms/cm2)						
Time (min)	suit mat'l (50%)	visor mat'l (15%)	glove (10%)	suit seam (15%)	suit/visor (5%)	zipper mat'l (5%)	Cum Perr Wei
12	17.67	0.00	3.00	26.00	0.00	3.00	
42	24.67	0.00	6.00	37.67	0.00	6.00	
72	36.00	0.00	6.00	46.67	0.00	9.67	
102	40.67	0.00	6.00	46.67	0.00	22.33	
360	40.67	0.00	6.00	46.67	0.00	374.67	
720	40.67	0.00	6.00	46.67	0.00	935.00	
1080	40.67	0.00	6.00	46.67	0.00	1403.00	
1440	215.00	0.00	6.00	198.00	0.00	1743.67	2

Appendix H: Trellchem HPS Suit





Appendix H: Trellchem HPS Suit

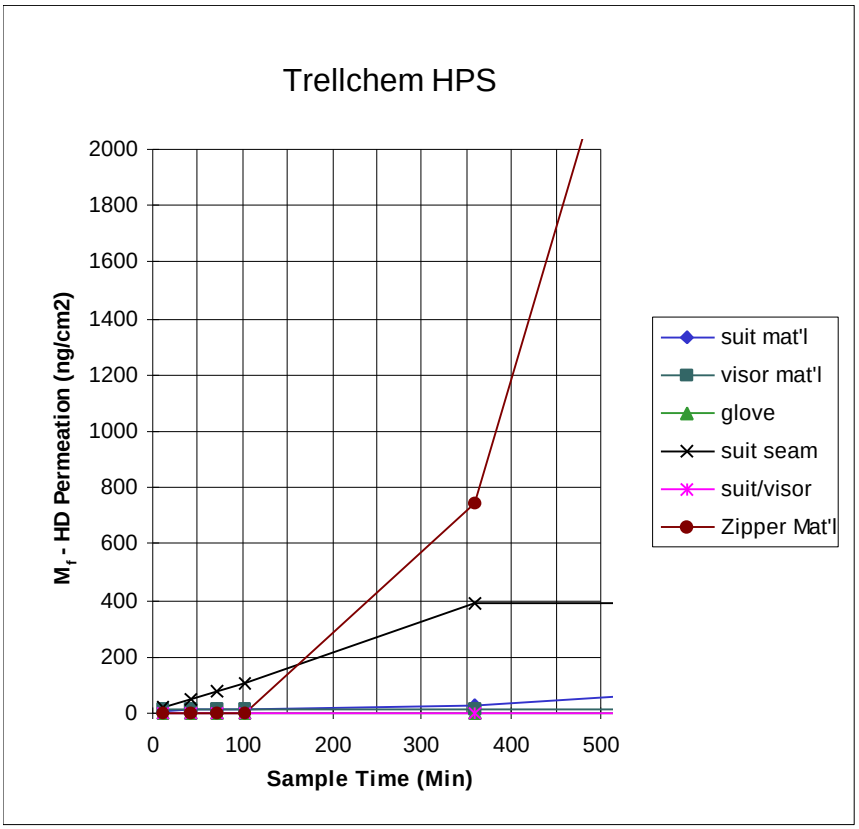


Figure H-3: Trellchem HPS - Cumulative Weigh

Figure H-4: Trellchem HPS - Cumu

GB

Permeation

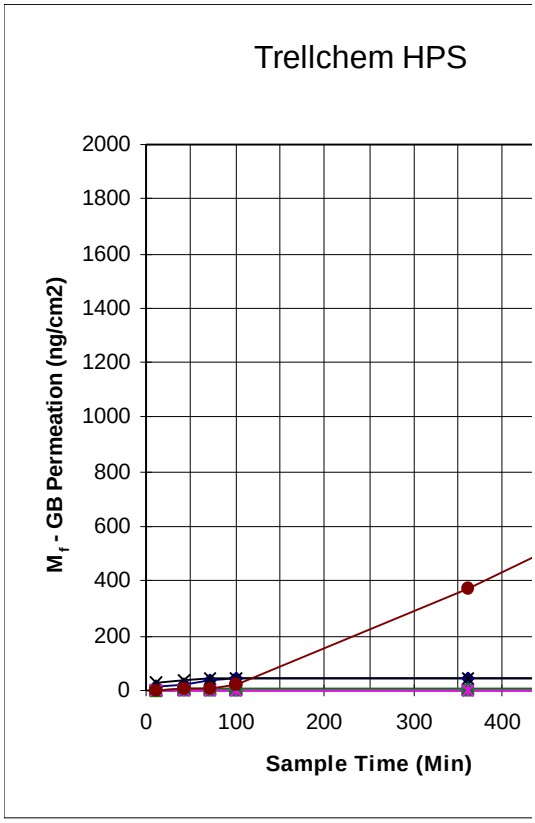


Figure H-5: Trellchem HPS: HD Permeation By Swatch Location

Figure H-6: Trellchem HPS: GB Permeation

Appendix H: Trellchem HPS Suit

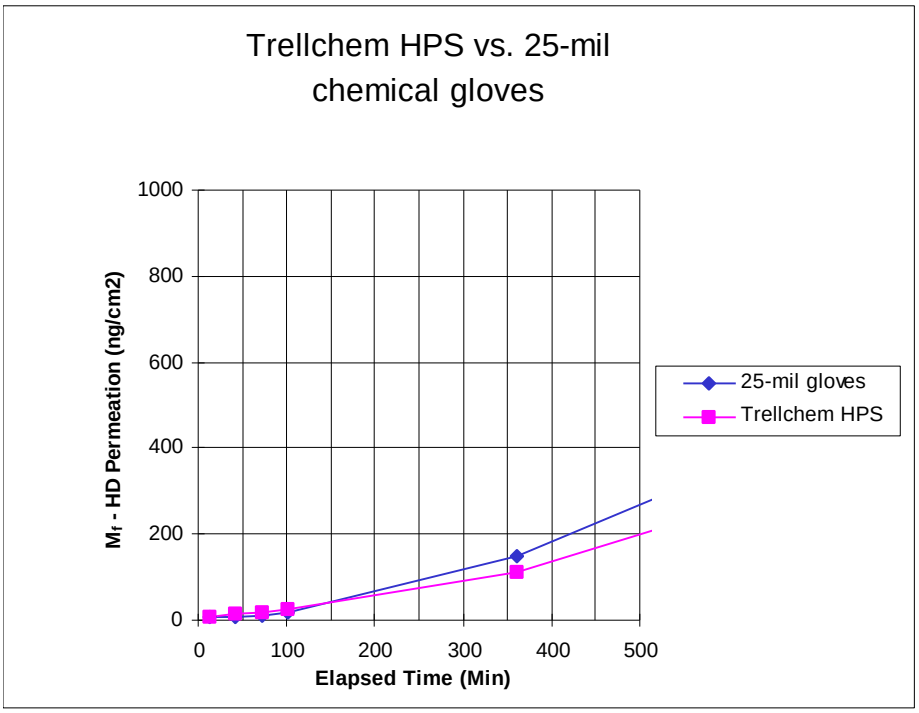


Figure H-7: Trellchem HPS - Cumulative Weighted Average HD Permeation vs. 25-Mil Chemical Protective Glove HD Permeation

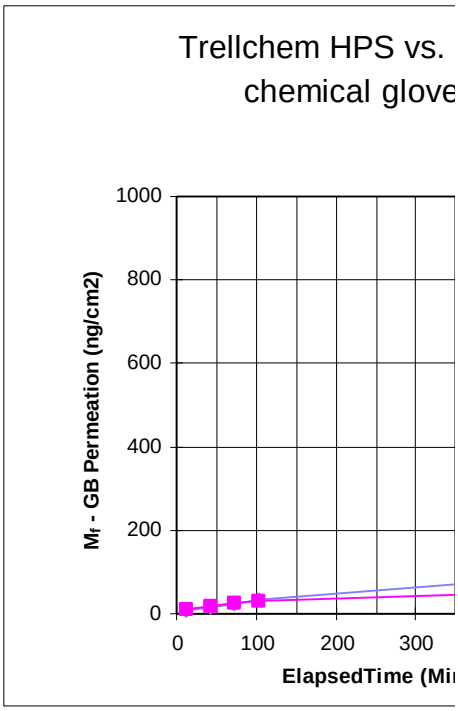


Figure H-8: Trellchem HPS - Cumulativ
Permeation vs. 25-Mil Chemical Protect

Appendix H: Trellchem HPS Suit

Table H - 3: Trellchem HPS: System Test (Vapor Simulant) Results

Suit	Overall PF	Systemic MRED (mg-min/m^3)	Localized MRED (mg-min/m^3)	Skin Area Affected
1	1590	15900	30790	Groin
2	1435	14350	33310	Groin
3	1127	11270	30430	Groin
4	1173	11730	78630	Groin
5	2577	25770	228500	Groin
6	2018	20180	37090	Groin
7	2114	21140	226900	Groin
8	1767	17670	45530	Groin
9	1329	13290	74550	Chin & Neck
10	1569	15690	232700	Groin
11	1497	14970	46740	Groin
12	734	7339	15480	Groin
13	1731	17310	47080	Groin
14	1490	14900	37480	Groin

Overall PF (Median)	Overall PF (Minimum)	Overall PF (Maximum)	Average Systemic MRED	Average Localized MRED
1533	734	2577	15350	87630

Table H - 4. Trellchem HPS – System Test (Aerosol Simulant) Results

Pre-Operational Exercises Visor Region/Upper Arm Combined				**Operational Exercises Visor Region/Upper Arm Combined**			
PF	*Frequency*	*Cumulative %*	Pass %	*PF*	*Frequency*	*Cumulative %*	Pass %
10	0	0	100	10	0	0	100
50	0	0	100	50	0	0	100
100	0	0	100	100	0	0	100
500	0	0	100	500	0	0	100
1000	0	0	100	1000	0	0	100
1667	4	5.1	94.9	1667	0	0	100
2000	2	7.7	91.3	2000	2	2.9	97.1
5000	34	51.3	50.0	5000	14	22.9	77.1
6667	15	70.5	23.9	6667	9	35.7	64.3
10000	18	93.6	2.2	10000	12	52.9	47.1
20000	5	100	0	20000	17	77.1	22.9
50000	0	100	0	50000	14	97.1	2.9
100000	0	100	0	100000	2	100	0
	78				70		

Table H-5. Trellchem HPS - Overall Test Results

Breakthrough time (minutes)		Aerosol PF Pass Rate at PF equal to:				Overall Vapor PF		
incapacitation	erythema							
GB	HD	100	1000	2000		Min	Mec	
>480	>480	100	100	92.3	(Pre-operational)	734	1533	
		100	100	97.1	(Operational)			

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Appendix I: Ready 1 Limited Use Suit: 91

Figure I-1: Ready 1 Limited Use Suit: 91- Front View

Figure I-2: Ready 1 Limited Use Suit: 91- Side Vi

Appendix I: Ready 1 Limited Use Suit: 91

Table I-1. Ready 1 LU Suit: 91 - Average HD Permeation

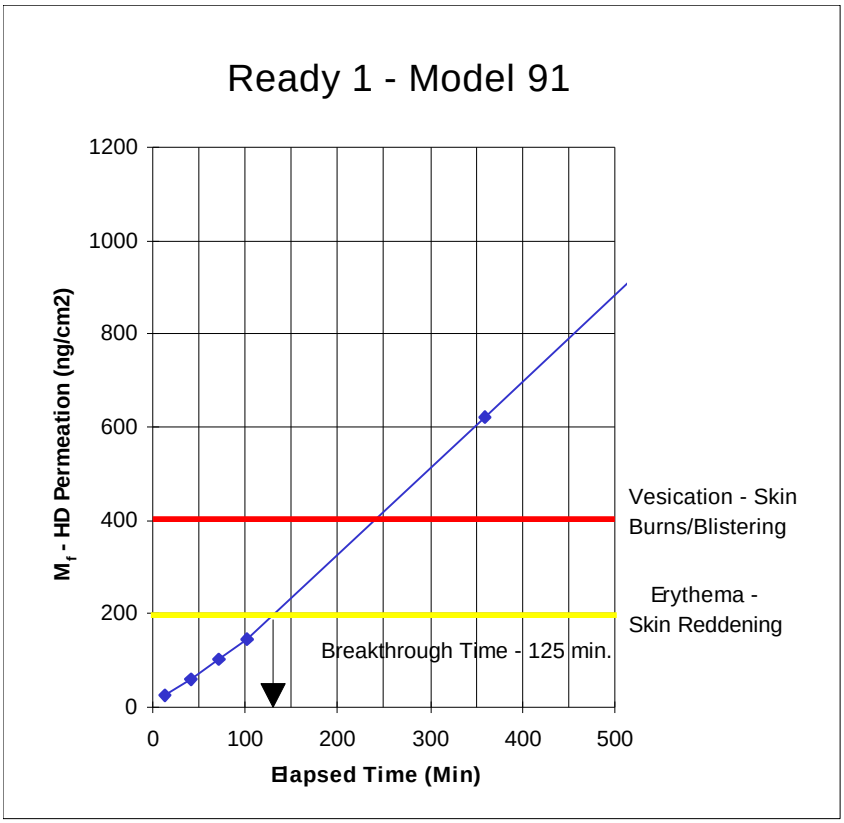
	Swatch Material Source (Weighting Factor) (Nanograms/cm2)						
Time (min)	suit mat'l	visor mat'l	glove	suit seam	suit/visor	zipper mat'l	Cum Perr Wei
	(50%)	(15%)	(10%)	(15%)	(5%)	(5%)	
12	35.67	5.33	17.67	14.33	24.00	41.67	
42	71.67	10.67	34.33	26.33	46.00	224.00	
72	112.33	10.67	52.67	44.67	68.00	554.33	1
102	159.00	10.67	79.00	58.33	94.33	888.00	1
360	627.67	13.33	399.00	298.00	508.00	3940.00	6
720	1207.67	95.67	811.33	596.67	1301.67	8778.67	12
1080	1738.00	177.00	1302.00	859.67	2224.67	14833.67	20
1440	2123.33	231.00	1792.00	1026.67	3040.67	20354.33	25

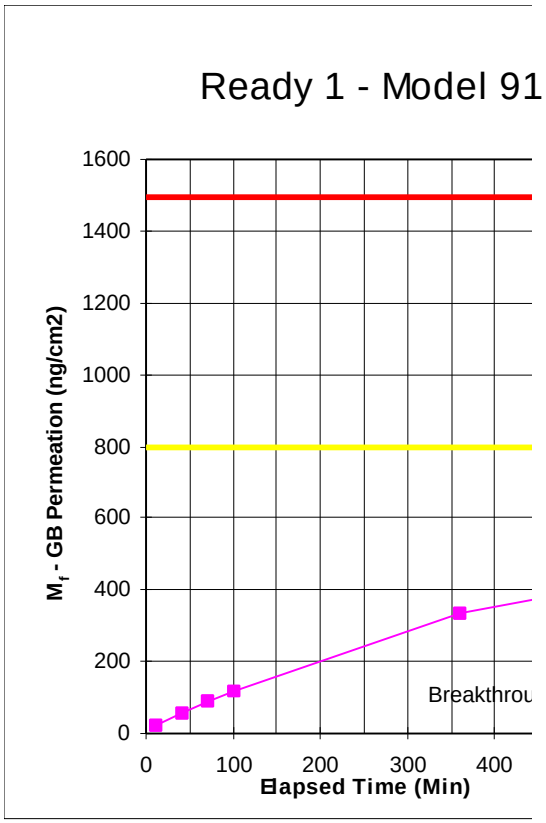
Table I-2. Ready 1 LU Suit: 91 - Average GB Permeation

	Swatch Material Source (Weighting Factor) (Nanograms/cm2)						
Time (min)	suit mat'l	visor mat'l	glove	suit seam	suit/visor	zipper mat'l	Cum Perm Wei
	(50%)	(15%)	(10%)	(15%)	(5%)	(5%)	
12	33.67	13.50	5.33	13.00	20.40	7.33	
42	73.67	36.50	10.33	45.00	59.80	15.33	
72	116.33	61.75	10.33	85.00	99.40	15.33	
102	158.33	86.25	10.33	125.00	140.20	15.33	1
360	421.67	274.50	10.33	382.00	456.60	15.33	3
720	622.67	388.75	10.33	594.00	765.20	15.33	4
1080	740.00	406.75	10.33	721.00	957.80	15.33	5
1440	740.67	406.75	10.33	724.00	1030.40	15.33	5

Appendix I: Ready 1 Limited Use Suit: 91

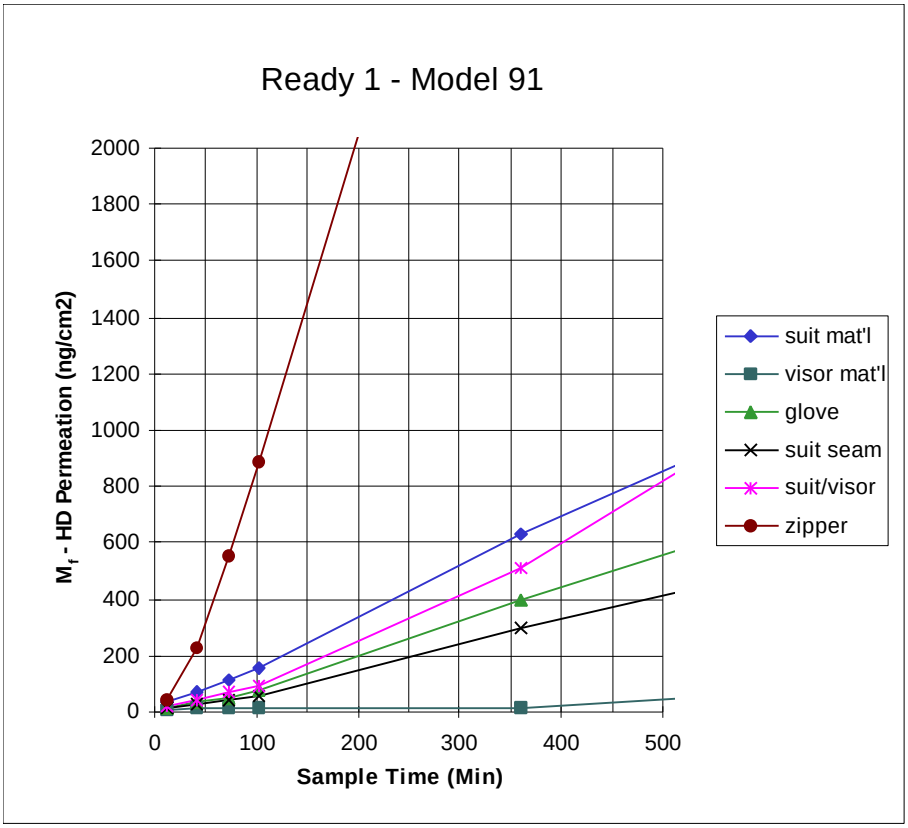
91





Appendix I: Ready 1 Limited Use Suit: 91

Figure I-3: Ready 1 Limited Use Suit: 91- Cumulative Weighted Average
Figure I-4: Ready 1 Limited Use Suit: 91- Cumulative Weighted Average HD Permeation
GB
Permeation



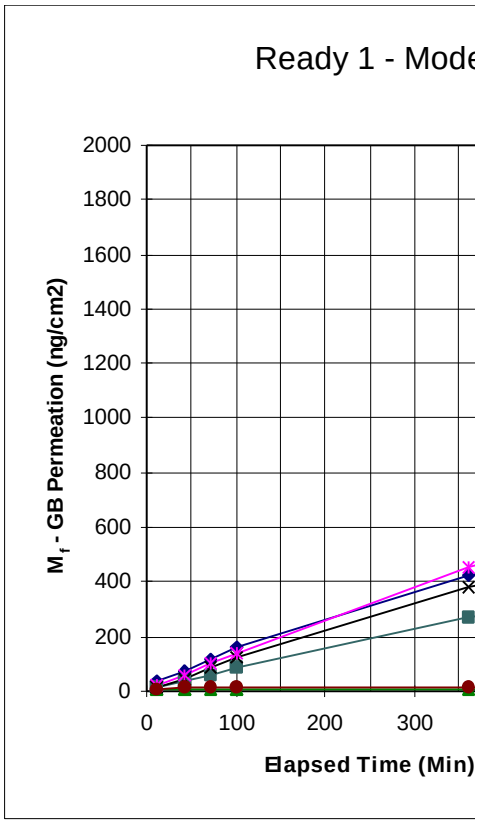


Figure I-5: Ready 1 Limited Use Suit: 91 - HD Permeation by Swatch Location

Figure I-6: Ready 1 Limited Use Suit: 91 - Location

Appendix I: Ready 1 Limited Use Suit: 91

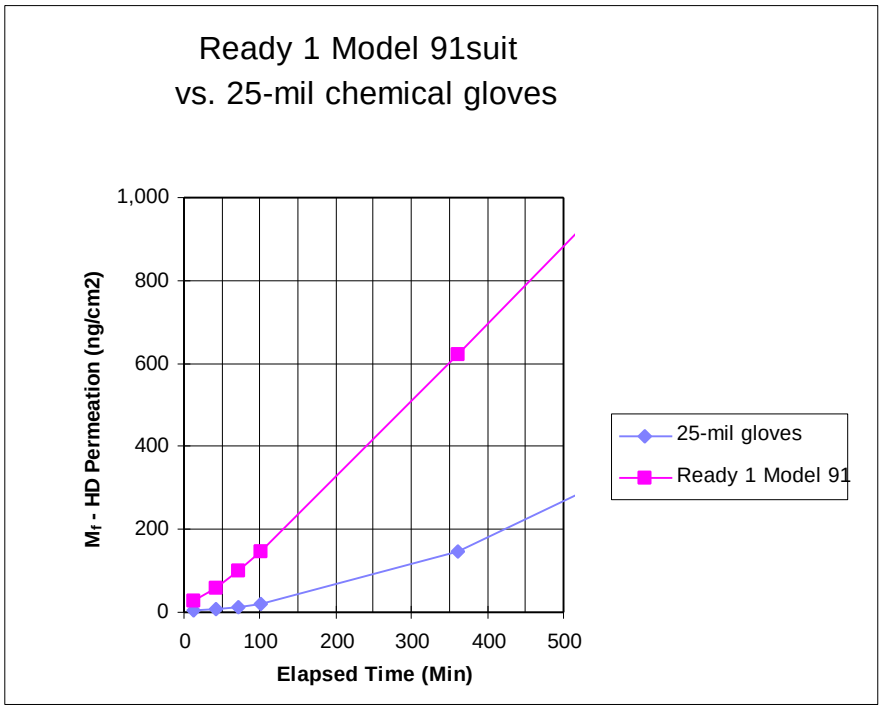


Figure I-7: Ready 1 Limited Use Suit: 91- Cumulative Weighted Average HD Permeation vs. 25-Mil Chemical Protective Glove HD Permeation

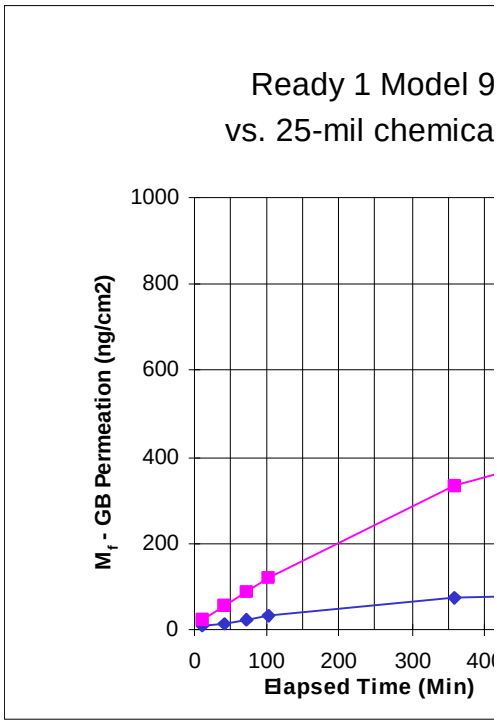


Figure I-8: Ready 1 Limited Use Suit: 91- Cu
GB Permeation vs. 25-Mil Chemical Protecti

Appendix I: Ready 1 Limited Use Suit: 91

Table I - 3: Ready 1 Limited Use Suit: 91- System Test (Vapor Simulant) Results

Suit	Overall PF	Systemic MRED (mg-min/m^3)	Localized MRED (mg-min/m^3)	Skin Area Affected
1	2053	20530	38620	Groin
2	1546	15460	69670	Chin & Neck
3	1923	19230	24740	Groin
4	2014	20140	44620	Axillae
5	1000	9996	18140	Groin
6	2140	21420	251800	Groin
7	1895	18950	221300	Chin & Neck
8	1214	12140	19600	Groin
9	6166	61660	253200	Groin
10	2288	22880	51420	Groin
11	2782	27820	255300	Groin
12	1391	13910	29970	Groin
13	2387	23870	46810	Groin
14	889	8890	18610	Groin

Overall PF (Median)	Overall PF (Minimum)	Overall PF (Maximum)	Average Systemic MRED	Average Localized MRED
1987.8	889.2	6166.0	21206.6	95984.3

Table I - 4. Ready 1 Limited Use Suit: 91- System Test (Aerosol Simulant) Results

Pre-Operational Exercises Visor Region/Upper Arm Combined				**Operational Exercises Visor Region/Upper Arm Combined**			
PF	*Frequency*	*Cumulative %*	Pass %	*PF*	*Frequency*	*Cumulative %*	Pass %
10	0	0	100	10	0	0	100
50	0	0	100	50	0	0	100
100	0	0	100	100	0	0	100
500	0	0	100	500	0	0	100
1000	0	0	100	1000	0	0	100
1667	2	4.2	95.8	1667	0	0	100
2000	5	14.6	85.4	2000	0	0	100
5000	25	66.7	33.3	5000	16	35.6	64.4
6667	11	89.6	10.4	6667	10	57.8	42.2
10000	4	97.9	2.1	10000	12	84.4	15.6
20000	1	100	0	20000	5	95.6	4.4
50000	0	100	0	50000	2	100	0
100000	0	100	0	100000	0	100	0
	48				45		

Table I-5. Ready 1 Limited Use Suit: 91- Overall Test Results

Breakthrough time (minutes)		Aerosol PF Pass Rate at PF equal to:				Overall Vapor PF	
incapacitation	erythema						
GB	HD	100	1000	2000		Min	Median
>480	125	100	100	85.4	(Pre-operational)	889	19880
		100	100	100	(Operational)		

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Appendix J: First Team XE HazMat Suit

Figure J-1: First Team XE HazMat Suit- Front View

Figure J-2: First Team XE HazMat Suit - Side

Appendix J: First Team XE HazMat Suit

Table J-1. First Team XE HazMat Suit - Average HD Permeation

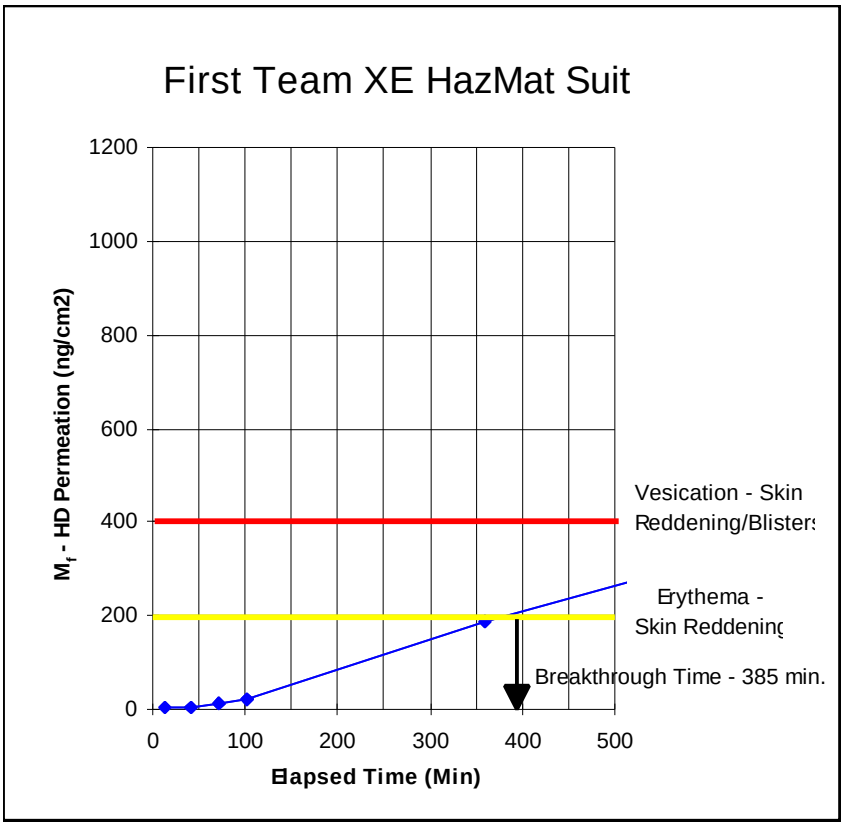
	Swatch Material Source (Weighting Factor) (Nanograms/cm2)						
Time (min)	suit mat'l (50%)	visor mat'l (15%)	glove (10%)	suit seam (15%)	suit/visor (5%)	zipper mat'l (5%)	Cum Perm Weig
12	0.00	3.00	4.00	0.67	6.00	36.33	
42	2.00	4.67	4.67	2.67	11.67	62.00	
72	7.67	10.33	6.33	7.67	16.00	88.67	
102	17.67	24.00	10.67	15.00	23.67	116.67	
360	205.00	186.67	98.33	137.67	114.33	392.67	1
720	428.33	339.33	195.33	302.00	216.67	862.33	3
1080	641.00	512.67	271.33	442.33	302.67	1525.67	5
1440	722.67	977.67	320.00	543.33	389.00	2234.67	7

Appendix J: First Team XE HazMat Suit

Table J-2. First Team XE HazMat Suit - Average GB Permeation

	Swatch Material Source (Weighting Factor) (Nanograms/cm2)						
Time (min)	suit mat'l	visor mat'l	glove	suit seam	suit/visor	zipper mat'l	Cum Perm Wei
	(50%)	(15%)	(10%)	(15%)	(5%)	(5%)	
12	0.00	0.00	18.33	94.67	27.00	80.00	2
42	0.00	6.67	57.33	180.00	113.33	208.67	4
72	0.00	23.00	106.00	261.67	246.67	334.33	8
102	0.00	53.33	155.00	339.00	394.00	459.67	11
360	0.00	432.00	565.00	872.00	1703.33	2067.67	44
720	0.00	777.67	982.67	1295.33	2968.00	4763.00	79
1080	0.00	1052.33	1317.67	1599.67	3776.33	7469.67	109
1440	0.00	1241.00	1559.33	1791.33	4263.00	9675.00	130

Appendix J: First Team XE HazMat Suit



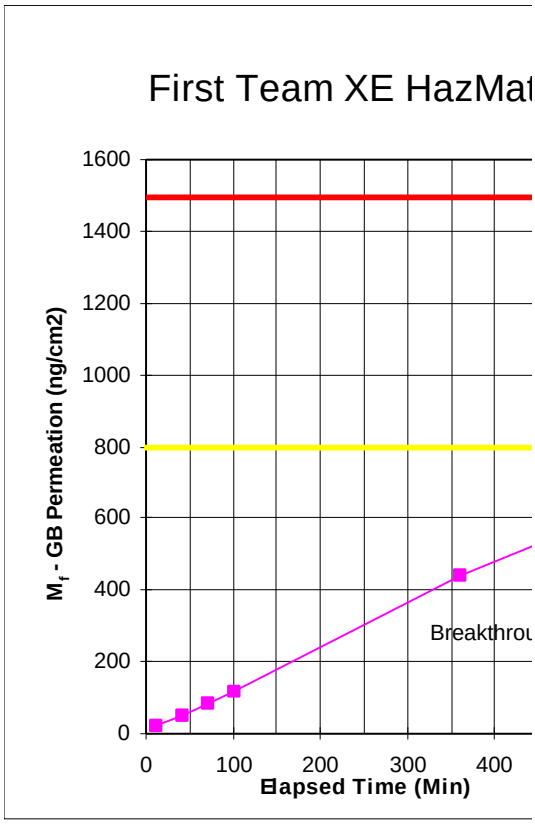


Figure J-3: First Team XE HazMat Suit-

Figure J-4: Appendix J: First Team XE HazM

Appendix J: First Team XE HazMat Suit

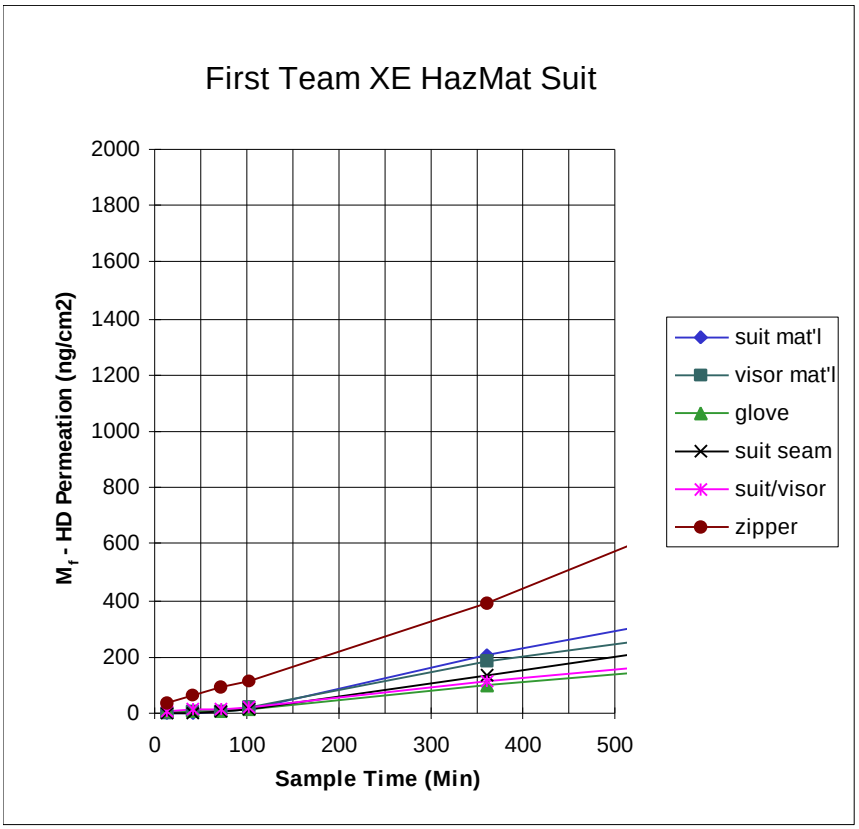


Figure J-5: First Team XE HazMat Suit: HD Permeation by Swatch Location Location

Cumulative Weighted Average HD Permeation
Cumulative Weighted Average GB

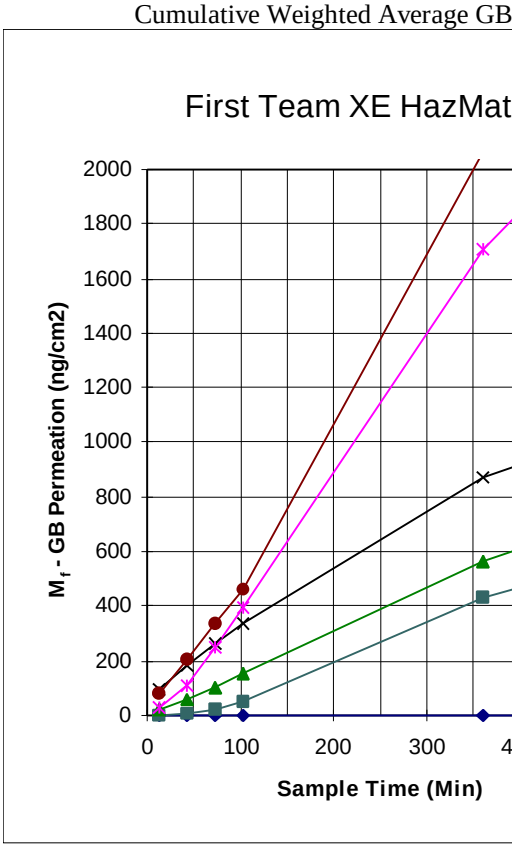


Figure J-6: First Team XE HazMat Suit : GB

Appendix J: First Team XE HazMat Suit

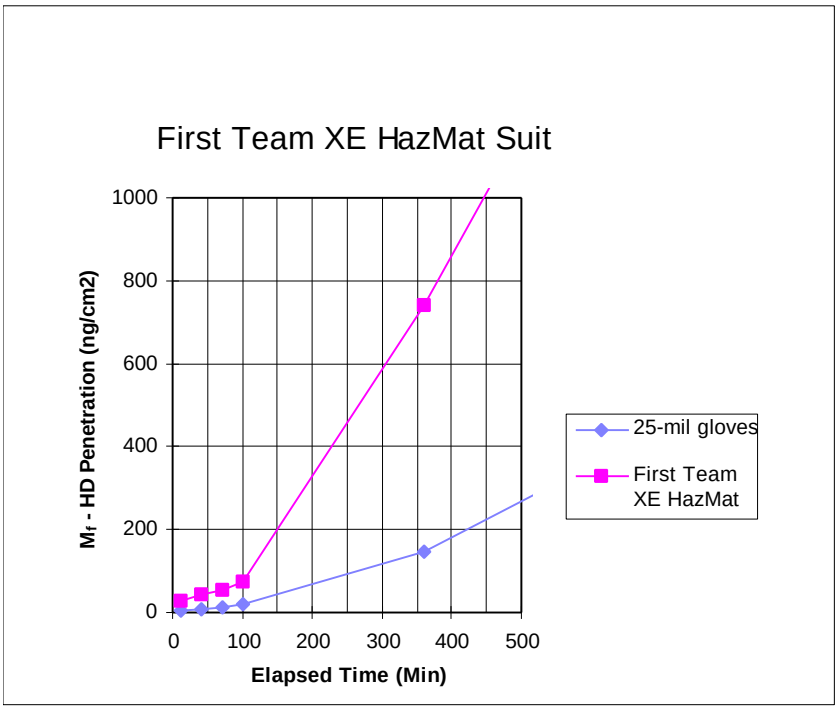


Figure J-7: First Team XE HazMat Suit - Cumulative Weighted Average HD Permeation vs. 25-Mil Chemical Protective Glove HD Permeation

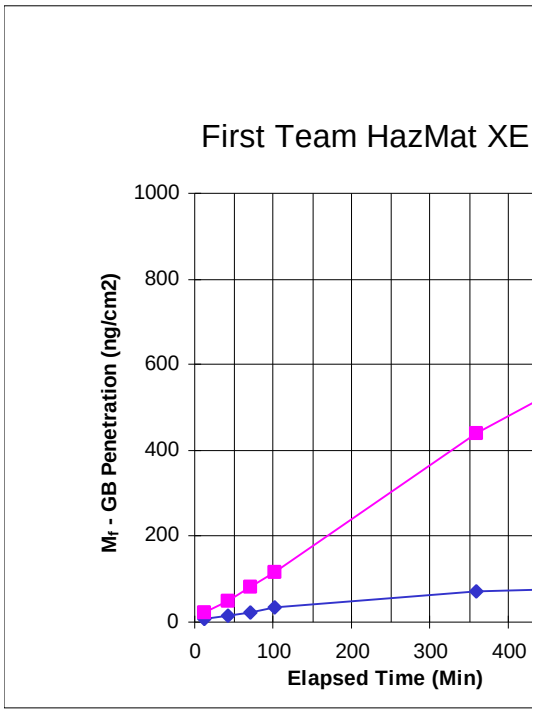


Figure J-8: First Team XE HazMat Suit - Cumul
GB Permeation vs. 25-Mil Chemical Protective C

Table J - 3: First Team XE HazMat Suit: System Test (Vapor Simulant) Results

Suit	Overall PF	Systemic MRED (mg-min/m^3)	Localized MRED (mg-min/m^3)	Skin Area Affected
1	2169	21690	233800	Groin
2	2220	22200	92010	Chin & Neck
3	1929	19290	108500	Elbowfold
4	1530	15300	55020	Groin
5	1475	14750	66240	Groin
6	364	3640	4268	Groin
7	1315	13150	49170	Groin
8	841	8410	25630	Groin
9	275	2750	5146	Groin
10	2767	27670	106600	Groin
11	2211	22110	105900	Groin
12	743	7430	75180	Axillae
13	2357	23570	256900	Groin
14	437	4370	62230	Groin

Overall PF (Median)	Overall PF (Minimum)	Overall PF (Maximum)	Average Systemic MRED	Average Localized MRED
1502	275	2767	12840	57980

Table J - 4. Appendix J: First Team XE HazMat Suit – System Test (Aerosol Simulant) Result

Pre-Operational Exercises Visor Region/Upper Arm Combined				**Operational Exercises Visor Region/Upper Arm Combined**			
PF	*Frequency*	*Cumulative %*	Pass %	*PF*	*Frequency*	*Cumulative %*	Pass %
10	0	0	100	10	0	0	100
50	2	4.3	95.7	50	3	6.5	93.5
100	2	8.5	91.5	100	2	10.9	89.1
500	2	12.8	87.2	500	1	13.0	87.0
1000	0	12.8	87.2	1000	1	15.2	84.8
1667	2	17.0	83.0	1667	1	17.4	82.6
2000	2	21.3	78.7	2000	0	17.4	82.6
5000	16	55.3	44.7	5000	3	23.9	76.1
6667	13	83.0	17.0	6667	3	30.4	69.6
10000	6	95.7	4.3	10000	3	37.0	63.0
20000	2	100	0	20000	16	71.7	28.3
50000	0	100	0	50000	13	100	0
100000	0	100	0	100000	0	100	0
	47				46		

Table J-5. First Team XE HazMat Suit - Overall Test Results

Breakthrough time (minutes)		Aerosol PF Pass Rate at PF equal to:				Overall Vapor PF	
incapacitation	erythema						
GB	HD	100	1000	2000		Min	Median
>480	385	91.5	87.2	78.7	(Pre-operational)	275	1502
		89.1	84.8	82.6	(Operational)		

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Appendix K: Commander Ultrapro Suit 79102

Figure K-1: Commander Ultrapro Suit 79102- Front View

Figure K-2: Commander Ultrapro Su

Appendix K: Commander Ultrapro Suit 79102

Table K-1. Commander Ultrapro 79102 - Average HD Permeation

		Swatch Material Source (Weighting Factor) (Nanograms/cm2)						
	Time (min)	suit mat'l	visor mat'l	glove	suit seam	suit/visor	zipper mat'l	Cum Perr Wei
		(50%)	(15%)	(10%)	(15%)	(5%)	(5%)	
	12	3.67	0.00	0.00	0.00	0.00	0.00	
	42	6.00	0.00	0.00	0.00	0.00	0.00	
	72	12.33	6.67	0.00	10.67	0.00	0.00	
	102	26.00	35.00	0.00	42.33	4.00	0.00	
	360	226.33	449.67	147.00	462.67	124.67	39.33	2
	720	396.67	697.33	316.00	856.67	155.00	399.33	4
	1080	479.00	709.33	390.33	1100.67	155.00	1151.67	6
	1440	540.33	709.33	414.67	1285.33	155.00	1943.33	7

Appendix K: Commander Ultrapro Suit 79102

Table K-2. Commander Ultrapro 79102 - Average GB Permeation

	Swatch Material Source (Weighting Factor) (Nanograms/cm2)						
Time (min)	suit mat'l	visor mat'l	glove	suit seam	suit/visor	zipper mat'l	Cum Perr Wei
	(50%)	(15%)	(10%)	(15%)	(5%)	(5%)	
12	0.00	16.00	5.00	9.00	17.67	0.00	
42	5.00	42.67	5.00	23.00	39.33	6.67	
72	16.00	78.33	5.00	39.00	72.00	13.00	
102	27.00	114.67	5.00	54.67	106.33	13.00	
360	38.00	372.33	5.00	62.67	356.33	13.00	1
720	38.00	585.67	5.00	62.67	576.33	13.00	1
1080	38.00	741.33	5.00	62.67	759.67	13.00	1
1440	38.00	843.33	5.00	62.67	885.00	13.00	2

Appendix K: Commander Ultrapro Suit 79102

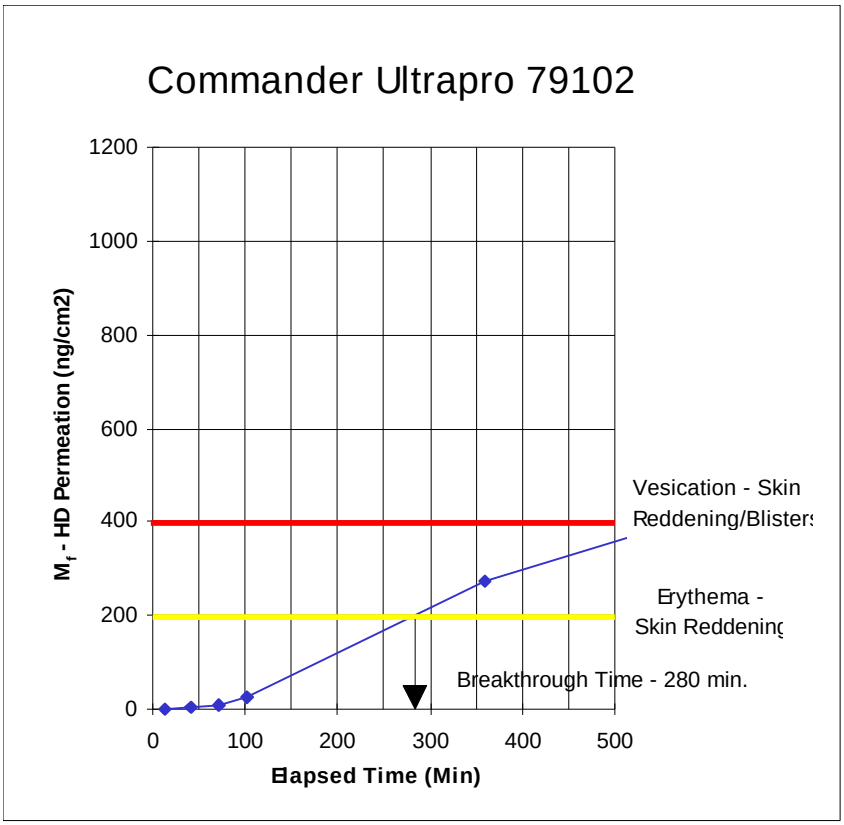

Figure K-3: Commander Ultrapro Suit 79102- Cumulative Weighted

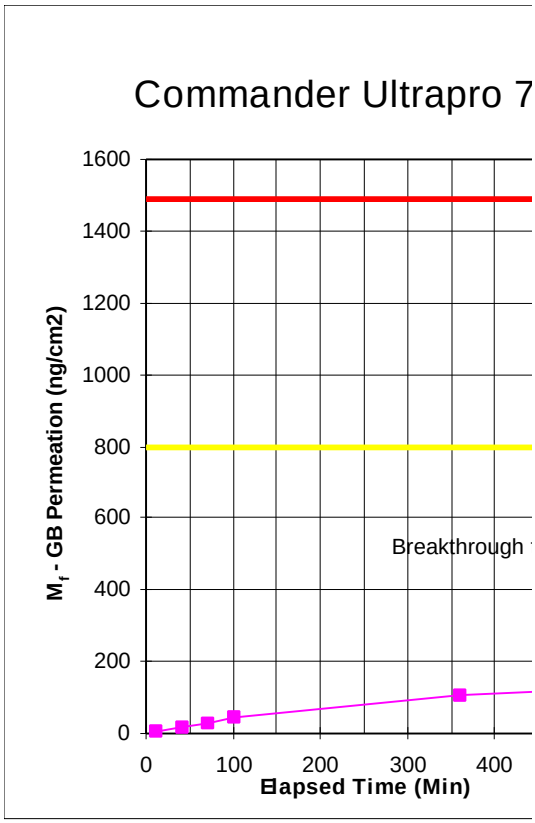

Figure K-4: Commander Ultrapro Suit 79102-

Appendix K: Commander Ultrapro Suit 79102

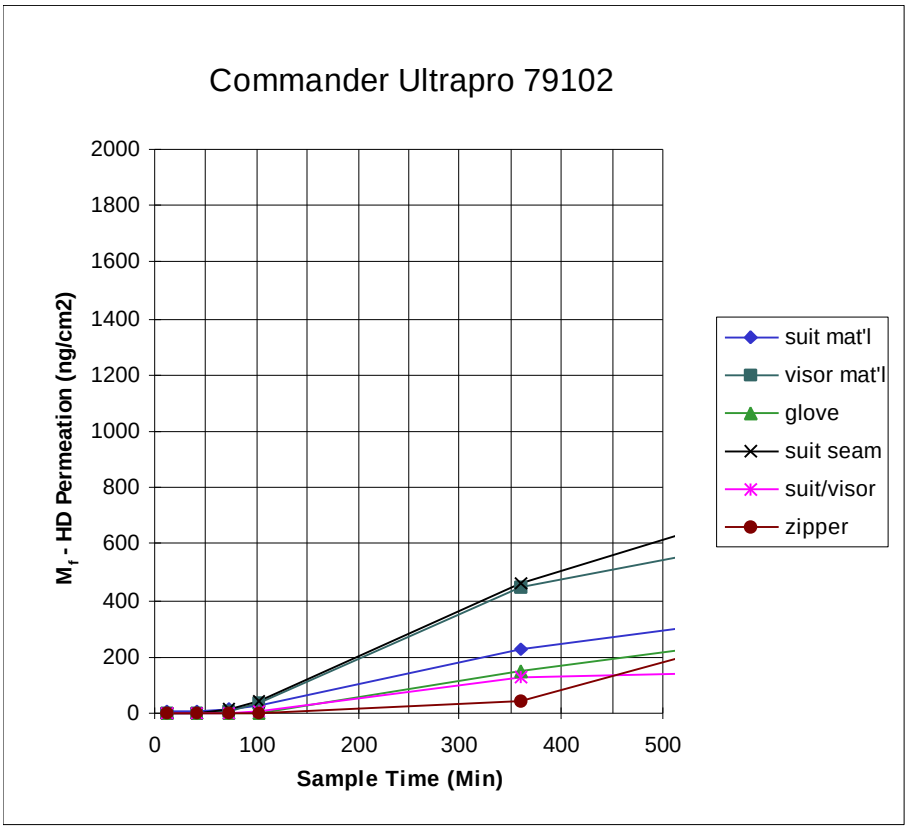

Figure K-5: Commander Ultrapro Suit 79102: HD Permeation by

Average HD Permeation
Average GB
Permeation

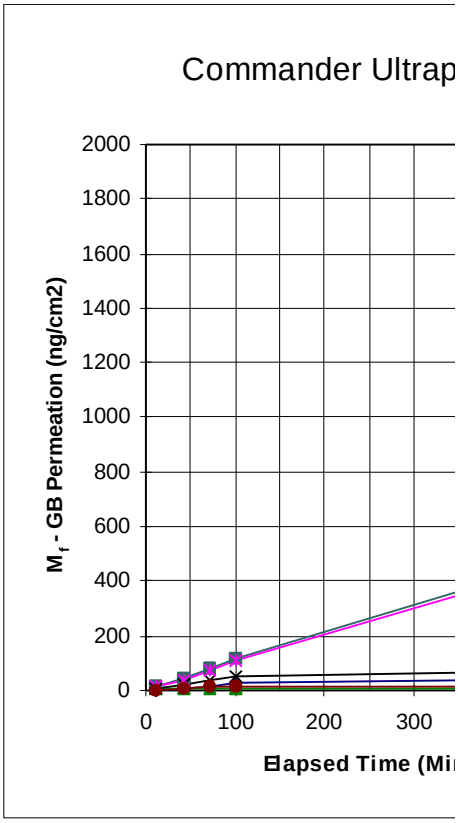

Figure K-6: Commander Ultrapro Suit 7

Appendix K: Commander Ultrapro Suit 79102

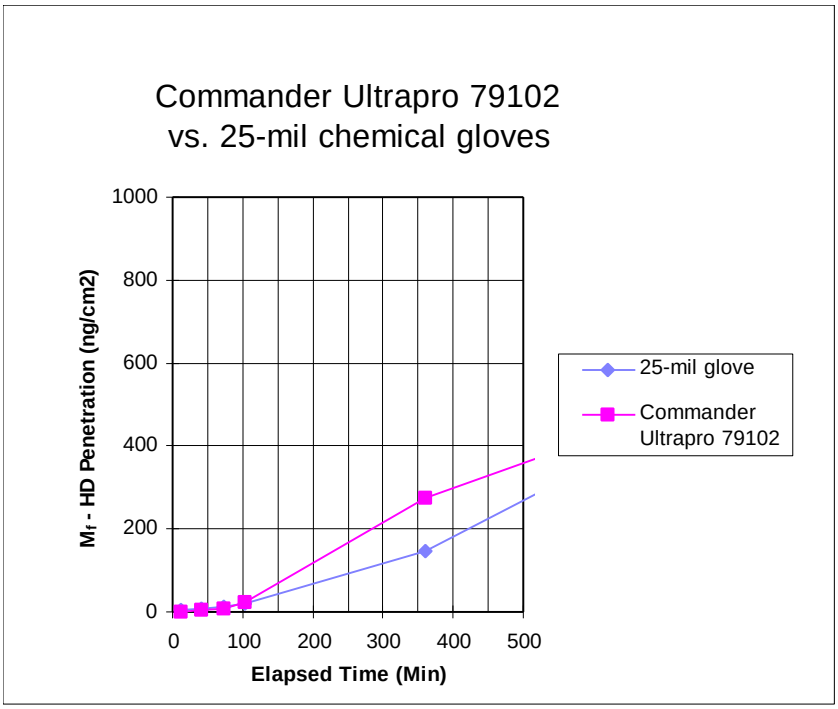

Figure K-7: Commander Ultrapro Suit 79102- Cumulative Weighted Average HD Permeation vs. 25-Mil Chemical Protective Glove HD Permeation

Swatch Location

Swatch Location

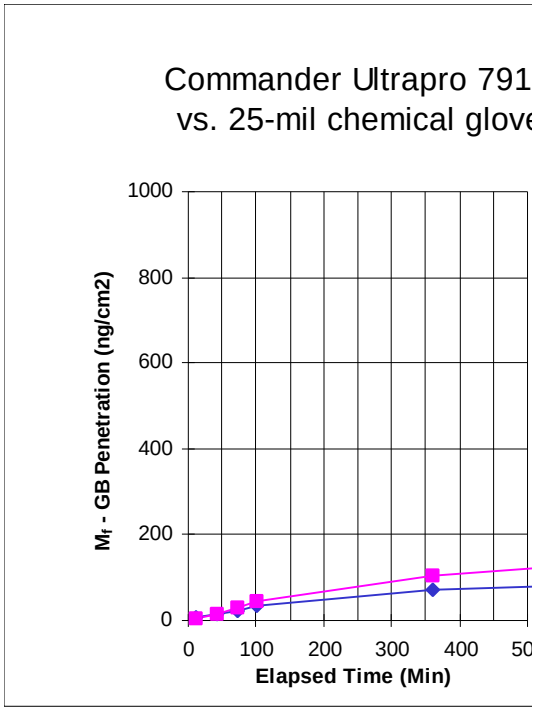

Figure K-8: Commander Ultrapro Suit 79102- GB Permeation vs. 25-Mil Chemical Protective

Appendix K: Commander Ultrapro Suit 79102

Table K - 3: Commander Ultrapro Suit 79102: System Test (Vapor Simulant) Results

Suit	Overall PF	Systemic MRED (mg-min/m^3)	Localized MRED (mg-min/m^3)	Skin Area Affected
1	909	9090	17890	Groin
2	1098	10980	58180	Chin & Neck
3	4657	46570	250300	Groin
4	2356	23560	41470	Groin
5	527	5266	13600	Chin & Neck
6	600	5996	33170	Chin & Neck
7	5692	56920	225400	Groin
8	5610	56100	225400	Groin
9	661	6611	10240	Groin
10	415	4145	19930	Groin
11	1122	11220	142900	Chin & Neck
12	672	6716	17070	Groin
13	4600	46000	252500	Groin
14	5927	59270	252500	Groin

Overall PF (Median)	Overall PF (Minimum)	Overall PF (Maximum)	Average Systemic MRED	Average Localized MRED
1110	415	5927	24890	111500

Table K – 4: Commander Ultrapro Suit 79102- System Test (Aerosol Simulant) Results

Pre-Operational Exercises Visor Region/Upper Arm Combined				**Operational Exercises Visor Region/Upper Arm Combined**			
PF	*Frequency*	*Cumulative %*	Pass %	*PF*	*Frequency*	*Cumulative %*	Pass %
10	0	0	100	10	0	0	100
50	0	0	100	50	0	0	100
100	0	0	100	100	0	0	100
500	0	0	100	500	0	0	100
1000	1	2.2	97.8	1000	0	0	100
1667	3	8.7	91.3	1667	0	0	100
2000	0	8.7	91.3	2000	2	4.3	95.7
5000	19	50.0	50.0	5000	1	6.5	93.5
6667	12	76.1	23.9	6667	4	15.2	84.8
10000	10	97.8	2.2	10000	11	39.1	60.9
20000	1	100	0	20000	16	73.9	26.1
50000	0	100	0	50000	10	95.7	4.3
100000	0	100	0	100000	2	100	0
	46				46		

Table K-5. Commander Ultrapro Suit 79102 - Overall Test Results

Breakthrough time (minutes)		Aerosol PF Pass Rate at PF equal to:				Overall Vapor PF	
incapacitation	erythema						
GB	HD	100	1000	2000		Min	Median
>480	280	100	97.8	91.3	(Pre-operational)	414.5	1109.8
		100	100.0	95.7	(Operational)		

Appendix L: Kappler Model 50660

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Figure L-1: Kappler 50660 - Front View

Figure L-2: Kappler 50660 - Side View

Appendix L: Kappler Model 50660

Table L-1. Kappler Model 50660 (Less NFPA Overcover) - Average HD Permeation

Swatch Material Source (Weighting Factor)
(Nanograms/cm2)

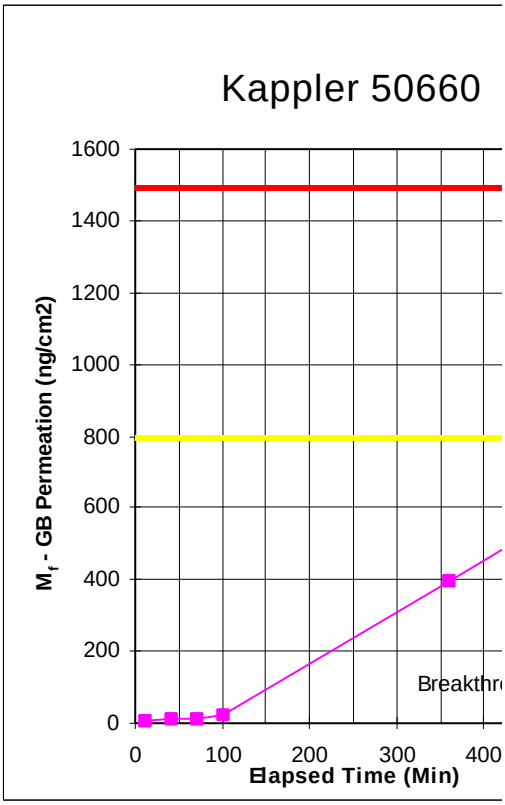
Time (min)	suit mat'l (50%)	visor mat'l (15%)	glove (10%)	suit seam (15%)	suit/visor (5%)	zipper mat'l (5%)	Cum Perm Weig
12	0.00	0.00	0.00	0.00	0.00	2.33	
42	0.00	0.00	0.00	0.00	0.00	4.33	
72	0.00	0.00	0.00	0.00	0.00	4.33	
102	0.00	0.00	0.00	0.00	0.00	7.00	
360	41.00	24.33	62.33	0.00	0.00	1601.67	1
720	71.67	37.67	164.00	0.00	0.00	9422.33	5
1080	71.67	37.67	249.33	0.00	0.00	19089.00	10
1440	71.67	37.67	319.00	0.00	0.00	28021.67	14

Appendix L: Kappler Model 50660

Table L-2. Kappler Model 50660 (Less NFPA Overcover) - Average GB Permeation

	Swatch Material Source (Weighting Factor) (Nanograms/cm2)						
Time (min)	suit mat'l	visor mat'l	glove	suit seam	suit/visor	zipper mat'l	Cum Perr Wei
	(50%)	(15%)	(10%)	(15%)	(5%)	(5%)	
12	5.00	5.67	8.67	2.67	10.33	17.67	
42	6.00	8.67	13.33	2.67	24.33	36.00	
72	6.33	9.00	16.67	2.67	54.00	64.67	
102	6.33	9.00	19.33	2.67	101.67	185.33	
360	6.33	9.00	263.67	2.67	583.33	6671.00	3
720	6.33	9.00	609.67	2.67	1006.33	16064.33	9
1080	6.33	9.00	816.67	2.67	1315.00	22587.33	12
1440	6.33	9.00	932.33	2.67	1535.00	26904.00	15

Appendix L: Kappler Model 50660



Appendix L: Kappler Model 50660

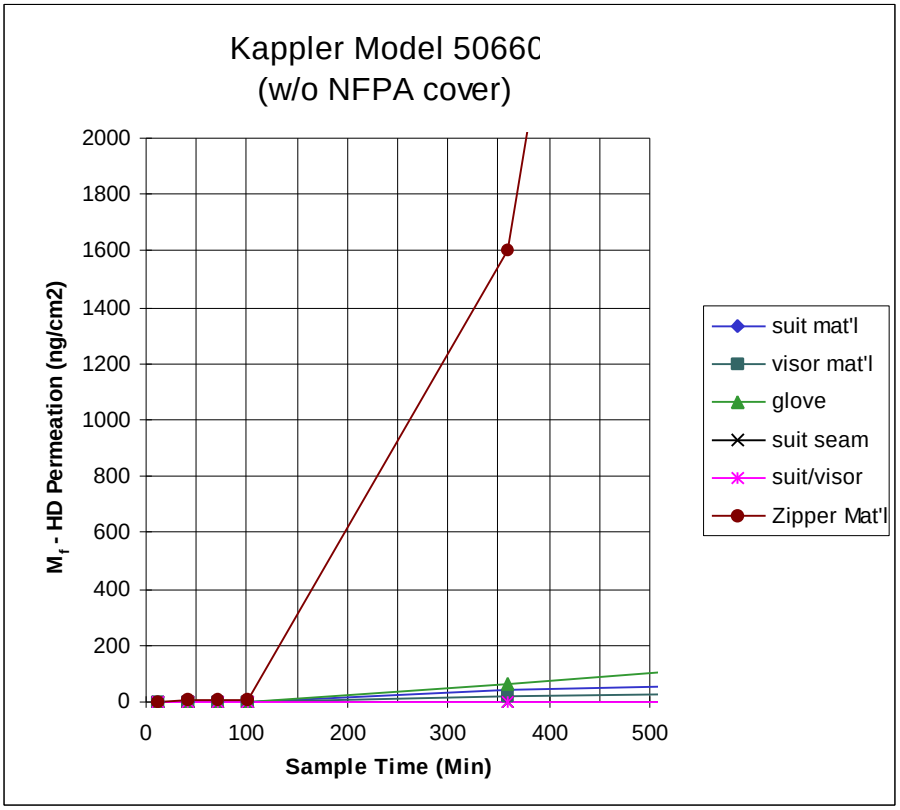


Figure L-3: Kappler 50660 (Less Overcover)

Figure L-4: Kappler 50660 (Less

Weighted Average Average HD Permeation

GB Per

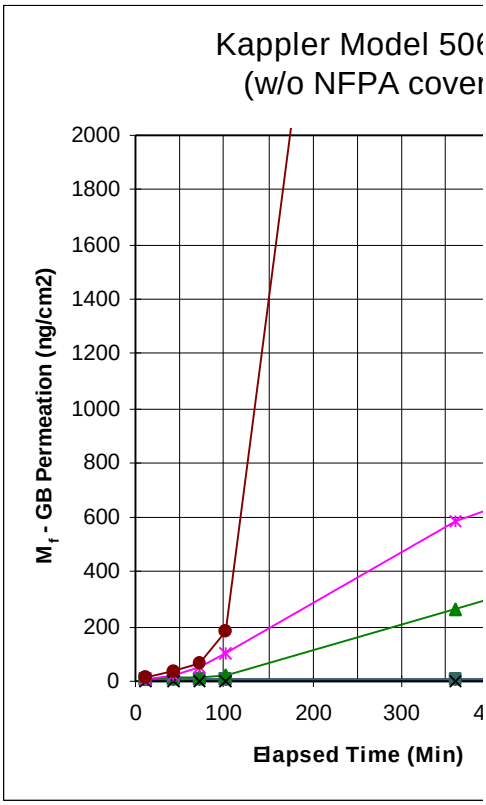


Figure L-5: Kappler Model 50660 (w/o NFPA cover): HD Permeation by Swatch Location

Figure L-6: Kappler Model 50660 (w/o NFP

Swatch Location

Appendix L: Kappler Model 50660

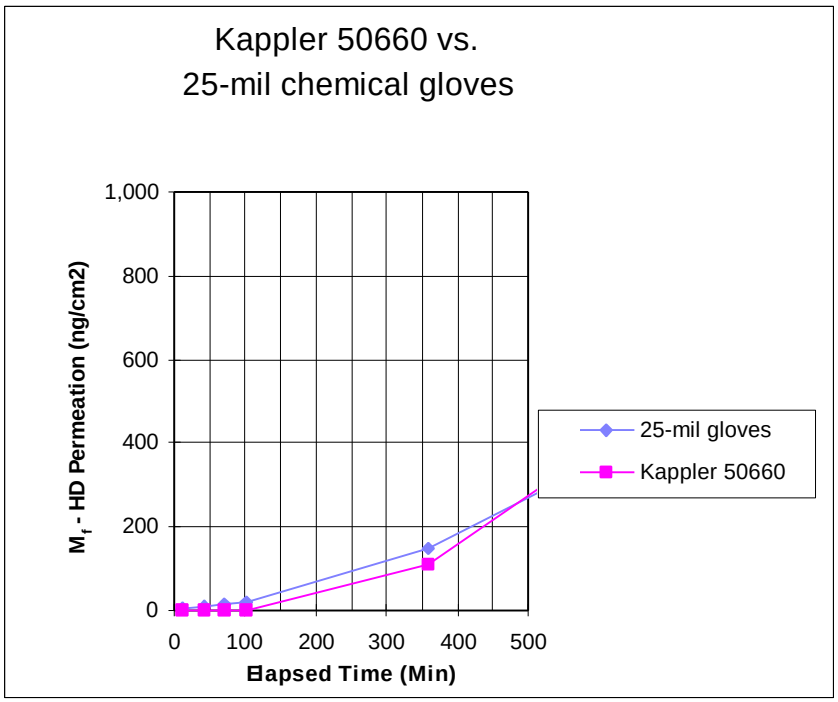


Figure L-7: Kappler 50660 (w/o NFPA cover) - Cumulative Weighted Average HD Permeation vs. 25-Mil Chemical Protective Glove HD Permeation

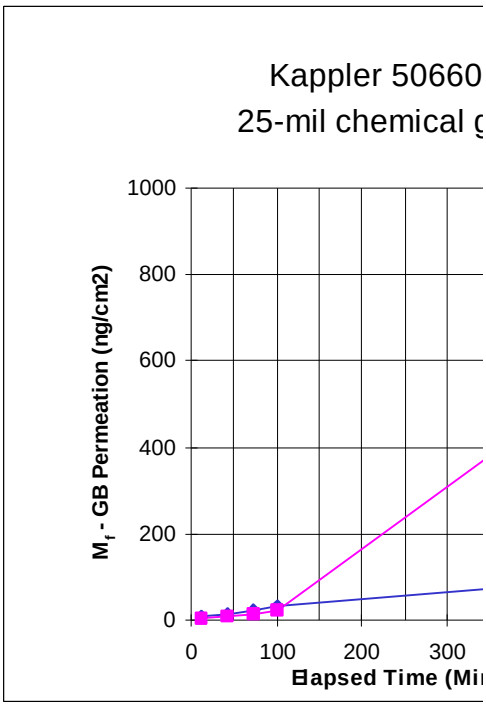


Figure L-8: Kappler 50660 (w/o NFPA cov
Average GB Permeation vs. 25-Mil Chemica
Permeation

Table L-3: Kappler 50660: System Test (Vapor Simulant) Results

Not tested

Table L-4. Kappler 50660 – System Test (Aerosol Simulant) Results

Pre-Operational Exercises Visor Region/Upper Arm Combined				**Operational Exercises Visor Region/Upper Arm Combined**			
PF	*Frequency*	*Cumulative %*	Pass %	*PF*	*Frequency*	*Cumulative %*	Pass %
10	0	0.0	100	10	0	0.0	100
50	0	0.0	100	50	0	0.0	100
100	0	0.0	100	100	0	0.0	100
500	11	22.9	77.1	500	8	17.4	82.6
1000	7	37.5	62.5	1000	4	26.1	73.9
1667	10	58.3	41.7	1667	4	34.8	65.2
2000	6	70.8	29.2	2000	7	50.0	50.0
5000	10	91.7	8.3	5000	19	91.3	8.7
6667	1	93.5	6.5	6667	3	97.8	2.2
10000	3	100	0	10000	1	100	0
20000	0	100	0	20000	0	100	0
50000	0	100	0	50000	0	100	0
100000	0	100	0	100000	0	100	0
	48				48		

Table L-5. Kappler Model 50660 - Overall Test Results

Breakthrough time (minutes)		Aerosol PF Pass Rate at PF equal to:				Overall Vapor PF
incapacitation	erythema					
GB	HD		100	1000	2000	Mec
>480	435	100	62.5	29.2	(Pre-operational)	Not tested
		100	73.9	50.0	(Operational)	

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Appendix M: TYCHEM 11645

Figure M-1: Tychem 11645 - Front View

Figure G-2: Tychem 11645 - Side V

Appendix M: TYCHEM 11645

Table M-1. TYCHEM Pkg 11645 Suit - Average HD Permeation

	Swatch Material Source (Weighting Factor) (Nanograms/cm2)						
Time (min)	suit mat'l	visor mat'l	glove	suit seam	suit/visor	zipper mat'l	Cum Perr Wei
	(50%)	(15%)	(10%)	(15%)	(5%)	(5%)	
12	23.33	0.00	1.67	53.00	19.00	7.67	
42	46.67	0.00	3.67	74.00	52.67	15.67	
72	46.67	0.67	3.67	74.00	91.67	19.67	
102	46.67	3.00	7.33	74.00	135.67	34.33	
360	46.67	10.33	26.00	74.00	530.33	1477.33	1
720	46.67	10.33	109.00	74.00	878.67	2762.00	2
1080	46.67	10.33	193.33	74.00	1116.00	9727.67	5
1440	46.67	10.33	243.67	74.00	1270.67	12948.33	7

Table M-2. TYCHEM Pkg 11645 Suit - Average GB Permeation

	Swatch Material Source (Weighting Factor) (Nanograms/cm2)						
Time (min)	suit mat'l	visor mat'l	glove	suit seam	suit/visor	zipper mat'l	Cum Perr Wei
	(50%)	(15%)	(10%)	(15%)	(5%)	(5%)	
12	23.33	0.00	1.67	53.00	19.00	7.67	
42	46.67	0.00	3.67	74.00	52.67	15.67	
72	46.67	0.67	3.67	74.00	91.67	19.67	
102	46.67	3.00	7.33	74.00	135.67	34.33	
360	46.67	10.33	26.00	74.00	530.33	1477.33	[illegible]
720	46.67	10.33	109.00	74.00	878.67	2762.00	[illegible]
1080	46.67	10.33	193.33	74.00	1116.00	9727.67	[illegible]
1440	46.67	10.33	243.67	74.00	1270.67	12948.33	[illegible]

Appendix M: TYCHEM 11645

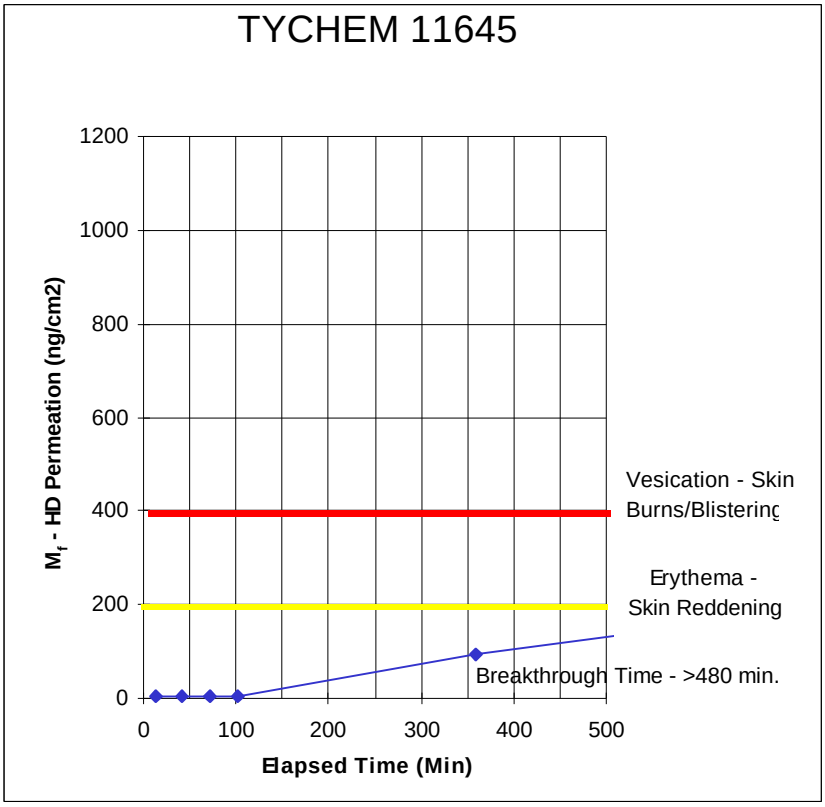


Figure M-3: TYCHEM 11645 - Cumulative Weighted Average HD Permeation

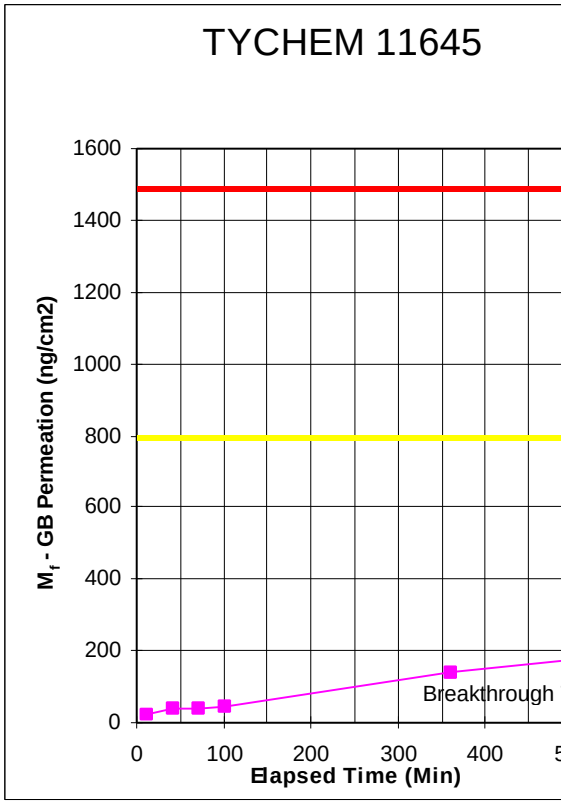


Figure M-4: TYCHEM 11645 - Cumulative Wei

Appendix M: TYCHEM 11645

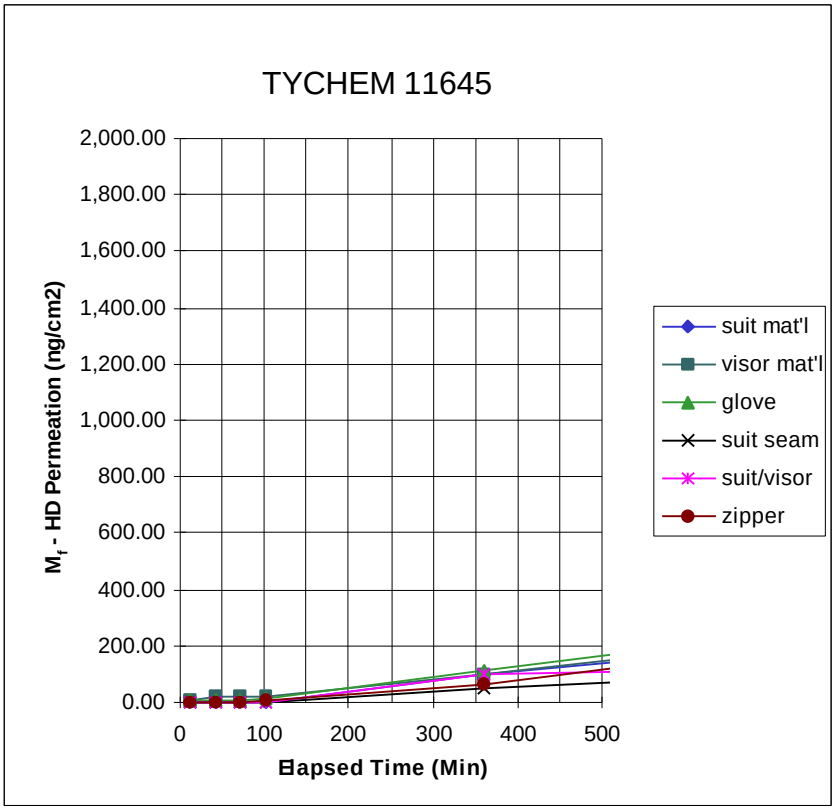


Figure M-5: TYCHEM 11645: HD Permeation by Swatch Location

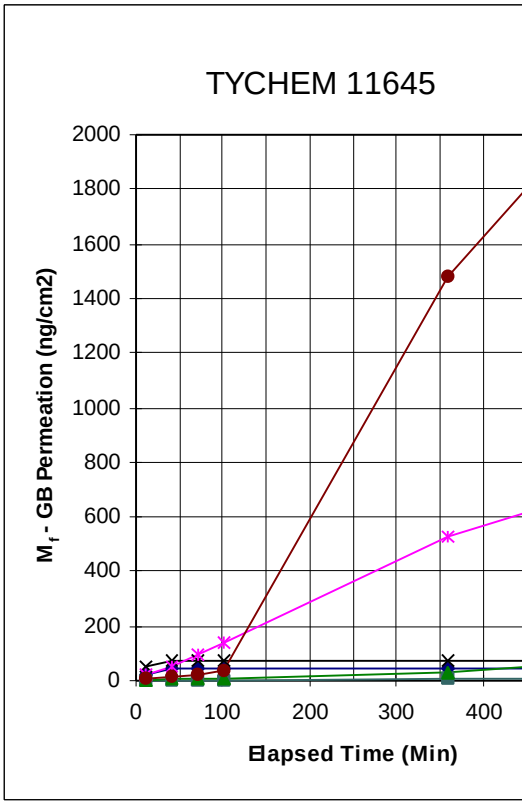
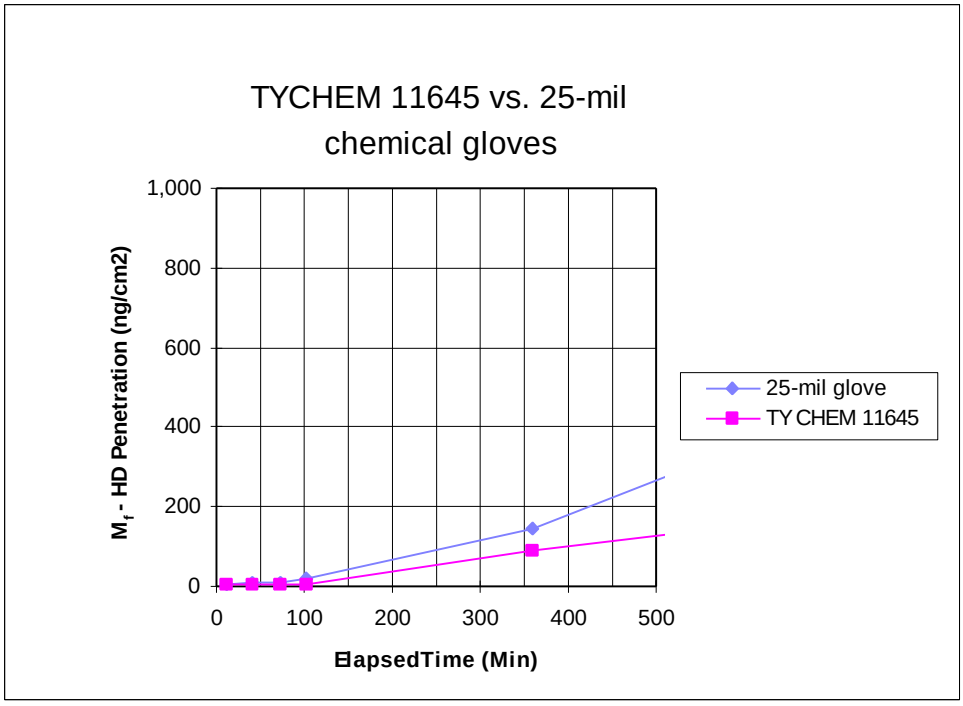


Figure M-6: TYCHEM 11645: GB Permeatio

Appendix M: TYCHEM 11645



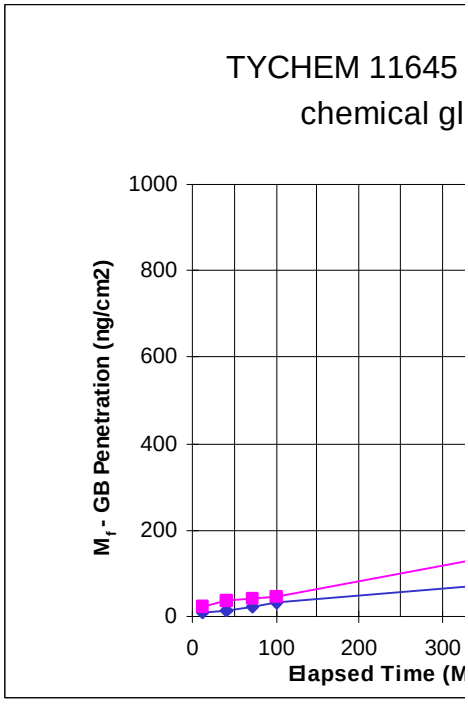


Figure M-7: TYCHEM 11645 - Cumulative Weighted Average HD Permeation vs. 25-Mil Chemical Protective Glove HD Permeation

Figure M-8: TYCHEM 11645 - Cumulative V
Permeation vs. 25-Mil Chemical Protective G

Table M-3. TYCHEM 11645- System Test (Vapor Simulant) Results

No Test

Table M - 4. TYCHEM 11645 – System Test (Aerosol Simulant) Results

Pre-Operational Exercises Visor Region/Upper Arm Combined				**Operational Exercises Visor Region/Upper Arm Combined**			
PF	*Frequency*	*Cumulative %*	Pass %	*PF*	*Frequency*	*Cumulative %*	Pass %
10	0	0	100	10	0	0	100
50	0	0	100	50	0	0	100
100	0	0	100	100	0	0	100
500	17	37.0	73.0	500	17	38.6	61.4
1000	8	54.6	45.4	1000	11	63.6	36.4
1667	6	67.4	32.6	1667	7	79.6	20.4
2000	1	69.6	30.4	2000	2	84.1	15.9
5000	13	97.8	2.2	5000	6	97.7	2.3
6667	0	97.8	2.2	6667	1	100	0
10000	1	100	0	10000	0	100	0
20000	0	100	0	20000	0	100	0
50000	0	100	0	50000	0	100	0
100000	0	100	0	100000	0	100	0
	46				46		

Table M-5. TYCHEM 11645 - Overall Test Results

Breakthrough time (minutes)		Aerosol PF Pass Rate at PF equal to:				Overall Vapor PF
GB incapacitation	HD erythema	100	1000	2000		Median
>480	>480	100	45.4	30.4	(Pre-operational)	No Test
		100	36.4	15.9	(Operational)	

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Appendix N Trellchem TLU Suit

Figure N-1: Trellchem TLU Suit - Front View

Figure N-2: Trellchem TLU Suit - Side View

Appendix N: Trellchem TLU Suit

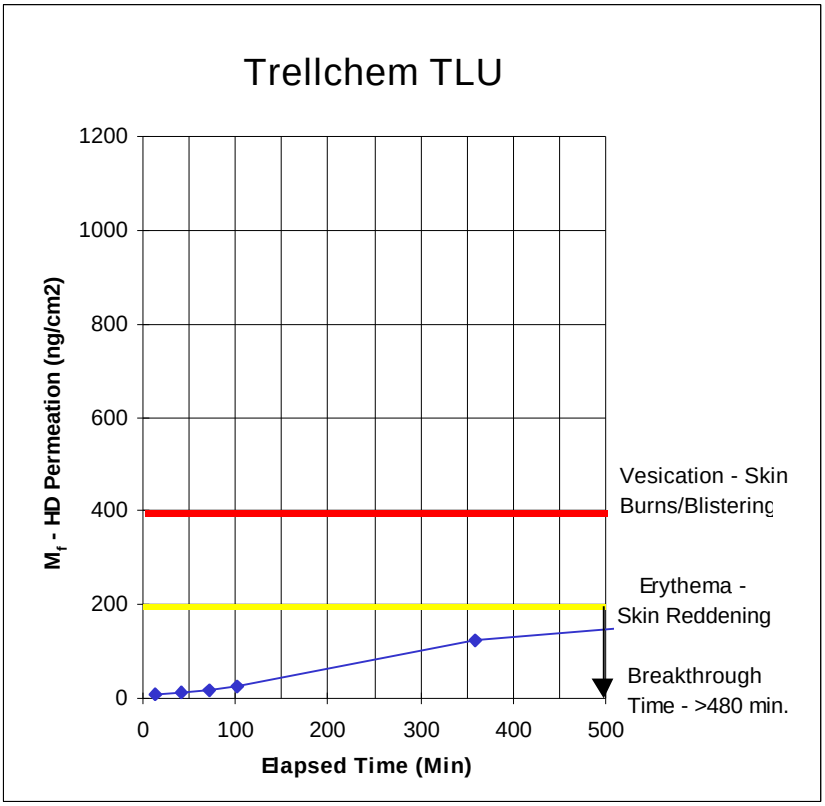
Table N-1. Trellchem TLU - Average HD Permeation

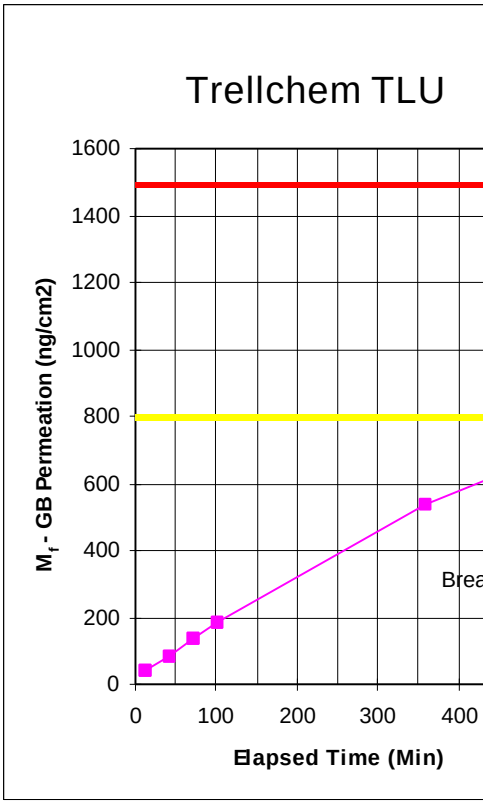
	Swatch Material Source (Weighting Factor) (Nanograms/cm2)						
Time (min)	suit mat'l	visor mat'l	glove	suit seam	suit/visor	zipper mat'l	Cun Perr Wei
	(50%)	(15%)	(10%)	(15%)	(5%)	(5%)	
12	13.00	0.00	0.00	4.00	0.00	0.00	
42	23.67	0.00	0.00	4.00	0.00	0.00	
72	35.67	0.00	0.00	4.00	0.00	0.00	
102	49.67	0.00	0.00	4.67	0.00	0.00	
360	213.67	43.33	0.00	47.33	0.00	62.33	1
720	281.67	78.33	0.00	67.67	0.00	399.33	1
1080	405.00	79.33	19.33	88.67	0.00	1350.67	2
1440	559.33	79.33	41.00	90.67	1.00	3032.33	4

Table N-2. Trellchem TLU - Average GB Permeation

	Swatch Material Source (Weighting Factor) (Nanograms/cm2)						
Time (min)	suit mat'l (50%)	visor mat'l (15%)	glove (10%)	suit seam (15%)	suit/visor (5%)	zipper mat'l (5%)	Cum Perm Wei
12	34.67	17.67	66.33	64.00	51.00	5.67	
42	81.33	33.67	196.67	107.33	80.00	16.33	
72	130.00	55.33	334.67	149.67	115.33	30.67	
102	174.00	79.33	473.00	189.00	154.00	47.67	
360	461.67	223.00	1676.33	466.00	455.33	236.00	
720	743.67	368.67	2909.33	725.33	798.33	406.33	
1080	950.33	494.00	3829.67	932.33	1102.67	534.67	1
1440	1097.67	588.33	4438.67	1041.33	1336.00	622.67	1

Appendix N: Trellchem TLU Suit

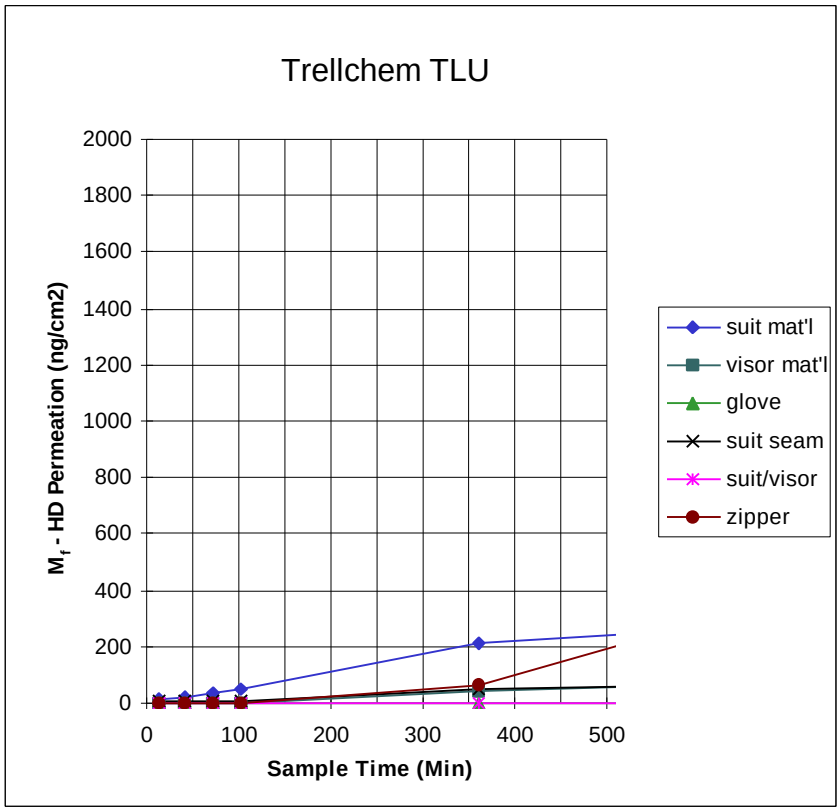




Appendix N: Trellchem TLU Suit

Figure N-3: Trellchem TLU - Cumulative Weighted Average HD Permeation

Figure N-4: Trellchem TLU - Cumulative Weighted Average GB Permeation



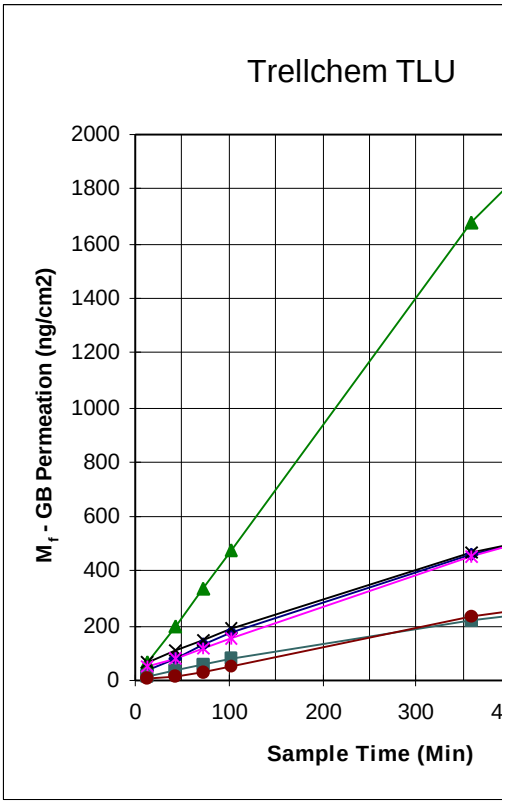


Figure N-5: Trellchem TLU: HD Permeation By Swatch Location

Figure N-6: Trellchem TLU: GB Permeatior

Appendix N: Trellchem TLU Suit

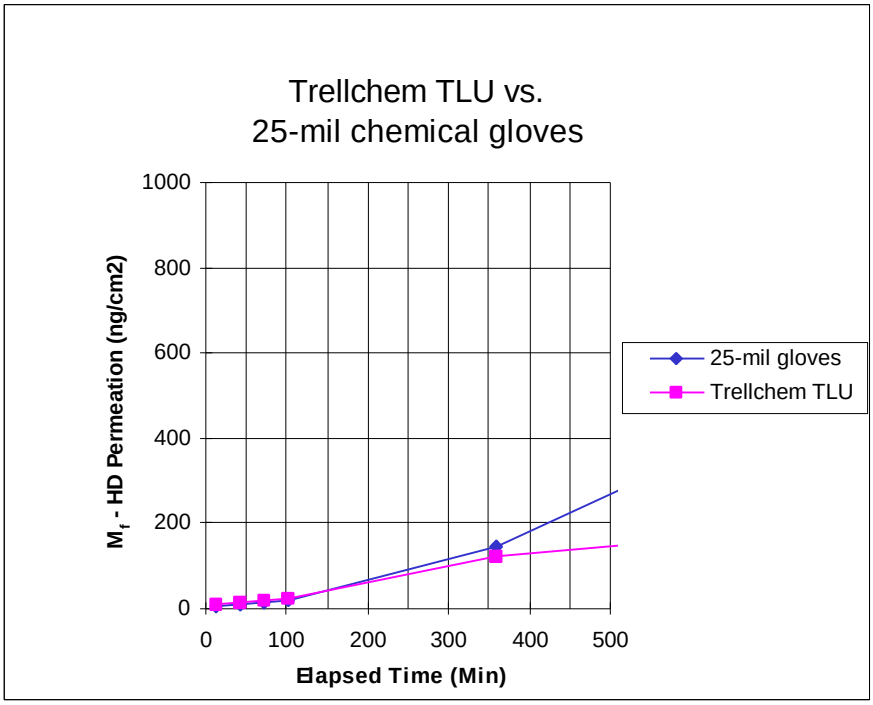


Figure N-7: Trellchem TLU - Cumulative Weighted Average HD Permeation vs. 25-Mil Chemical Protective Glove HD Permeation

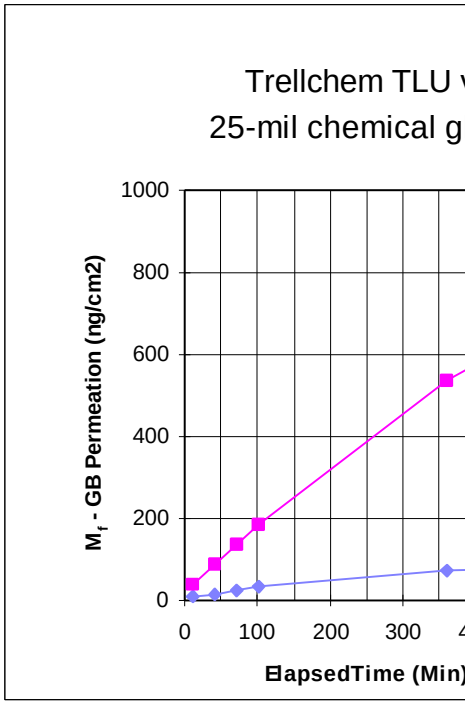


Figure N-8: Trellchem TLU - Cumulati
Permeation vs. 25-Mil Chemical Protect

Appendix N: Trellchem TLU Suit

Table N - 3: Trellchem TLU: System Test (Vapor Simulant) Results

Not Tested

Table N - 4. Trellchem TLU – System Test (Aerosol Simulant) Results

Pre-Operational Exercises Visor Region/Upper Arm Combined				**Operational Exercises Visor Region/Upper Arm Combined**			
PF	*Frequency*	*Cumulative %*	Pass %	*PF*	*Frequency*	*Cumulative %*	Pass %
10	0	0	100	10	0	0	100
50	0	0	100	50	0	0	100
100	0	0	100	100	0	0	100
500	0	0	100	500	0	0	100
1000	0	0	100	1000	0	0	100
1667	1	2.1	97.9	1667	0	0	100
2000	0	2.1	97.9	2000	1	2.1	97.9
5000	17	37.5	62.5	5000	11	25.0	75.0
6667	9	56.3	43.7	6667	11	47.9	52.1
10000	9	75.0	25.0	10000	8	64.6	35.4
20000	9	93.8	6.2	20000	15	95.8	4.2
50000	2	97.9	2.1	50000	2	100	0
100000	1	100	0	100000	0	100	0
	48				48		

Table N-5. Trellchem TLU - Overall Test Results

Breakthrough time (minutes)		Aerosol PF Pass Rate at PF equal to:				Overall Vapor PF
incapacitation	erythema					
GB	HD	100	1000	2000		Mec
>480	>480	100	100	97.9	(Pre-operational)	No Test
		100	100	97.9	(Operational)	

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Appendix O: Chemturion Suit: Model 13

Figure O-1: Chemturion Suit: Model 13- Front View

Figure O-2: Chemturion Suit: Model 13- Side View

Appendix O: Chemturion Suit: Model 13

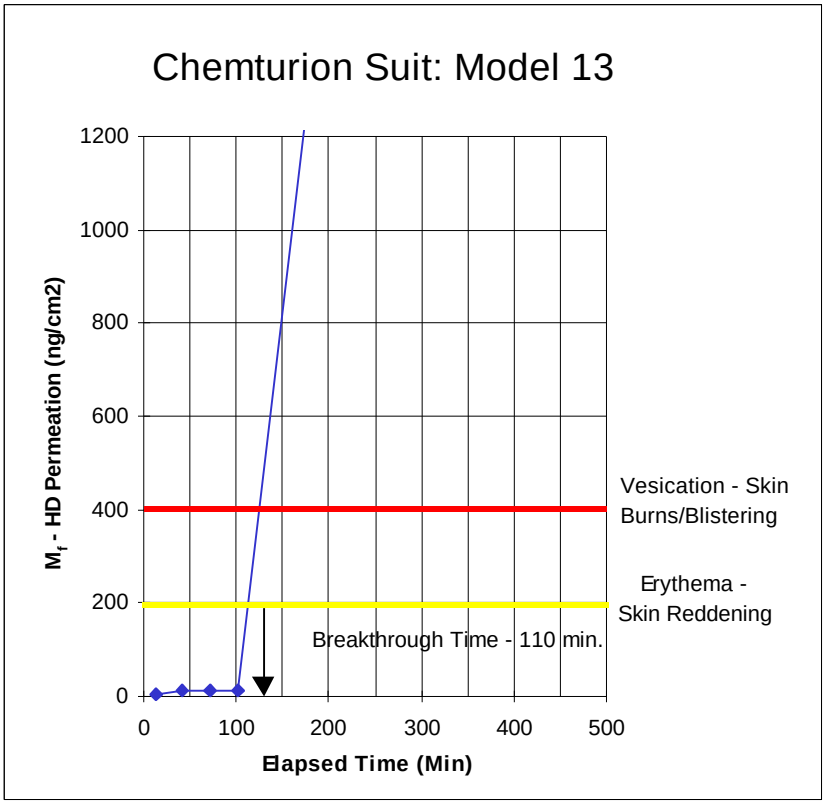
Table O-1. Chemturion Suit: Model 13- Average HD Permeation

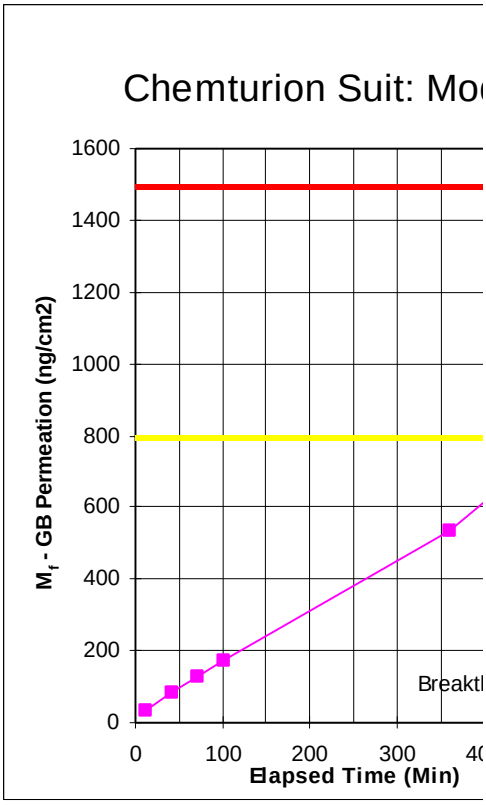
	Swatch Material Source (Weighting Factor) (Nanograms/cm2)						
Time (min)	suit mat'l	visor mat'l	glove	suit seam	suit/visor	zipper mat'l	Cum Perm Wei
	(50%)	(15%)	(10%)	(15%)	(5%)	(5%)	
12	10.00	0.00	4.72	0.00	1.00	6.00	
42	20.00	0.00	7.33	0.00	2.33	11.00	
72	20.00	0.00	9.89	0.00	2.33	14.33	
102	21.00	0.00	19.00	9.23	2.33	18.67	
360	6637.67	38.33	202.67	6542.67	6.00	99.00	4
720	16095.67	97.33	495.56	15983.67	26.33	212.33	10
1080	25674.00	107.33	1215.89	25415.67	83.33	313.00	16
1440	33894.67	122.33	2564.33	33573.67	212.67	404.33	22

Table O-2. Chemturion Suit: Model 13- Average GB Permeation

	Swatch Material Source (Weighting Factor) (Nanograms/cm2)						
Time (min)	suit mat'l	visor mat'l	glove	suit seam	suit/visor	zipper mat'l	Cum Perm Wei
	(50%)	(15%)	(10%)	(15%)	(5%)	(5%)	
12	0.00	0.00	8.50	167.67	105.00	12.33	
42	0.00	0.00	14.61	407.33	400.00	47.67	
72	0.00	0.00	23.00	537.00	800.00	117.67	1
102	0.00	0.00	33.83	650.67	1231.33	206.00	1
360	4.33	0.00	72.44	1513.33	5236.33	788.00	5
720	677.67	0.00	89.44	2681.33	9181.67	962.33	1
1080	2429.33	0.00	101.72	4488.33	12346.33	1634.33	2
1440	4421.00	0.00	107.11	6470.67	14893.33	1989.00	4

Appendix O: Chemturion Suit: Model 13





Appendix O: Chemturion Suit: Model 13

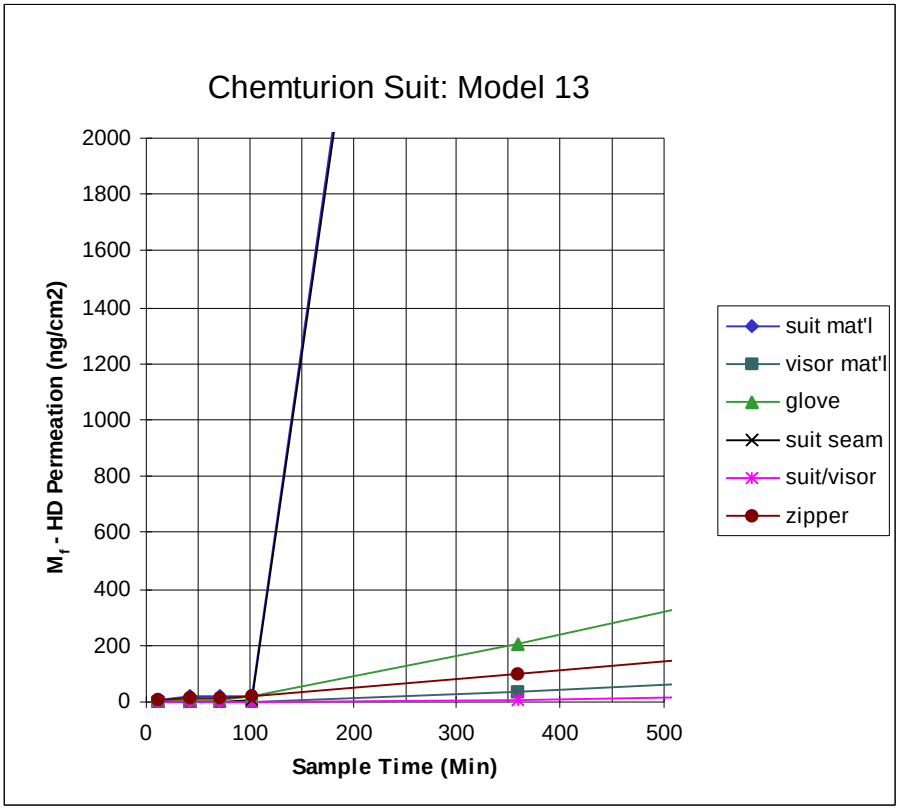


Figure O-3: Chemturion Suit: Model 13 - C

Figure O-4: Chemturion Suit: I

Average Permeation

GB

Permeation

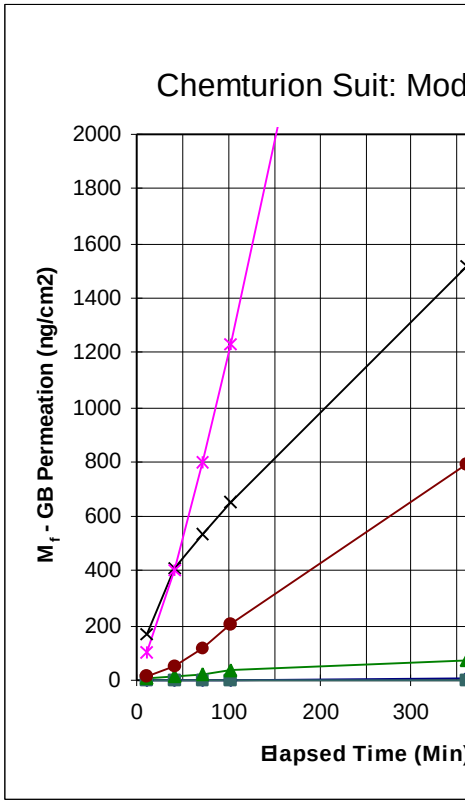


Figure O-5: Chemturion Suit: Model 13- HD Permeation by Swatch Location

Figure O-6: Chemturion Suit: Model 13 -

Location

Appendix O: Chemturion Suit: Model 13

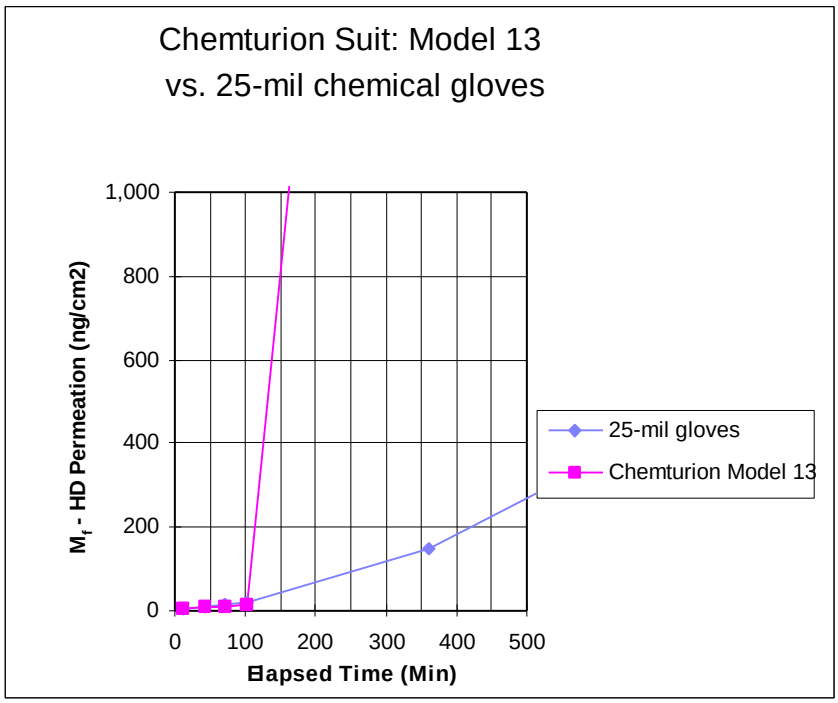


Figure O-7: Chemturion Suit: Model 13 - Cumulative Weighted Average HD Permeation vs. 25-Mil Chemical Protective Glove HD Permeation

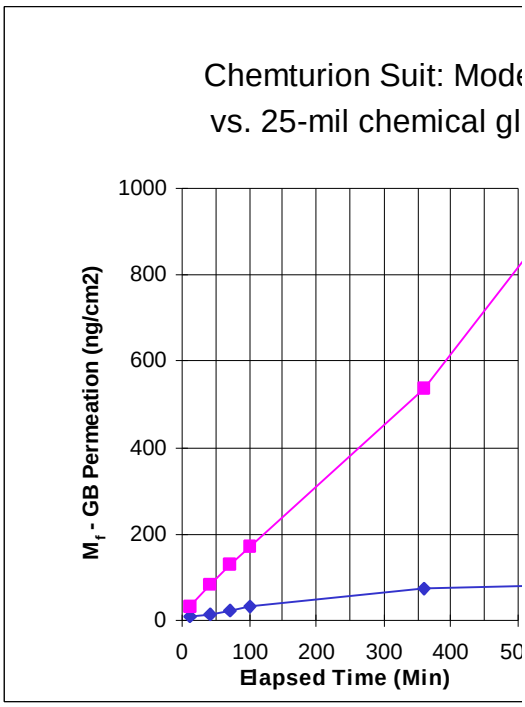


Figure O-8: Chemturion Suit: Model 13 - Cu
GB Permeation vs. 25-Mil Chemical Protecti

Table O - 3: Chemturion Suit: Model 13- System Test (Vapor Simulant) Results

Not Tested

Table O - 4. Chemturion Suit: Model 13- System Test (Aerosol Simulant) Results

Pre-Operational Exercises Visor Region/Upper Arm Combined				**Operational Exercises Visor Region/Upper Arm Combined**			
PF	*Frequency*	*Cumulative %*	Pass %	*PF*	*Frequency*	*Cumulative %*	Pass %
10	0	0	100	10	0	0	100
50	0	0	100	50	0	0	100
100	0	0	100	100	0	0	100
500	4	8.5	91.5	500	4	8.5	91.5
1000	0	8.5	91.5	1000	7	23.4	76.6
1667	3	14.9	85.1	1667	1	25.5	74.5
2000	4	23.4	76.6	2000	0	25.5	74.5
5000	18	61.7	38.3	5000	12	51.1	48.9
6667	11	85.1	14.9	6667	5	61.7	38.3
10000	4	93.6	6.4	10000	8	78.7	21.3
20000	2	97.9	2.1	20000	9	97.9	2.1
50000	1	100	0	50000	1	100	0
100000	0	100	0	100000	0	100	0
	47				47		

Table O-5. Chemturion Suit: Model 13- Overall Test Results

Breakthrough time (minutes)		Aerosol PF Pass Rate at PF equal to:				Overall Vapor PF
GB incapacitation	HD erythema	100	1000	2000		Mec
>480	110	100	91.5	76.6	(Pre-operational)	No Test
		100	76.6	74.5	(Operational)	

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Appendix P: Chempruf II BETEX Suit

Figure P-1: Chempruf II BETEX Suit - Front View

Figure P-2: Chempruf II BETEX Suit - Side V

Appendix P: Chempruf II BETEX Suit

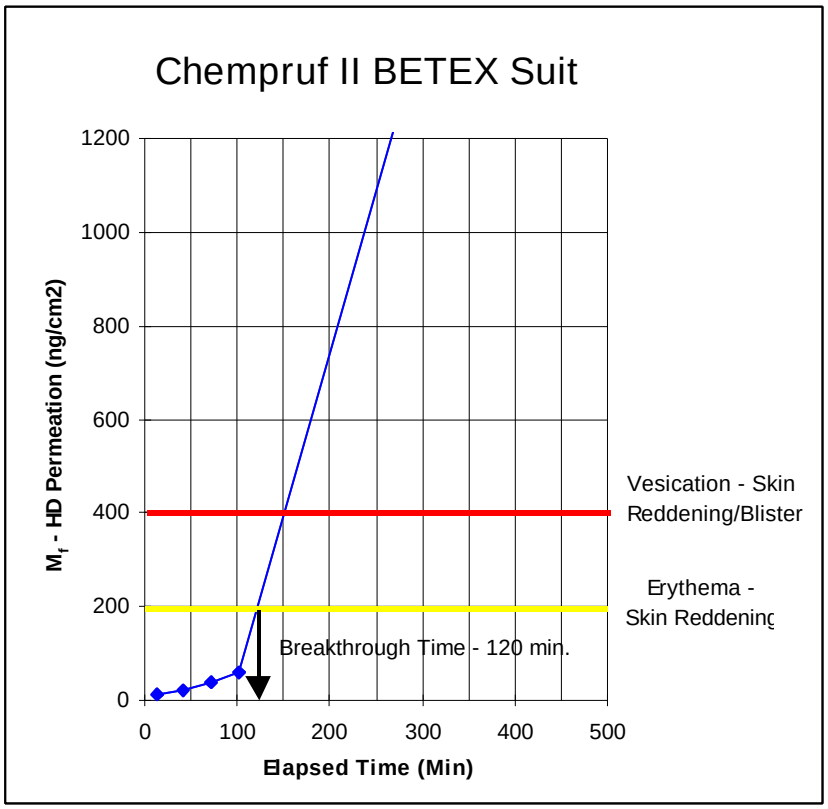
Table P-1. Chempruf II BETEX Suit - Average HD Permeation

	Swatch Material Source (Weighting Factor) (Nanograms/cm2)						
Time (min)	suit mat'l (50%)	visor mat'l (15%)	glove (10%)	suit seam (15%)	suit/visor (5%)	zipper mat'l (5%)	Cum Perm Weig
12	14.67	12.33	16.67	10.67	9.00	16.33	
42	19.33	20.67	31.33	16.00	14.67	82.67	
72	22.67	28.00	48.33	19.00	20.67	274.33	
102	27.67	36.33	68.33	22.67	26.00	596.67	
360	749.33	6315.00	407.00	192.00	1747.33	7242.33	18
720	8244.33	15980.00	1046.00	2038.67	9686.00	17600.67	82
1080	16972.33	24422.00	1650.00	5746.67	19667.00	27848.00	155
1440	24439.33	27986.00	2101.00	9405.67	28097.33	36784.00	212

Table P-2. Chempruf II BETEX Suit - Average GB Permeation

	Swatch Material Source (Weighting Factor) (Nanograms/cm2)						
Time (min)	suit mat'l	visor mat'l	glove	suit seam	suit/visor	zipper mat'l	Cum Perm Wei
	(50%)	(15%)	(10%)	(15%)	(5%)	(5%)	
12	106.67	29.00	6.00	44.33	31.00	8.33	6
42	383.67	106.33	17.00	175.00	109.00	22.00	24
72	499.67	202.00	28.33	342.33	201.00	46.67	34
102	646.67	291.00	39.00	471.00	286.00	97.67	46
360	1328.67	875.67	150.33	1109.67	843.67	2774.00	115
720	1834.33	1379.33	368.00	1578.33	1306.00	7240.00	182
1080	2148.00	1852.67	595.67	1900.00	1772.67	11830.33	237
1440	2398.67	2059.67	766.33	2095.67	1970.33	15156.67	275

Appendix P: Chempruf II BETEX Suit



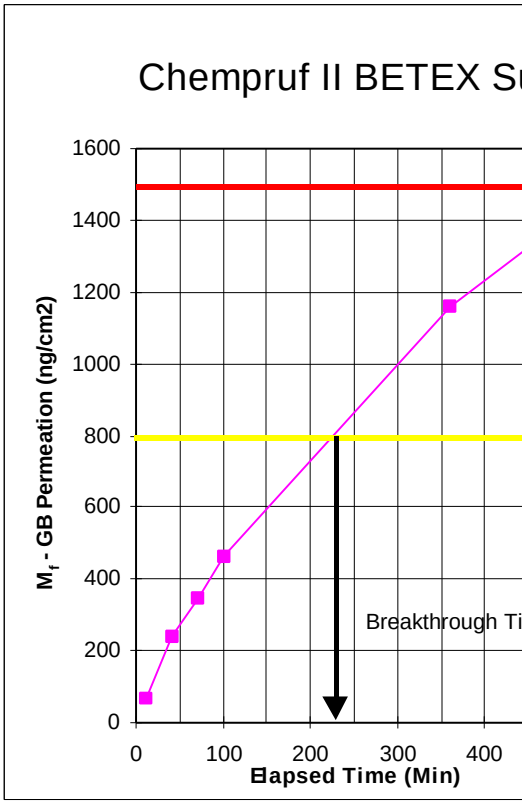
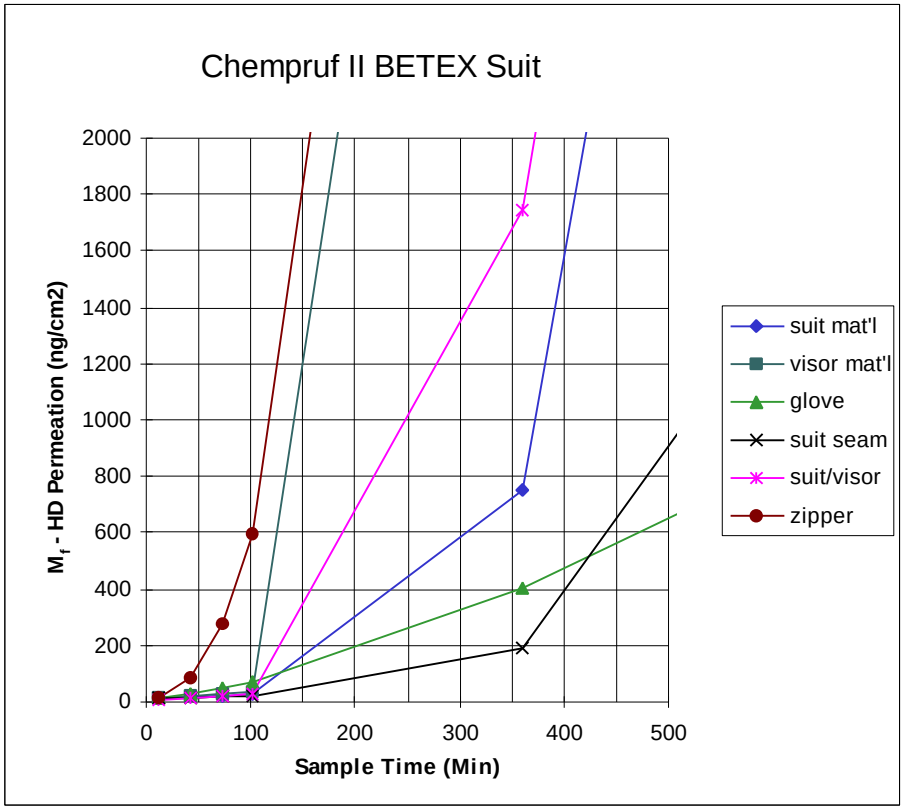


Figure P-3: Chempruf II BETEX Suit - Cumulative Weighted Average Weighted

Figure P-4: Appendix J: First Team XI

Appendix P: Chempruf II BETEX Suit



HD Permeation

Average GB Permeation

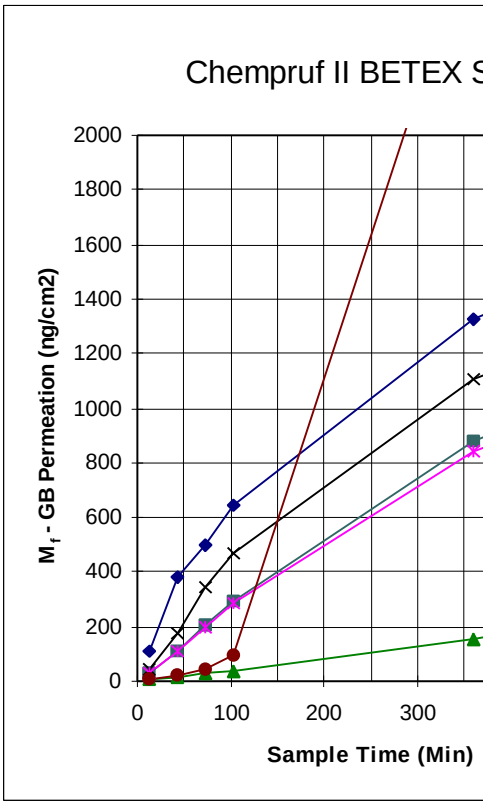


Figure P-5: Chempruf II BETEX Suit: HD Permeation by Swatch Location

Figure P-6: Chempruf II BETEX Suit: GB Pe

Appendix P: Chempruf II BETEX Suit

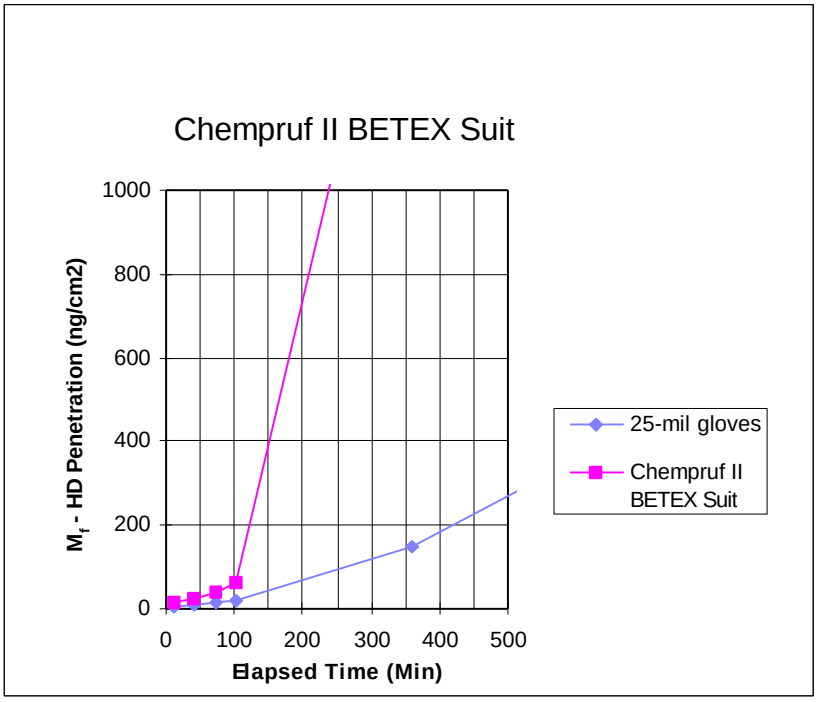


Figure P-7: Chempruf II BETEX Suit - Cumulative Weighted Average HD Permeation vs. 25-Mil Chemical Protective Glove HD Permeation

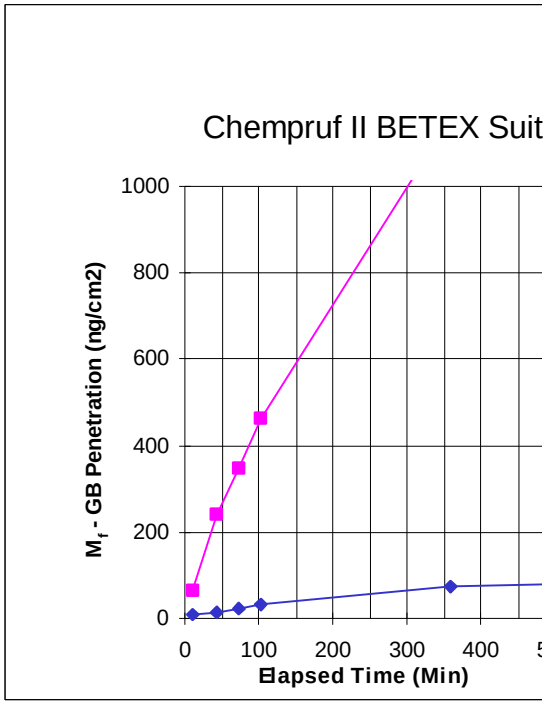


Figure P-8: Chempruf II BETEX Suit - Cumulati
GB Permeation vs. 25-Mil Chemical Protective C

Table P - 3: Chempruf II BETEX Suit: System Test (Vapor Simulant) Results

No Test

Table P - 4. Appendix J: Chempruf II BETEX Suit – System Test (Aerosol Simulant) Results

Pre-Operational Exercises Visor Region/Upper Arm Combined				**Operational Exercises Visor Region/Upper Arm Combined**			
PF	*Frequency*	*Cumulative %*	Pass %	*PF*	*Frequency*	*Cumulative %*	Pass %
10	4	8.9	91.1	10	4	9.1	90.1
50	2	13.3	86.7	50	2	13.6	86.4
100	1	15.6	84.4	100	0	13.6	86.4
500	1	17.8	82.2	500	3	20.5	79.5
1000	9	37.8	62.2	1000	2	25.0	75.0
1667	8	55.6	44.4	1667	0	25.0	75.0
2000	4	64.4	35.6	2000	4	34.1	65.9
5000	15	97.8	2.2	5000	14	65.9	34.1
6667	1	100	0	6667	10	88.6	11.4
10000	1	100	0	10000	1	90.9	9.1
20000	2	100	0	20000	4	100	0
50000	0	100	0	50000	0	100	0
100000	0	100	0	100000	0	100	0
	48				48		

Table P-5. Chempruf II BETEX Suit - Overall Test Results

Breakthrough time (minutes)		Aerosol PF Pass Rate at PF equal to:				Overall Vapor PF
GB incapacitation	HD erythema	100	1000	2000		Mec
225	125	84.4	62.2	35.6	(Pre-operational)	No Test
		86.4	75.0	65.9	(Operational)	

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Appendix Q: Commander Brigade F91

Figure Q-1: Commander Brigade F91 - Front View

Figure Q-2: Commander Brigade F91 - Side V

Appendix Q: Commander Brigade F91

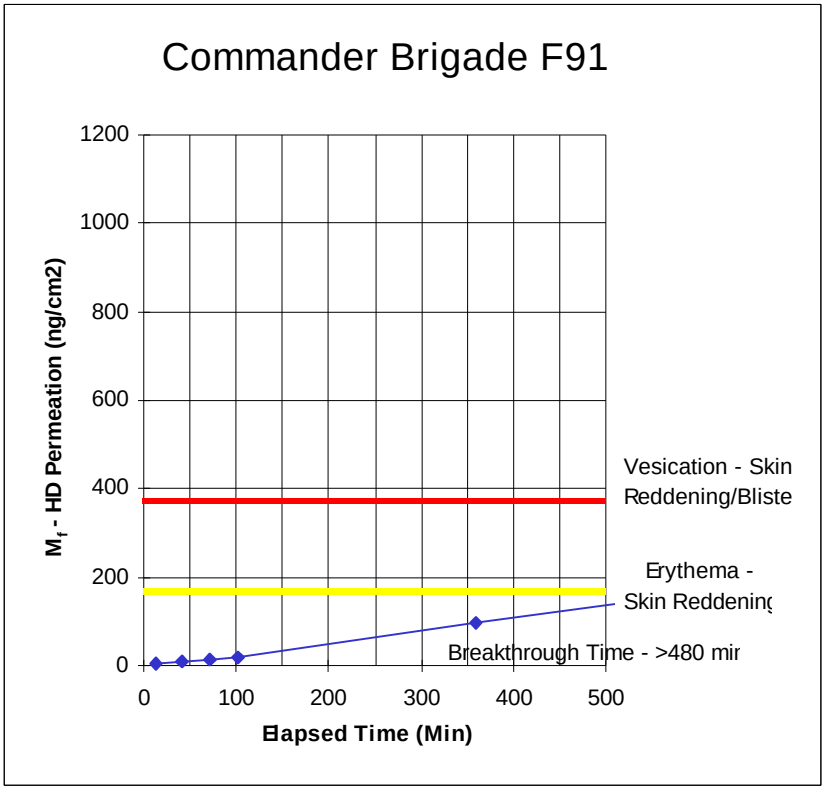
Table Q-1. Commander Brigade F91 - Average HD Permeation

	Swatch Material Source (Weighting Factor) (Nanograms/cm2)						
Time (min)	suit mat'l	visor mat'l	glove	suit seam	suit/visor	zipper mat'l	Cum Perr Wei
	(50%)	(15%)	(10%)	(15%)	(5%)	(5%)	
12	8.00	1.00	0.00	0.00	4.00	3.33	
42	16.33	1.00	0.00	0.00	5.67	6.33	
72	25.00	1.67	0.00	0.00	8.00	9.67	
102	35.67	3.00	0.00	0.67	10.67	13.00	
360	159.67	31.67	0.00	23.00	43.67	127.00	
720	277.67	53.33	0.00	37.00	70.33	812.00	1
1080	357.33	53.33	0.00	37.00	87.67	1857.00	2
1440	638.67	53.33	6.67	37.00	102.67	2768.00	4

Table Q-2. Commander Brigade F91 - Average GB Permeation

	Swatch Material Source (Weighting Factor) (Nanograms/cm2)						
Time (min)	suit mat'l	visor mat'l	glove	suit seam	suit/visor	zipper mat'l	Cum Perr Wei
	(50%)	(15%)	(10%)	(15%)	(5%)	(5%)	
12	16.67	12.00	5.67	26.33	15.33	37.67	
42	70.00	34.33	5.67	90.33	65.33	116.33	
72	143.67	57.67	7.67	164.67	148.00	223.67	1
102	214.67	84.00	13.00	233.00	254.33	347.00	1
360	463.33	298.33	184.00	450.00	1317.67	2348.33	5
720	606.33	528.67	451.33	580.33	2440.33	5815.33	9
1080	709.00	696.00	671.67	676.67	3245.67	9383.67	12
1440	780.00	806.67	789.00	743.33	3783.67	11392.33	14

Appendix Q: Commander Brigade F91



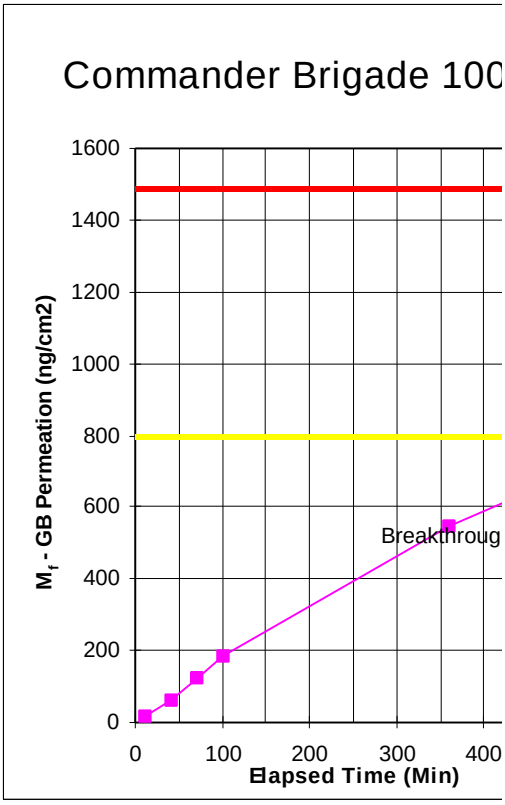


Figure Q-3: Commander Brigade F91 - Cumulative Weighted Average

Figure Q-4: Commander Brigade F91 -

Appendix Q: Commander Brigade F91

HD Permeation

Permeation

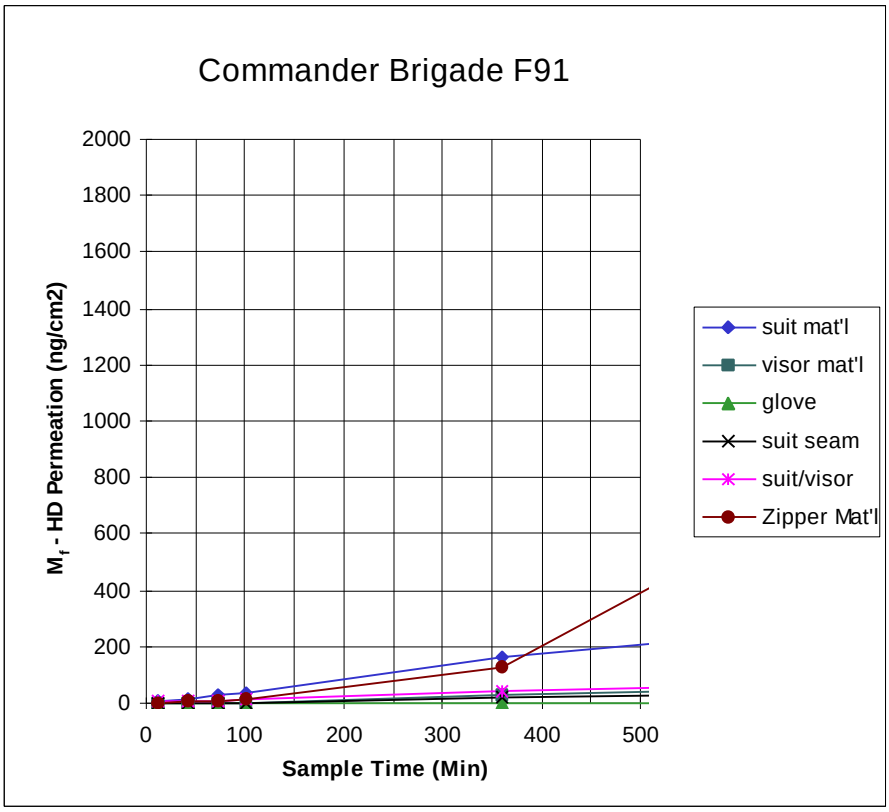


Figure Q-5: Commander Brigade F91: HD Permeation by Swatch Location

GB

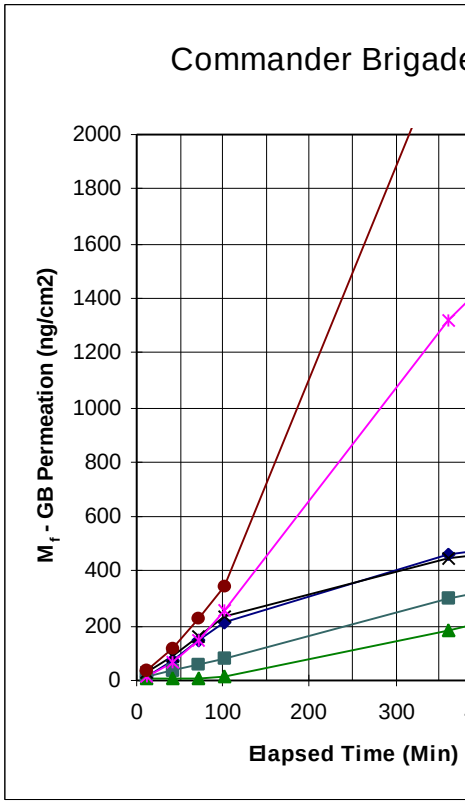
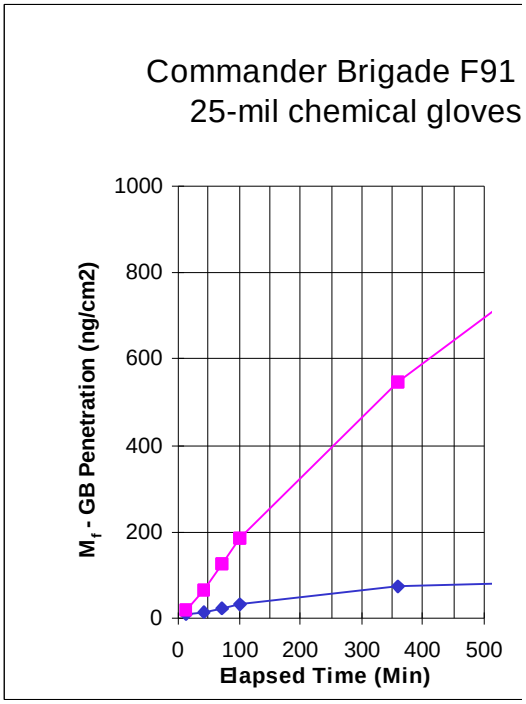
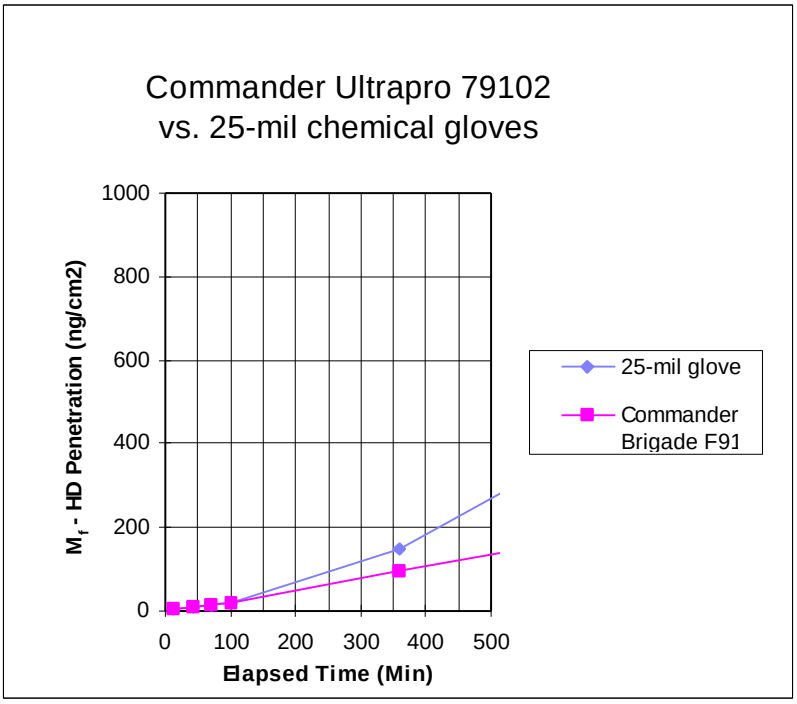


Figure Q-6: Commander Brigade F91: G
Location


Commander Brigade F91
25-mil chemical gloves
1000
800
600
400
200
0
0
100
200
300
400
500
Elapsed Time (Min)
M f - GB Penetration (ng/cm2)


Commander Ultrapro 79102
vs. 25-mil chemical gloves
1000
800
600
400
200
0
0
100
200
300
400
500
Elapsed Time (Min)
M f - HD Penetration (ng/cm2)
25-mil glove
Commander Brigade F91

Appendix Q: Commander Brigade F91

Figure Q-7: Commander Brigade F91 - Cumulative Weighted Average HD Permeation vs. 25-Mil Chemical Protective Glove HD Permeation

Figure K-8: Commander Brigade F91 - Cumulat
GB Permeation vs. 25-Mil Chemical Protective

Table Q - 3: Commander Brigade F91: System Test (Vapor Simulant) Results

No Test

Table Q – 4: Commander Brigade F91 - System Test (Aerosol Simulant) Results

Pre-Operational Exercises Visor Region/Upper Arm Combined				**Operational Exercises Visor Region/Upper Arm Combined**			
PF	*Frequency*	*Cumulative %*	Pass %	*PF*	*Frequency*	*Cumulative %*	Pass %
10	0	0	100	10	0	0	100
50	0	0	100	50	0	0	100
100	0	0	100	100	0	0	100
500	0	0	100	500	2	4.6	95.4
1000	4	8.3	91.7	1000	1	6.8	93.2
1667	7	22.9	77.1	1667	1	9.1	90.9
2000	5	33.3	66.7	2000	1	11.4	88.6
5000	24	83.3	16.7	5000	14	43.2	56.8
6667	2	87.5	12.5	6667	10	65.9	34.1
10000	3	93.8	6.2	10000	7	81.8	18.2
20000	3	100	0	20000	5	93.2	6.8
50000	0	100	0	50000	3	100	0
100000	0	100	0	100000	2	100	0
	48				44		

Table Q-5. Commander Brigade F91 - Overall Test Results

Breakthrough time (minutes)		Aerosol PF Pass Rate at PF equal to:				Overall Vapor PF
GB incapacitation	HD erythema	100	1000	2000		Mec
>480	>480	100	91.7	66.7	(Pre-operational)	No Test
		100	93.2	88.6	(Operational)	

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Appendix R: Overall Results

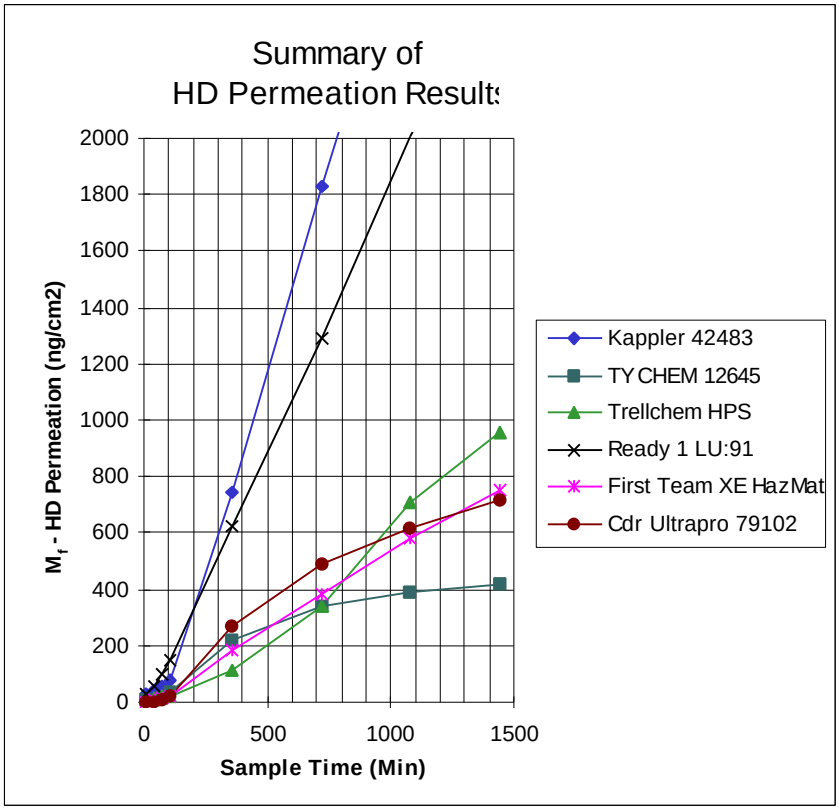


Figure R-1: First Six Suits- Cumulative Weighted Average HD Permeation Permeation

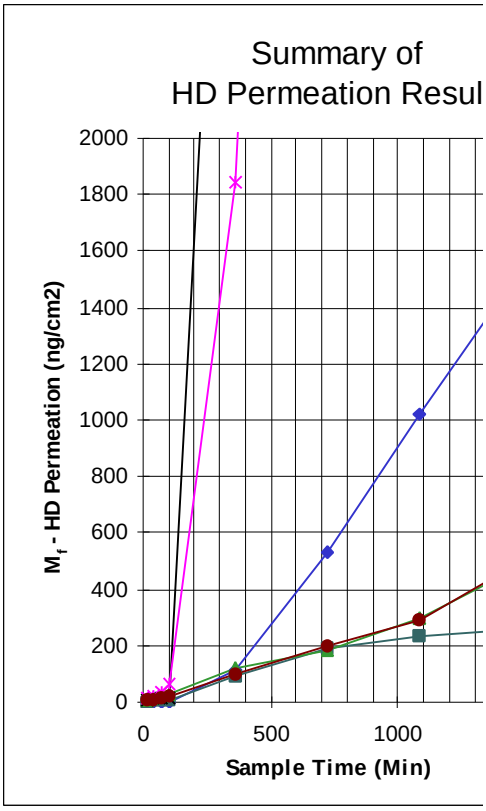
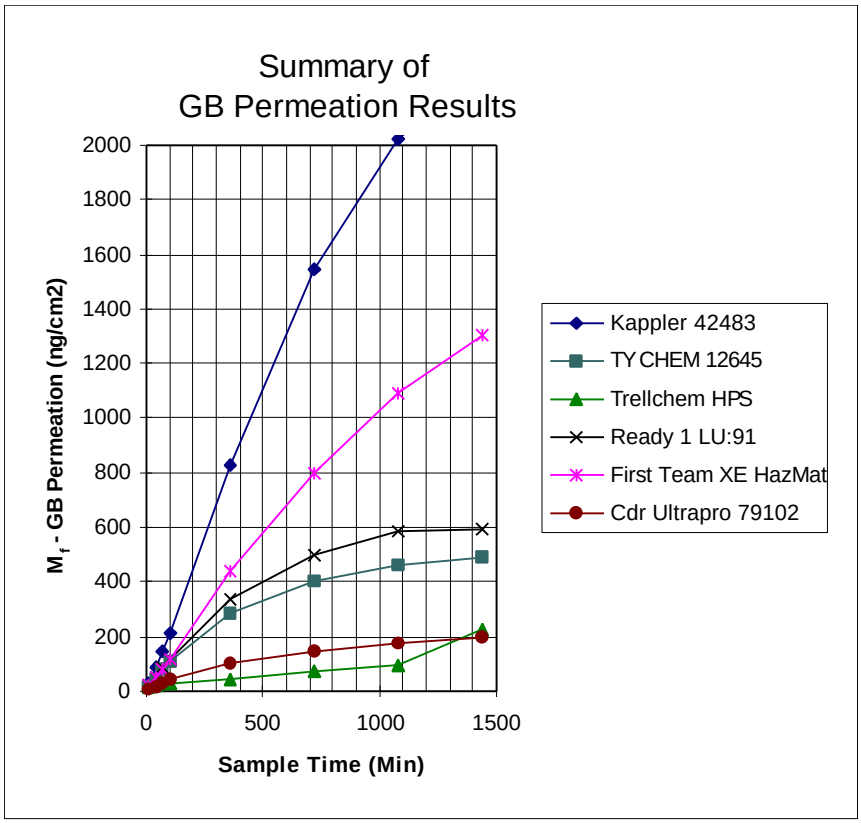
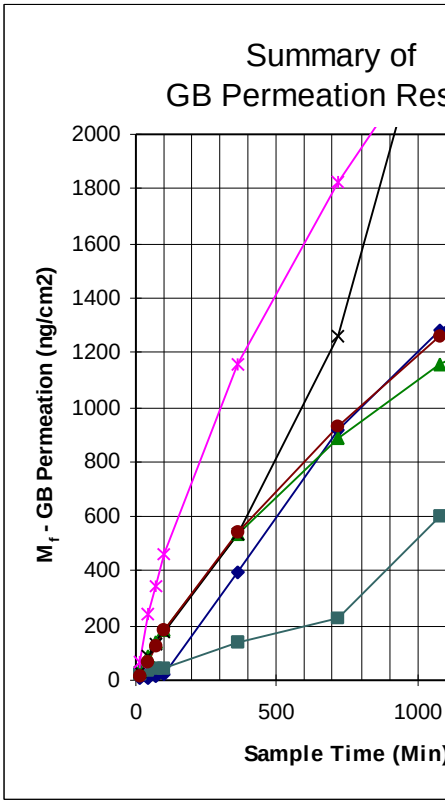


Figure R-2: Second Six Suits- Cumulative We

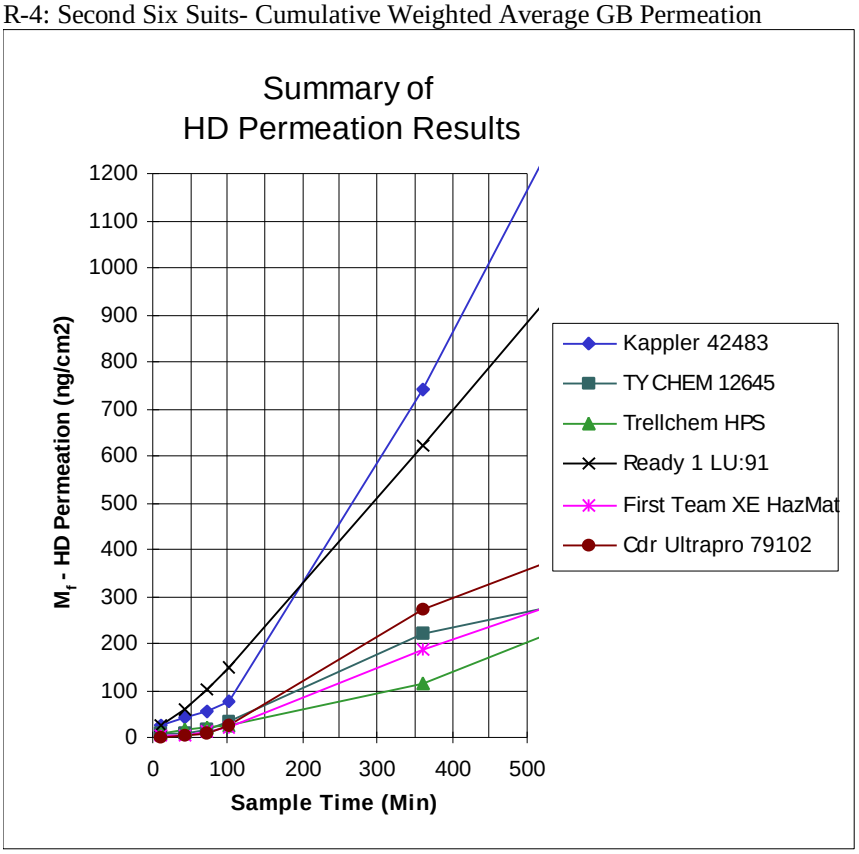
Appendix R: Overall Results





Appendix R: Overall Results

Figure R-3: First Six Suits- Cumulative Weighted Average GB Permeation
R-4: Second Six Suits- Cumulative Weighted Average GB Permeation



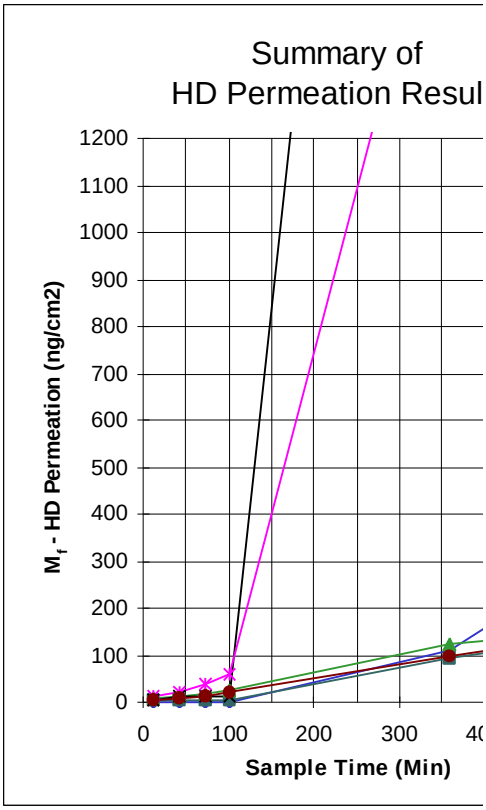


Figure R-5: First Six Suits- Cumulative Weighted Average HD Permeation (500 min)

Figure R-5: Second Six Suits- Cumulative Weig
(500 min)

Appendix R: Overall Results

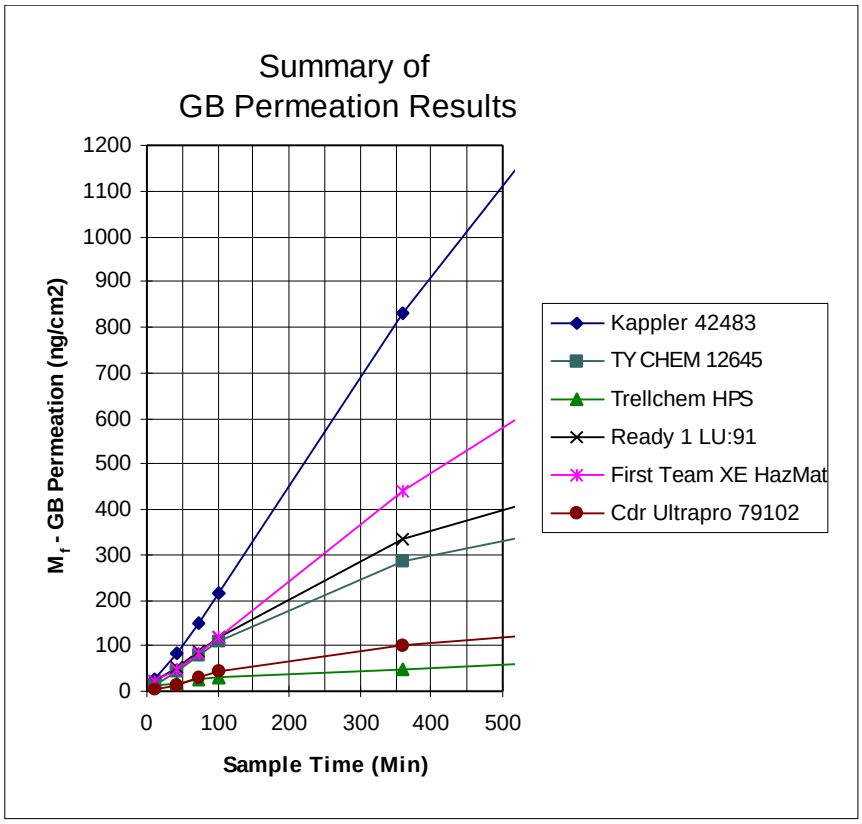


Figure R-7: First Six Suits- Cumulative Weighted Average GB Permeation (500 min)

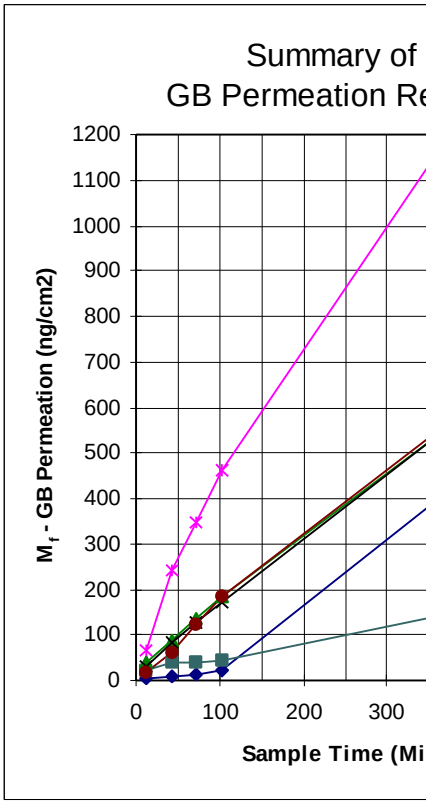


Figure R-8: Second Six Suits- Cumula
Permeation (500 min)

Table R-1. Summary of Overall Results for all Level A Suits and 25-mil chemical protective gloves

Item	Breakthrough time (minutes)		Aerosol PF Pass Rate at PF equal to:			
	incapacitation GB	erythema HD	100	1000	20	
Median						
25-mil chemical protective gloves	>480	360	N/A	N/A	N/A	
Kappler Suit Model 42483	350	150	95.7	45.7	19.6	(Pr
			95.7	45.7	26.1	(Op
TYCHEM 10,000 Pkg Style No. 12645	>480	330	93.8	16.7	4.2	(Pre
			76.6	10.6	0.0	(Op
Trellchem HPS suit	>480	>480	100	100	92.3	(Pre
			100	100	97.1	(Op
Ready 1 Limited Use Suit: Model 91	>480	125	100	100	85.4	(Pre
			100	100	100	(Op
First Team XE HazMat suit	>480	385	91.5	87.2	78.7	(Pre
			89.1	84.8	82.6	(Op
Commander Ultrapro Suit, Style 79102	>480	280	100	97.8	91.3	(Pre

100 100 95.7 (Op

185

Table R-1. Summary of Overall Results for all Level A Suits and 25-mil chemical protective gloves (continued)

Item	Breakthrough time (minutes)		Aerosol PF Pass Rate at PF equal to:			
	incapacitation GB	erythema HD	100	1000	2000	
Median						
Kappler Suit Model 50660	>480	435	100	62.5	29.2	(Pre-(
			100	73.9	50.0	(Ope
TYCHEM 10,000 Pkg Style No. 11645	>480	>480	100	45.4	30.4	(Pre-(
			100	36.4	15.9	(Ope
Trellchem TLU suit	>480	>480	100	100	97.9	
Not						
			100	100	97.9	(Ope
Chemturion Suit: Model 13	>480	110	100	91.5	76.6	(Pre-(
			100	76.6	74.5	(Ope
Chempruf II BETEX Suit	225	125	84.4	62.2	35.6	(Pre-
			86.4	75.0	65.9	(Ope
Commander Brigade: F91	>480	>480	100	91.7	66.7	(Pre-(
			100	93.2	88.6	(Ope