ECBC-TR-

# SWATCH TEST RESULTS OF PHASE 2 COMMERCIAL CHEMICAL PROTECTIVE GLOVES TO CHALLENGE BY CHEMICAL WARFARE AGENTS: SUMMARY REPORT

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January 2001

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# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



| 1. AGENCY USE ONLY *(Leave Blank)* | 2. REPORT DATE | 3. REPORT TYPE AND DATES COVERED |
|---|---|---|
| | January 2001 | Final; 00 Aug – 00 Sep |

**4. TITLE AND SUBTITLE**
Swatch Test Results of Phase 2 Commercial Chemical Protective Gloves to Challenge by Chemical Warfare Agents: Summary Report

**5. FUNDING NUMBERS**
None

**6. AUTHOR(S)**
Lindsay, Robert S.
Procell, Suzanne A.
Baldauf, Frederick C.

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
DIR, ECBC, ATTN: AMSSB-RRT, APG, MD 21010-5424

**8. PERFORMING ORGANIZATION REPORT NUMBER**
ECBC–TR-

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
CDR, SBCCOM, 5183 Blackhawk Road, ATTN: AMSSB-RTD, APG, MD 21010-5424

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

**11. SUPPLEMENTARY NOTES**

**12a. DISTRIBUTION/AVAILABILITY STATEMENT**
Approved for public release; distribution is unlimited.

**12b. DISTRIBUTION CODE**

**13. ABSTRACT** *(Maximum 200 words)*

Swatches for four commercially available chemical protective gloves were challenged with liquid droplets of Sarin (GB) and mustard (HD) using modifications of the static diffusion procedure described in TOP 8-2-501. The cumulative mass of each agent that permeated each swatch was determined over time and the results for all swatches were used to determine an average cumulative mass for each glove. From these data, a breakthrough time was calculated for each glove/agent combination for the purposes of comparison.

**14. SUBJECT TERMS**
HD Swatch testing Permeation testing
GB Chemical protective gloves

**15. NUMBER OF PAGES**
53

**16. PRICE CODE**

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| **UNCLASSIFIED** | **UNCLASSIFIED** | **UNCLASSIFIED** | **UL** |

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## EXECUTIVE SUMMARY

As part of the Domestic Preparedness Program, four commercially available glove designs were tested to assess their capability to protect in a chemical warfare (CW) agent environment. Swatches of material from each glove design were tested for resistance to permeation for Sarin (GB) and mustard (HD). From these data, the authors calculated the estimated time it would take to permeate the glove with sufficient agent to cause physiological effects in a person wearing the glove. The tests are described and the calculated breakthrough times are presented.

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## PREFACE

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

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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## Acknowledgments

The authors acknowledge the technical contributions of the Expert Review Panel for Personal Protective Equipment (PPE) Testing as listed below:

Dr. Jimmy Perkins, University of Texas School of Public Health, San Antonio, TX.
Dr. Annetta Watson, Life Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN.
Dr. Ted Zellers, University of Michigan School of Public Health, Ann Arbor, MI.
Leo F. Saubier, Battelle Memorial Institute, Bel Air, MD.

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 PHASE 2 COMMERCIAL CHEMICAL PROTECTIVE GLOVES TO CHALLENGE BY CHEMICAL WARFARE AGENTS: SUMMARY REPORT

## 1. INTRODUCTION

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

## 2. OBJECTIVES

This study evaluated some commercially available and commonly used chemical protective gloves to assess how well they resist vapor permeation from liquid contamination[1] by chemical agents Sarin (GB) and mustard (HD). This information is intended for federal, state and local emergency and HAZMAT personnel as an aid in their evaluation (and possible modification) of current work rules regarding specific chemical protective gloves currently in

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

inventory, and as an aid in future procurement of appropriate chemical protective gloves. This is especially important if these personnel choose to include military chemical and biological agent protection as a criterion. The information supplements data and information provided by the glove manufacturers. The gloves were tested in new, as-received condition. The effects of aging, temperature extremes, laundering, and other factors were beyond the intended scope of this test program. These tests were conducted to assess percutaneous (i.e. skin) protection only.

# 3. TESTING AND DATA ANALYSIS

## 3.1 Testing Overview

The chemical protective gloves that were tested in this test program are listed in Appendix A. Testing gloves included a permeation test of material swatches to measure the permeation of both GB and HD through the swatches.

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

### 3.2.1 Liquid Challenge/Vapor Permeation Testing Procedures

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

The test methodology was taken from TOP 8-2-501[2] and is described in Appendix B. Twelve swatches were cut from three pairs of each glove design to be tested. Six of the

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

twelve swatches were cut from the palm and six were cut from the cuff. Swatches were taken from approximately the same locations for all gloves; from the center of the palm and from the cuff area near the end of the glove. Three of the palm swatches and three of the cuff swatches were allocated to GB testing and the remainder were allocated to HD testing. Swatches were taken from silicone (M45 military mask formulation) slabs for use as a source of HD or GB vapor, after contamination.

Swatch thicknesses were measured with an Ames Dial Comparator, Model 2 (B. C. Ames Co., Waltham, MA). Five readings per swatch were taken and averaged to yield an average thickness for each swatch. The individual thickness readings for all swatches were then used to calculate the average swatch thickness in mils.

The permeation apparatus contained seven test cells. For each test, swatches from one glove design were placed in six of the cells, palm and cuff swatches were placed in alternating cells, and a silicone swatch was placed in the seventh cell. Swatches were only taken from the palm (not the back) and the cuff. In the analysis, the palm swatch was assumed to represent the palm, fingers and back of the hand and the cuff was assumed to represent the remainder of the glove that covers the wrist and forearm area.

Laboratory personnel applied a predetermined liquid agent challenge of 10 $g/m^2$ to the top surface of each swatch. Agent droplets were applied to the surface of the first swatch at time zero. Agent was then applied to the surface of each succeeding swatch at 3-minute intervals. The upper chamber of each test cell was sealed. A 1.0 L/min flow of temperature- and humidity-controlled fresh air was supplied to the lower test cell chamber beneath each swatch.

During the 24-hr test period, gas samples were taken on a sequential basis from the airstream beneath each swatch by a laboratory MINICAMS™ with stream selection system (a miniaturized gas chromatograph with flame photometric detector and sampling system (OI Analytical, CMS Field Products Group, Birmingham, AL)). Gas sampling by the MINICAMS™ began for the first swatch approximately 3 minutes following agent application. Subsequent 3-minute cycles of the MINICAMS™ were 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 was sequential through the six glove material swatches, the silicone swatch[3], and three clean air gas samples (taken from the test cabinet to purge the MINICAMS™ and sampling line). The six glove material swatches, the silicone swatch, and three clean air gas samples were all sampled for the first time within the first 30 minutes of the test. Then the sampling sequence began anew.

The MINICAMS™ first determined the amount of agent vapor (ng) in each gas sample. Using this result, the amount of agent vapor per unit area ($ng/cm^2$) present in the airstream that passed beneath the swatch over the time from the previous gas sample to the current gas sample was determined by the MINICAMS™ permeation software. The calculations assumed that the permeation rate is constant such that the mass permeating increases linearly over the 30-min interval. The permeation for each time interval was the average of the permeation rates (flux, $ng/cm^2$ /min) for the current and the previous gas samples multiplied by 30 min. This amount of agent vapor per unit area was presumed to be the amount of agent vapor

[3] Originally, it was intended to use silicone swatches as references or controls, but it was soon found that permeation through the silicone varies too widely for it to be used for that purpose. Silicone swatches were used anyway, because they serve as a reliable source of agent vapor to assure the tester that the MINICAMS(r) is responding properly during tests when little or no agent permeates the actual test swatches.

per unit area that had permeated the swatch over that time interval. The cumulative mass of agent permeating the swatch per unit area at any elapsed time during the 24-hr test was defined as $M_f$. It was based on the mass permeated in the time interval over the effective swatch area, which was the opening in the permeation cell (10 $cm^2$), and was determined by the MINICAMS™ permeation software. Over the 24-hr test period, a series of $M_f$ values was calculated for each swatch.

3.2.2 Liquid Challenge/Vapor Permeation Testing Analysis

Each glove had $M_f$ data for 6 swatches for each of the two agents over the 24-hr test period. The $M_f$ data were taken for each of the three swatches from one sampling area tested with one of the agents. For this report, the average (of three swatches) cumulative permeation ($M_f$) was calculated. This average was then presented, at each of the reported elapsed times, as representative of the glove's permeation resistance at that sampling area. The reported elapsed time for each sampling area was the average of the elapsed times for the three swatches.

To estimate $M_f$ at each elapsed time for a glove, the simplifying assumption was that the exposure was uniform over the entire glove, and that the glove permeated in a way that is representative of the two sampled sites. This permitted the determination of an average $M_f$ at each average elapsed time. The average elapsed time was the sum of the reported elapsed times for both sampling areas divided by two. The palm and cuff surface areas of the gloves were assumed to be equal. The average $M_f$ at any average elapsed time was calculated using the following equation:

$$\text{Average } M_f = [(\text{palm material } M_f) + (\text{cuff material } M_f)]/2 \qquad \textbf{\textit{Equation 1}}$$

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

The permeation test was designed to distinguish among material swatches according to their permeation resistance to chemical agents. It was not intended to specifically replicate threat scenarios that may be encountered in actual use. As previously reported by Belmonte[4], it was instructive to estimate the agent dosage ($C_i t_{skin}$) that would result from such a standard agent challenge as a relative indication of possible physiological effects. This was done by converting the average $M_f$ values to equivalent agent dosages. This relationship was developed by Fedele (written communication, Dr. P. Fedele, R&T Directorate, ERDEC, July 1997) and was reported by Belmonte[4]. For air-impermeable glove materials, the only mechanism for removal of agent vapor that permeates the barrier was assumed to be its permeation through the skin, so the equation is:

$$\text{Agent Dosage } (\text{mg - min/m}^3) = \frac{M_f\ (\text{ng/cm}^2)}{\text{Permeability of skin to agent vapor (cm/min)}} \qquad \textbf{\textit{Equation 2}}$$

where skin permeability is 2 cm/min for HD and 0.1 cm/min for GB. The agent dosage was then compared to doses that are known to cause certain levels of toxicity. It was assumed that skin permeabilities of HD and GB are roughly constant over the entire body.

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

When analyzing the test results, it was useful to determine whether the data indicate that the chemical protective glove provides percutaneous protection over some period of time. Mustard vapor can produce erythema (reddening of the skin) at dosages of approximately

[4] Test Results of Level A Suits to Challenge by Chemical and Biological Warfare Agents and Simulants: Summary Report. U. S. Army Edgewood Research Development and Engineering Center, MD. August 1998, UNCLASSIFIED Report (AD A353013).

1039 mg-min/$m^3$ on the backs of the hands. It can produce vesication (skin burns and blisters) at 2078 mg-min/$m^3$ on the backs of the hands. It was assumed that the hands were protected by the test gloves and challenged uniformly by the liquid dose used on the swatches. Using the threshold skin reddening dosage, and the skin permeability for mustard and substituting values in Equation 2, we obtained the HD threshold $M_f$ value

$$\text{Threshold } M_f = 2 \text{ X } 1039 = 2078 \text{ ng/cm}^2 \qquad \textbf{\textit{Equation 3}}$$

Sarin vapor can produce incapacitation at percutaneous 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 doses ($C_i t_{skin}$). Unlike mustard, Sarin acts systemically: the body reacts to the total amount of Sarin absorbed by the body. For this analysis it was assumed that the gloves were incorporated into a full ensemble protecting the entire body, but that only the gloves were challenged by liquid agent. The amount of Sarin agent per unit area (average $M_f$) necessary to permeate glove material covering the hands and forearms and produce a predetermined systemic effect was estimated by using the whole body dosage threshold of incapacitation (8000 mg-min/$m^3$), the skin permeability to Sarin agent (0.1 cm/min) from Equation 2 and 8.41% as the fractional area (proportion of the total body area represented by the hands and forearms in the BRHA model[5]). The relationship is:

$$\text{Threshold } M_f = (\text{Threshold dose X skin permeability})/(\text{fractional area}) \qquad \textbf{\textit{Equation 4}}$$

[5] Fedele, Dr. Paul D., Nelson, Douglas, C., *A Method of Assessing Full Individual Protective System Performance Against Cutaneous Effects of Aerosol and Vapor Exposures*, U.S. Army Edgewood Research, Development and Engineering Center, Aberdeen Proving Ground, Maryland, October, 1995; Section 1-3 "Body Region Hazard Analysis Process" included in the report for the JSLIST Program: Cronin, Tracy D., *Final Report for the Development of the Man-In-Simulant Test (MIST) Methodology for Evaluation of Chemical/Biological (CB) Protective Garments*, TECOM Project No. 8-EI-825-ABO-004, U.S. Army Dugway Proving Ground, Dugway, Utah, April 1996.

Substituting,

$$M_f = (8000x0.1)/(0.0841) = 9{,}512 \text{ ng/cm}^2 \qquad \textit{Equation 5}$$

This value was used in the graphs of average $M_f$ versus time and was summarized in Table 1. The breakthrough time was the time at which the average $M_f$ reached the GB threshold value for $M_f$.

**Table 1. Agent Breakthrough Criteria**

| Agent | Threshold Dosage (mg-min/m$^3$) | Physiological Effect | Skin Permeability, $P_s$ (cm/min) | Threshold, $M_f$ (ng/cm$^2$) |
|---|---|---|---|---|
| HD | 1,039 | Erythema | 2 | 2,078 |
| HD | 2,078 | Vesication | 2 | 4,156 |
| GB | 8,000 | Incapacitation | 0.1 | 9,512 |
| GB | 15,000 | Lethality | 0.1 | 17,836 |

## 4. RESULTS AND DISCUSSION

The breakthrough times and average swatch thicknesses from all the glove designs were collected and presented in Table 2.

**Table 2. Swatch Test Results for Gloves**

| Item | Average Swatch Thickness, mils | Breakthrough time, minutes | |
|---|---|---|---|
| | | HD | GB |
| N-Dex Disposable Nitrile, B6005FPL | 4 | 53 | 51 |
| North Butyl, L112A0902 | 20 | >1440 | >1440 |
| North Viton, L112A0661 | 16 | >1440 | 132 |
| North Silver Shield, L112A0647 | 4 | >1440 | >1440 |

For the North Butyl and North Viton glove designs, it was observed that the cuff swatches were noticeably thinner than the palm swatches. The North Butyl cuff swatches averaged approximately 16 mils versus approximately 24 mils for the palm swatches. The North

Viton cuff swatches averaged approximately 12 mils versus approximately 20 mils for the palm swatches. This fact may be a possible explanation for the increased GB vapor permeation noted for the cuff swatches of the North Viton glove design.

## 5. CONCLUSIONS.

The test data revealed that the chemical protective glove designs tested can protect the wearers from liquid CW agents. Breakthrough time should not be interpreted as the time that a glove can be safely worn, either for HD or GB. Breakthrough times should only be used to compare glove materials.

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## ACRONYMS and ABBREVIATIONS

| | |
|---|---|
| Ct | Vapor exposure, product of vapor concentration ($mg/m^3$) and time (minutes) |
| $C_I t_{skin}$ | Vapor exposure to skin |
| $cm^2$ | Square centimeters |
| °F | Temperature in degrees Fahrenheit |
| delta p | Differential pressure |
| DoD | Department of Defense |
| ECBC | U.S. Army Edgewood Chemical Biological Center |
| ERDEC | U.S. Army Edgewood Research, Development and Engineering Center |
| g | Gram |
| GB | Sarin, Isopropylmethylphosphonofluoridate |
| HD | Sulfur Mustard; 2,2'-Dichlorodiethylsulfide |
| L | Liter |
| $M_f$ | Cumulative mass permeation through the material |
| $m^2$ | Square meters |
| $m^3$ | Cubic meters |
| mg | Milligram |
| µL | Microliter |
| ng | Nanogram |
| NBC | Nuclear, Biological and Chemical |
| PCT | Pre-concentrator tube |
| PPE | Personal Protective Equipment |
| $P_s$ | Skin permeability |
| RH | Relative Humidity |
| TOP | Test Operations Procedure |

# Appendix A
# Gloves Chosen for Testing

**Table A- 1 Gloves Tested**

| Model | Manufacturer | Address |
|---|---|---|
| N-Dex Disposable Nitrile, B6005FPL | Best Company | Baltimore, MD |
| North Butyl, L112A0902 | North Safety Products | Charleston, SC |
| North Viton, L112A0661 | North Safety Products | Charleston, SC |
| North Silver Shield, L112A0647 | North Safety Products | Charleston, SC |

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# Appendix B
# Modified Static Diffusion Test Procedure

## MODIFIED STATIC DIFFUSION TEST

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

The following procedure was used**:**

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

2. From each pair of gloves, one each 1 and 15/16 in diameter material swatch will be taken from the cuff area for HD and one like-sized material swatch will be taken from the cuff area for GB. From the same pair of gloves, one each 1 and 15/16 in diameter material swatch will be taken from the palm area for HD and one like-sized material swatch will be taken from the palm area for GB. Swatches will be taken from at least 3 pairs of gloves (a minimum of 6 HD swatches and 6 GB swatches will be tested) for each glove model/style. Thickness measurements will be taken and recorded for each swatch. 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.

3. The environmental chamber will be controlled at a temperature of 90 +/- 2 °F (32.2 +/- 1 °C) and the maximum achievable relative humidity without occurrence of condensation (60% +/- 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. [TOP 8-2-501 specifies that a system control and data acquisition system will be used but this system was not used due to budget constraints.] The temperature and RH will be recorded in a computer file. Flow rates will be manually recorded. [TOP 8-2-501 specifies that differential pressure monitoring will be done but differential pressure gages were not used due to budget constraints.]

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 L/min, 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 (cell lugs will be retightened if flows don't match).

5. The swatches will be preconditioned overnight in the environmental chamber. Eighty-mil silicone will be used as an indicator swatch to verify that the MINICAMS can detect agent vapor permeation (one silicone swatch per 6 glove swatches). [TOP 8-2-501 specifies that positive control and negative control swatches will be used but they were not used due to budgetary and schedule limitations.]

6. Agents GB and HD will be used. The contamination density will be 10 $g/m^2$ (eight 1 μL HD droplets or ten 1 μL GB droplets). The agent will be applied using the click/touch method with a Hamilton repeating dispenser. [TOP 8-2-501 specifies that a robotic agent application system will be used for agent application but this was not done due to budget constraints.]

7. Seven swatches will be tested at once. MINICAMS with stream selection system will monitor vapor permeation with a 3-minute cycle per swatch. There will be 3 blank sampling intervals following

the indicator swatch. Each swatch will be sampled once every 30 min. The MINICAMS will be standardized weekly.

8. The test length will be 24 hr.

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 permeation ($ng/cm^2$) versus elapsed time from contamination (min) for each swatch. All recorded data will be placed in laboratory notebooks and a technical report will be drafted at the conclusion of this effort.

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## Appendix C
## N-Dex Disposable Nitrile

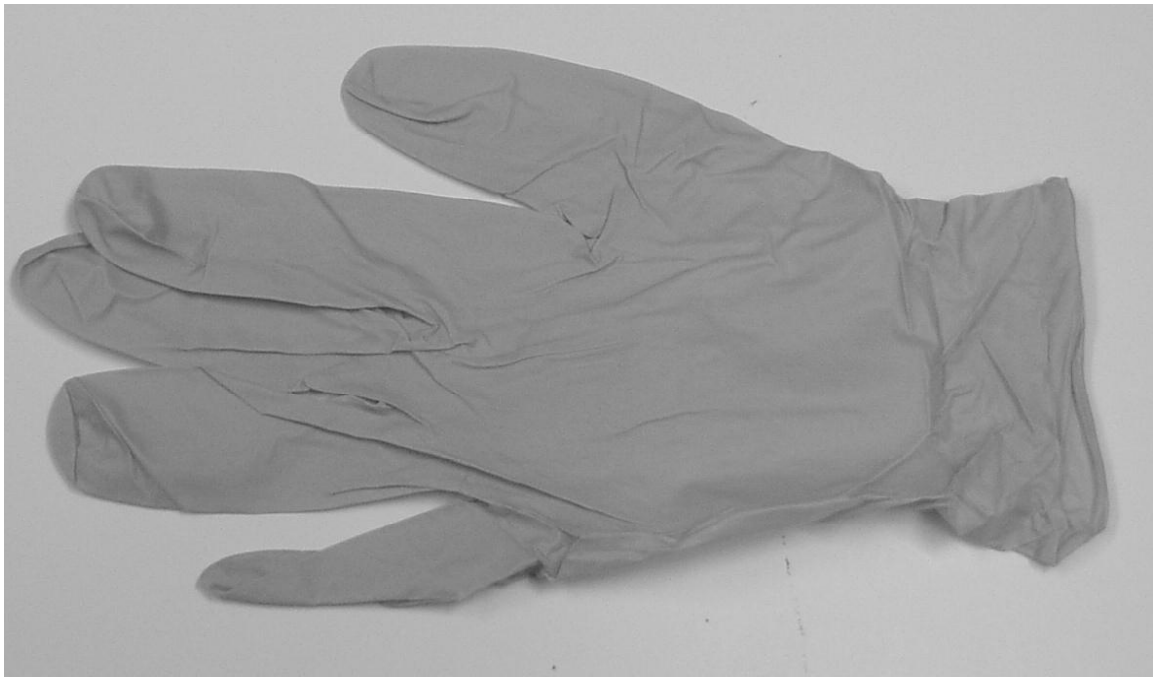

**Figure C- 1  N-Dex Disposable Nitrile Glove**

**Table C- 1 N-Dex Disposable Nitrile Glove - Average HD Permeation**

| N-Dex Disposable Nitrile Glove | | | | | |
|---|---|---|---|---|---|
| Time (minutes) | $M_f$, Palm ($ng/cm^2$) | Time (minutes) | $M_f$, Cuff ($ng/cm^2$) | Average Time (minutes) | Average $M_f$ ($ng/cm^2$) |
| 5 | 1 | 14 | 1 | 10 | 1 |
| 35 | 1458 | 44 | 729 | 40 | 1093 |
| 65 | 3701 | 74 | 2941 | 70 | 3321 |
| 95 | 5306 | 104 | 5913 | 100 | 5610 |
| 125 | 6951 | 134 | 9569 | 130 | 8260 |
| 155 | 8553 | 164 | 12540 | 160 | 10547 |
| 185 | 10172 | 194 | 14115 | 190 | 12144 |
| 215 | 12590 | 224 | 17089 | 220 | 14839 |
| 245 | 15010 | 254 | 20752 | 250 | 17881 |
| 275 | 18132 | 284 | 24425 | 280 | 21279 |
| 305 | 22649 | 314 | 28854 | 310 | 25752 |
| 335 | 27290 | 344 | 33291 | 340 | 30291 |
| 365 | 31856 | 374 | 37741 | 370 | 34799 |
| 395 | 36115 | 404 | 42178 | 400 | 39147 |
| 425 | 40237 | 434 | 46596 | 430 | 43416 |
| 455 | 44765 | 464 | 51037 | 460 | 47901 |
| 485 | 49774 | 494 | 55504 | 490 | 52639 |
| 515 | 54807 | 524 | 59977 | 520 | 57392 |
| 545 | 59851 | 554 | 64460 | 550 | 62155 |
| 575 | 64863 | 584 | 69081 | 580 | 66972 |
| 605 | 69792 | 614 | 73715 | 610 | 71753 |
| 635 | 74642 | 644 | 78347 | 640 | 76494 |
| 665 | 79167 | 674 | 83097 | 670 | 81132 |
| 695 | 83388 | 704 | 87859 | 700 | 85624 |
| 725 | 87221 | 734 | 92420 | 730 | 89821 |
| 755 | 90927 | 764 | 96971 | 760 | 93949 |
| 782 | 94359 | | | | |

Note: Sampling was ended prior to 24 hours to enable MINICAMS™ to return to baseline following high vapor permeation

**Table C- 2 N-Dex Disposable Nitrile Glove - Average GB Permeation**

| N-Dex Disposable Nitrile Glove | | | | | |
|---|---|---|---|---|---|
| Time (minutes) | $M_f$, Palm ($ng/cm^2$) | Time (minutes) | $M_f$, Cuff ($ng/cm^2$) | Average Time (minutes) | Average $M_f$ ($ng/cm^2$) |
| 5 | 1 | 14 | 3 | 9 | 2 |
| 35 | 5275 | 44 | 5352 | 39 | 5314 |
| 65 | 15811 | 74 | 16029 | 69 | 15920 |
| 95 | 23988 | 104 | 25870 | 99 | 24929 |
| 125 | 28432 | 134 | 33861 | 129 | 31147 |
| 155 | 30935 | 164 | 39945 | 159 | 35440 |
| 185 | 32638 | 194 | 44686 | 189 | 38662 |
| 215 | 33989 | 224 | 48728 | 219 | 41359 |
| 245 | 35127 | 254 | 52398 | 249 | 43763 |
| 275 | 36139 | 284 | 55877 | 279 | 46008 |
| 305 | 37059 | 314 | 59187 | 309 | 48123 |
| 335 | 37898 | 344 | 62327 | 339 | 50112 |
| 365 | 38686 | 374 | 65377 | 369 | 52032 |
| 395 | 39430 | 404 | 68273 | 399 | 53852 |
| 425 | 40143 | 434 | 71047 | 429 | 55595 |
| 455 | 40812 | 464 | 73725 | 459 | 57269 |
| 485 | 41449 | 494 | 76254 | 489 | 58851 |
| 515 | 42067 | 524 | 78712 | 519 | 60389 |
| 545 | 42649 | 554 | 81036 | 549 | 61842 |
| 575 | 43203 | 584 | 83223 | 579 | 63213 |
| 605 | 43730 | 614 | 85354 | 609 | 64542 |
| 635 | 44230 | 644 | 87336 | 639 | 65783 |
| 665 | 44704 | 674 | 89144 | 669 | 66924 |
| 695 | 45150 | 704 | 90866 | 699 | 68008 |
| 725 | 45585 | 734 | 92507 | 729 | 69046 |
| 755 | 45990 | 764 | 94048 | 759 | 70019 |

Note: Sampling was ended prior to 24 hours to enable MINICAMS™ to return to baseline following high vapor permeation.

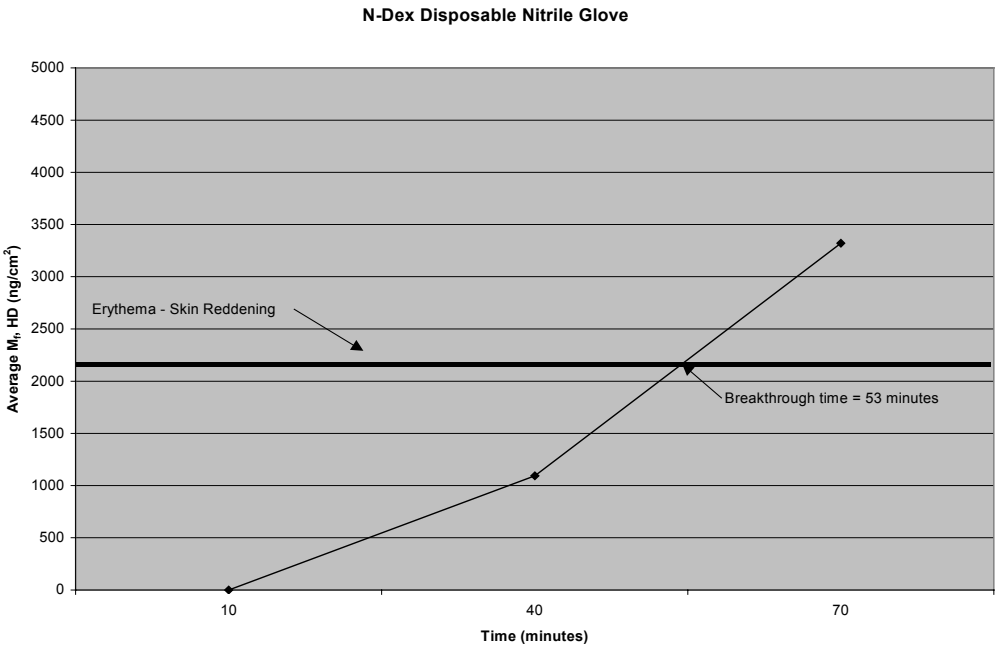


**Figure C- 2 N-Dex Disposable Nitrile Glove - Average HD Cumulative Permeation**

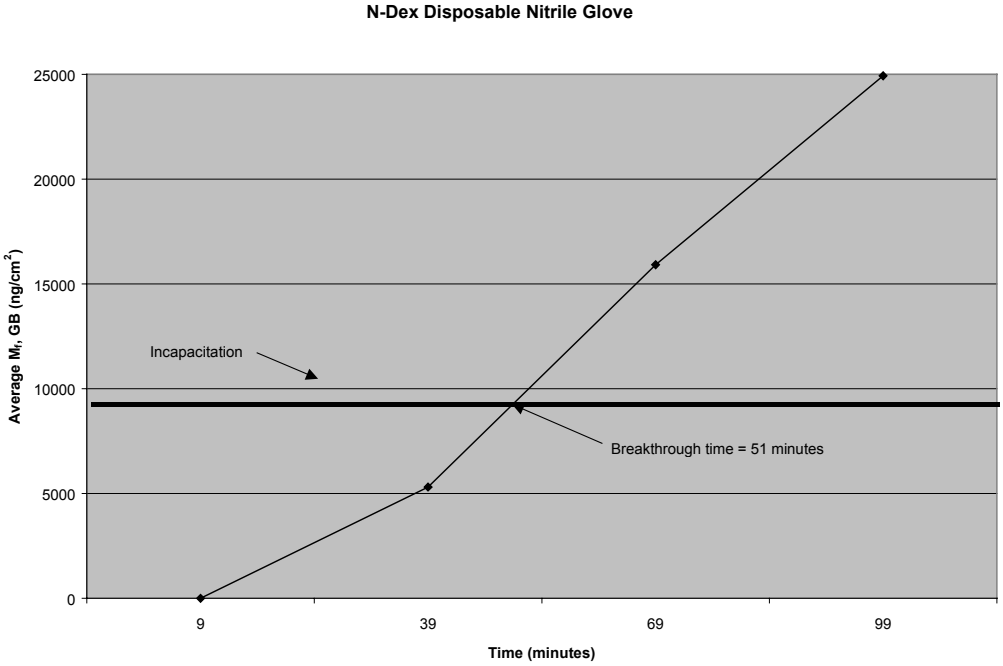


**Figure C- 3 N-Dex Disposable Nitrile Glove - Average GB Cumulative Permeation**

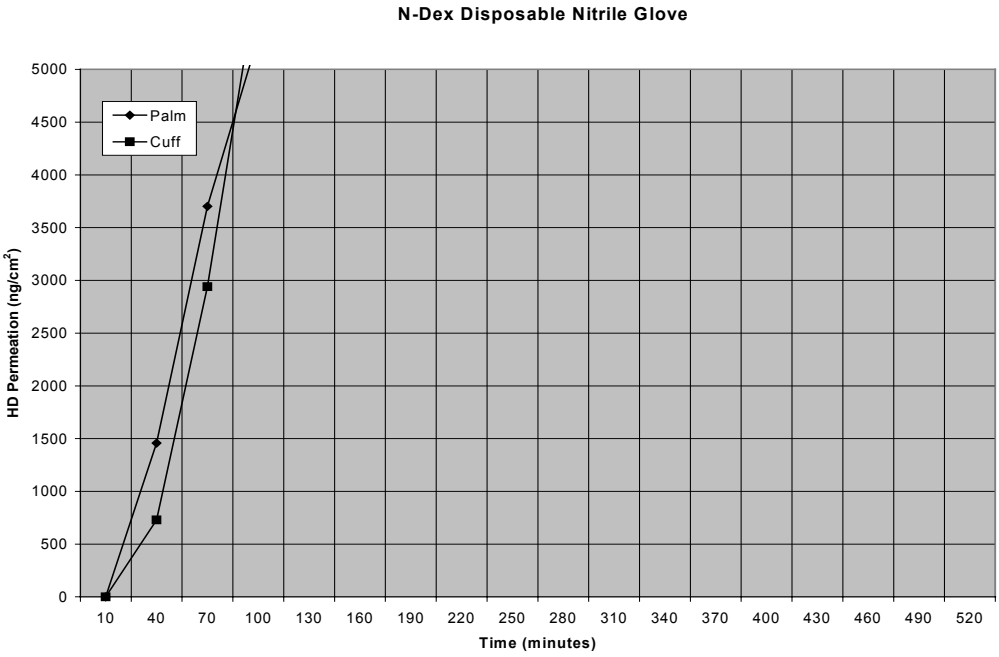


**Figure C- 4 N-Dex Disposable Nitrile Glove: HD Cumulative Permeation by Sampling Area**

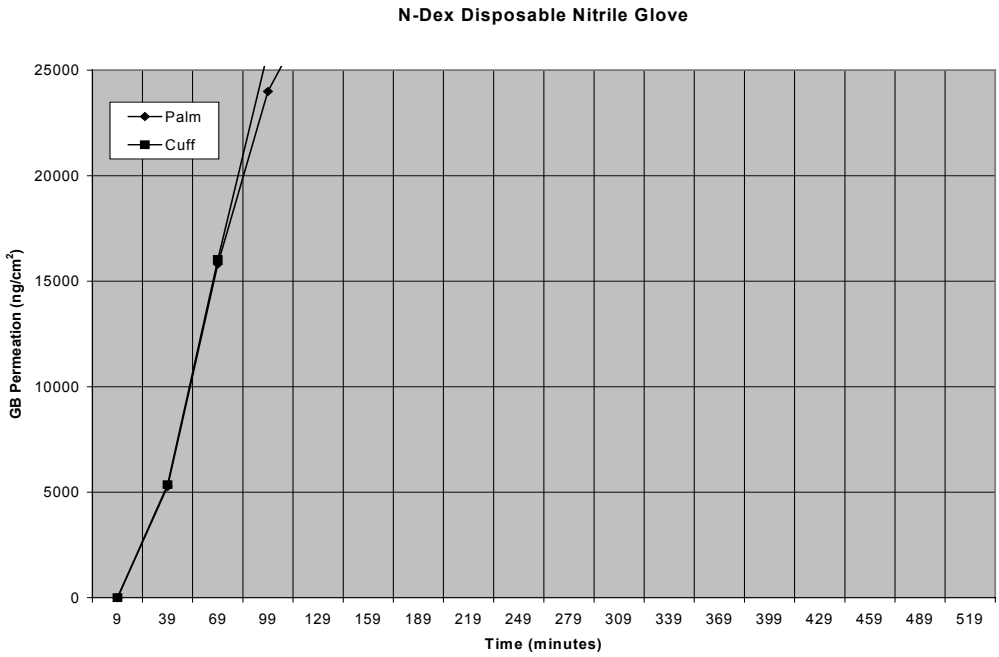


**Figure C- 5 N-Dex Disposable Nitrile Glove: GB Cumulative Permeation by Sampling Area**

## Appendix D
## North Butyl

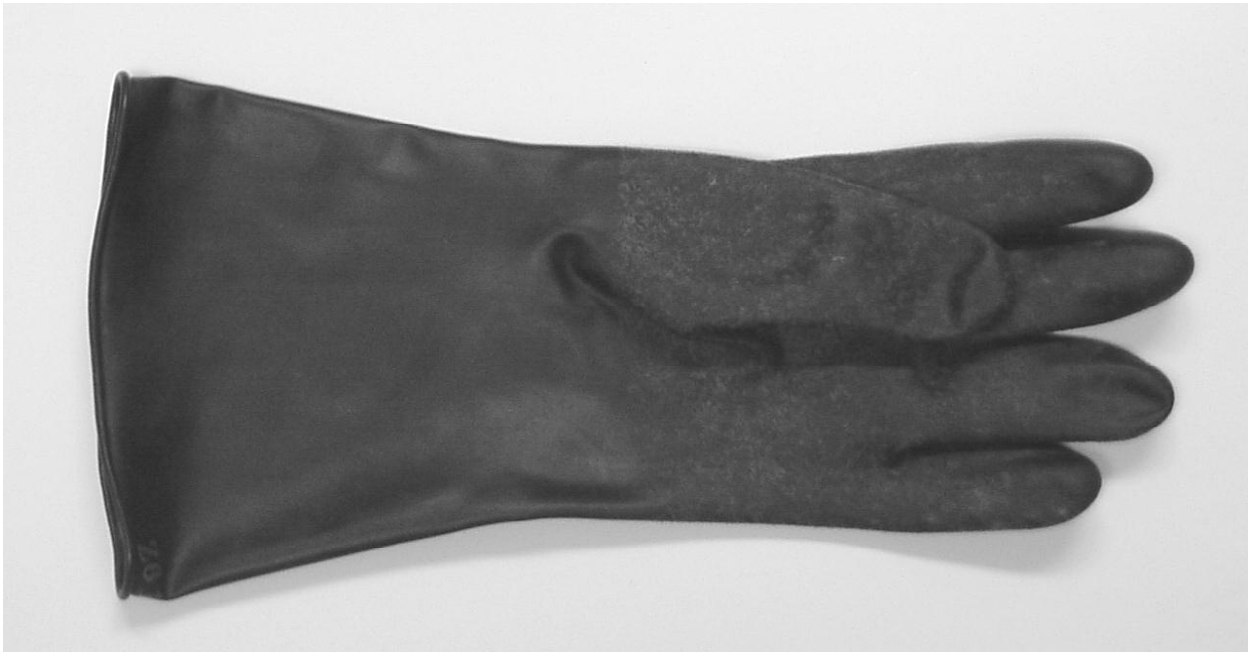

**Figure D- 1  North Butyl Glove**

**Table D- 1 North Butyl Glove - Average HD Permeation**

| North Butyl Glove | | | | | |
|---|---|---|---|---|---|
| Time (minutes) | $M_f$, Palm ($ng/cm^2$) | Time (minutes) | $M_f$, Cuff ($ng/cm^2$) | Average Time (minutes) | Average $M_f$ ($ng/cm^2$) |
| 4 | 0 | 14 | 0 | 9 | 0 |
| 34 | 0 | 44 | 0 | 39 | 0 |
| 64 | 1 | 74 | 0 | 69 | 0 |
| 94 | 1 | 104 | 1 | 99 | 1 |
| 124 | 1 | 134 | 1 | 129 | 1 |
| 154 | 1 | 164 | 1 | 159 | 1 |
| 184 | 1 | 194 | 1 | 189 | 1 |
| 214 | 3 | 224 | 1 | 219 | 2 |
| 244 | 5 | 254 | 1 | 249 | 3 |
| 274 | 8 | 284 | 1 | 279 | 5 |
| 304 | 13 | 314 | 3 | 309 | 8 |
| 334 | 19 | 344 | 5 | 339 | 12 |
| 364 | 26 | 374 | 7 | 369 | 17 |
| 394 | 37 | 404 | 11 | 399 | 24 |
| 424 | 51 | 434 | 16 | 429 | 34 |
| 454 | 68 | 464 | 21 | 459 | 44 |
| 484 | 85 | 494 | 27 | 489 | 56 |
| 514 | 103 | 524 | 32 | 519 | 67 |
| 544 | 120 | 554 | 37 | 549 | 78 |
| 574 | 137 | 584 | 43 | 579 | 90 |
| 604 | 153 | 614 | 48 | 609 | 100 |
| 634 | 168 | 644 | 53 | 639 | 110 |
| 664 | 183 | 674 | 58 | 669 | 121 |
| 694 | 198 | 704 | 63 | 699 | 131 |
| 724 | 213 | 734 | 68 | 729 | 140 |
| 754 | 227 | 764 | 72 | 759 | 150 |
| 784 | 241 | 794 | 77 | 789 | 159 |
| 815 | 254 | 825 | 82 | 820 | 168 |
| 845 | 266 | 855 | 86 | 850 | 176 |
| 876 | 277 | 886 | 90 | 881 | 184 |
| 906 | 288 | 916 | 94 | 911 | 191 |
| 937 | 299 | 947 | 98 | 942 | 198 |
| 967 | 310 | 978 | 102 | 972 | 206 |
| 995 | 316 | 1005 | 104 | 1000 | 210 |
| 1022 | 317 | 1032 | 105 | 1027 | 211 |
| 1050 | 318 | 1060 | 105 | 1055 | 211 |
| 1077 | 318 | 1087 | 105 | 1082 | 212 |
| 1105 | 319 | 1115 | 105 | 1110 | 212 |
| 1132 | 319 | 1142 | 105 | 1137 | 212 |
| 1160 | 320 | 1170 | 105 | 1165 | 213 |
| 1187 | 321 | 1197 | 105 | 1192 | 213 |
| 1215 | 321 | 1225 | 106 | 1220 | 214 |
| 1242 | 322 | 1252 | 106 | 1247 | 214 |
| 1270 | 323 | 1280 | 108 | 1275 | 215 |
| 1297 | 323 | 1307 | 109 | 1302 | 216 |
| 1324 | 324 | 1335 | 110 | 1330 | 217 |
| 1352 | 326 | 1362 | 112 | 1357 | 219 |
| 1379 | 327 | 1390 | 113 | 1384 | 220 |
| 1407 | 329 | 1417 | 115 | 1412 | 222 |
| 1434 | 330 | | | | |

**Table D- 2 North Butyl Glove - Average GB Permeation**

| North Butyl Glove | | | | | |
|---|---|---|---|---|---|
| Time (minutes) | $M_f$, Palm ($ng/cm^2$) | Time (minutes) | $M_f$, Cuff ($ng/cm^2$) | Average Time (minutes) | Average $M_f$ ($ng/cm^2$) |
| 4 | 0 | 13 | 0 | 8 | 0 |
| 34 | 7 | 43 | 7 | 38 | 7 |
| 64 | 16 | 73 | 18 | 68 | 17 |
| 94 | 19 | 103 | 24 | 98 | 22 |
| 124 | 21 | 133 | 27 | 128 | 24 |
| 154 | 23 | 163 | 29 | 158 | 26 |
| 184 | 25 | 193 | 31 | 188 | 28 |
| 214 | 27 | 223 | 33 | 218 | 30 |
| 244 | 28 | 253 | 34 | 248 | 31 |
| 274 | 30 | 283 | 35 | 278 | 32 |
| 304 | 31 | 313 | 36 | 308 | 34 |
| 334 | 32 | 343 | 37 | 338 | 34 |
| 364 | 34 | 373 | 37 | 368 | 35 |
| 394 | 35 | 403 | 37 | 398 | 36 |
| 424 | 36 | 433 | 37 | 428 | 36 |
| 454 | 37 | 463 | 37 | 458 | 37 |
| 484 | 38 | 493 | 37 | 488 | 37 |
| 514 | 39 | 523 | 37 | 518 | 38 |
| 544 | 40 | 553 | 37 | 548 | 38 |
| 574 | 41 | 583 | 37 | 578 | 39 |
| 604 | 41 | 613 | 37 | 608 | 39 |
| 634 | 41 | 643 | 37 | 638 | 39 |
| 664 | 41 | 673 | 37 | 668 | 39 |
| 694 | 41 | 703 | 37 | 698 | 39 |
| 724 | 41 | 733 | 37 | 728 | 39 |
| 754 | 41 | 763 | 37 | 758 | 39 |
| 784 | 41 | 793 | 37 | 788 | 39 |
| 814 | 41 | 823 | 37 | 818 | 39 |
| 844 | 41 | 853 | 37 | 848 | 39 |
| 874 | 41 | 883 | 37 | 878 | 39 |
| 904 | 41 | 913 | 37 | 908 | 39 |
| 934 | 41 | 943 | 37 | 938 | 39 |
| 964 | 41 | 973 | 37 | 968 | 39 |
| 994 | 41 | 1003 | 37 | 998 | 39 |
| 1024 | 41 | 1033 | 37 | 1028 | 39 |
| 1054 | 41 | 1063 | 37 | 1058 | 39 |
| 1084 | 41 | 1093 | 37 | 1088 | 39 |
| 1114 | 41 | 1123 | 37 | 1118 | 39 |
| 1144 | 41 | 1153 | 37 | 1148 | 39 |
| 1174 | 42 | 1183 | 37 | 1178 | 39 |
| 1204 | 42 | 1213 | 37 | 1208 | 40 |
| 1234 | 43 | 1243 | 37 | 1238 | 40 |
| 1264 | 44 | 1273 | 37 | 1268 | 40 |
| 1294 | 44 | 1303 | 37 | 1298 | 41 |
| 1324 | 44 | 1333 | 37 | 1328 | 41 |
| 1354 | 44 | 1363 | 37 | 1358 | 41 |
| 1384 | 45 | 1393 | 37 | 1388 | 41 |
| 1414 | 45 | 1423 | 37 | 1418 | 41 |

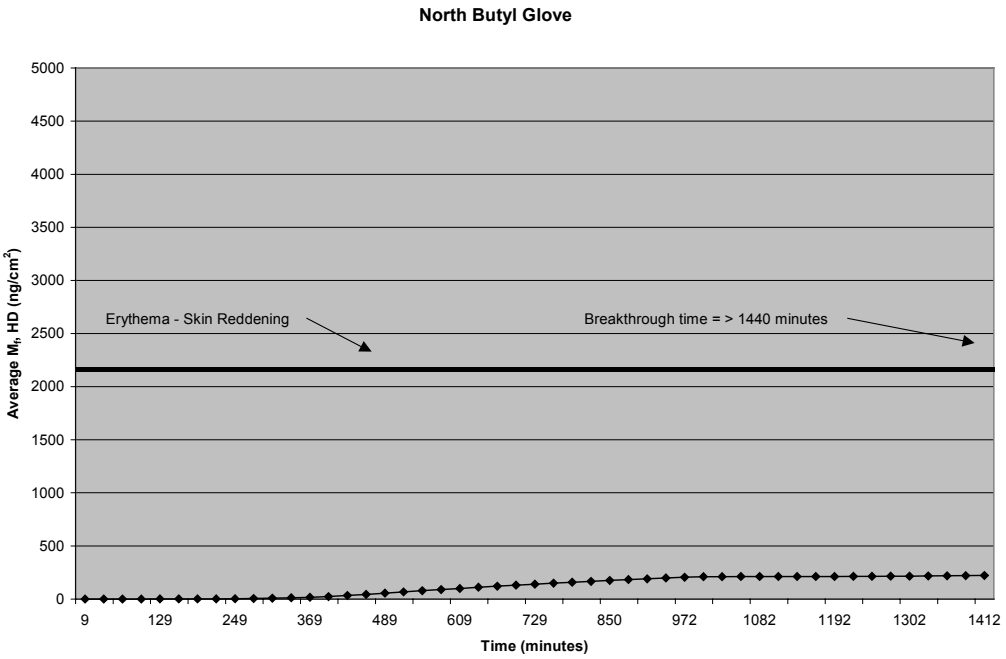


**Figure D- 2. North Butyl Glove - Average HD Cumulative Permeation**

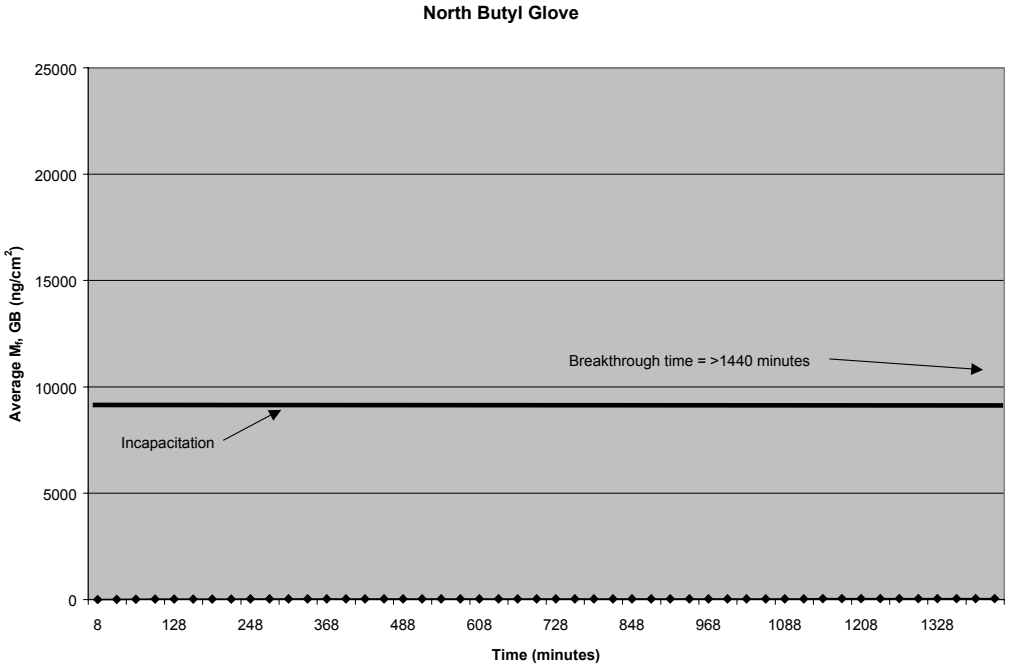


**Figure D- 3 North Butyl Glove -Average GB Cumulative Permeation**

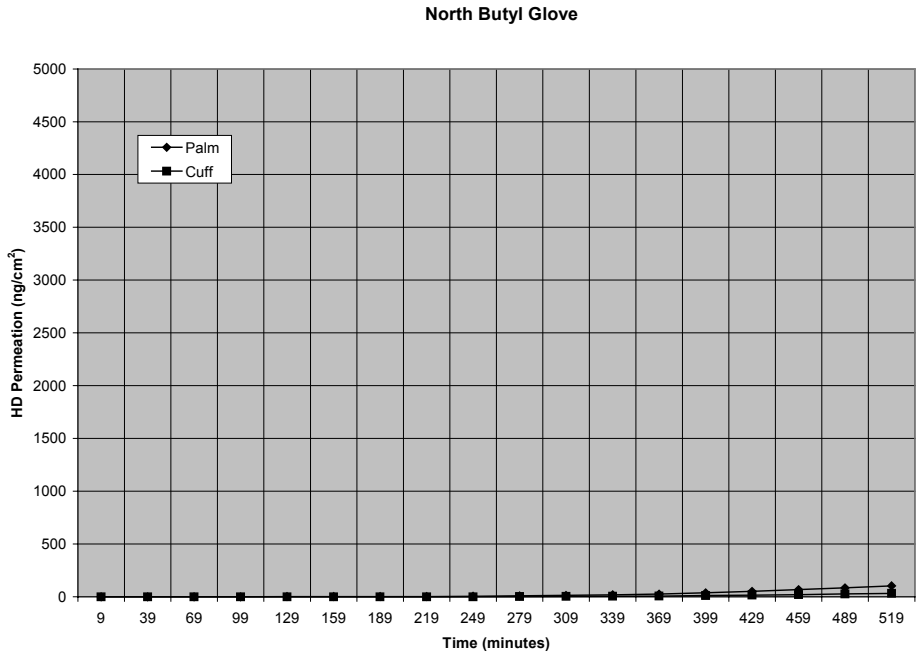


**Figure D- 4 North Butyl Glove - HD Cumulative Permeation by Sampling Area**

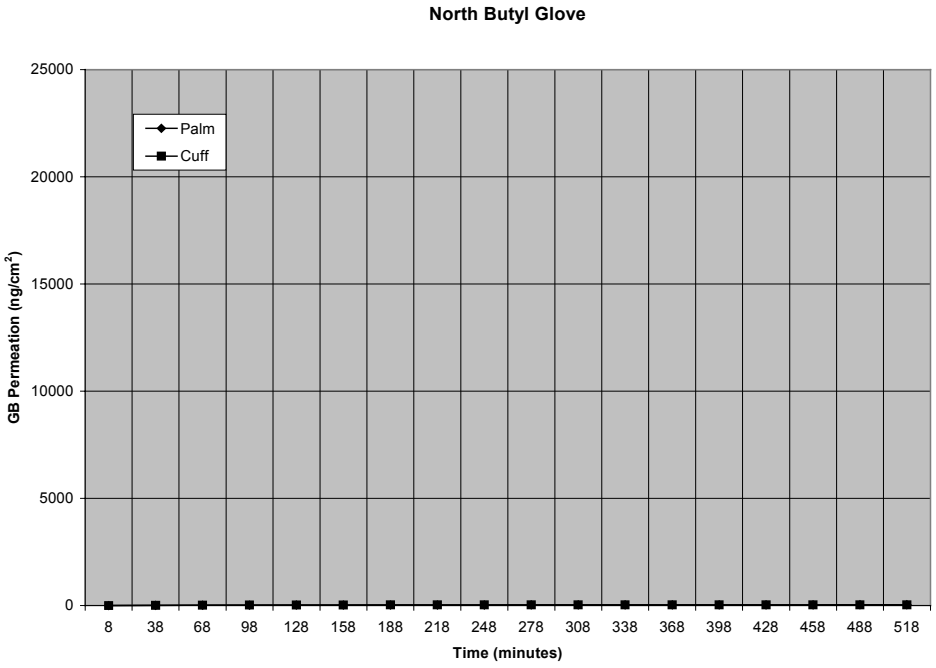


**Figure D- 5 North Butyl Glove - GB Cumulative Permeation by Sampling Area**

## Appendix E
## North Viton


**Figure E- 1 North Viton Glove**

**Table E- 1 North Viton Glove - Average HD Permeation**

| North Viton Glove | | | | | |
|---|---|---|---|---|---|
| Time (minutes) | $M_f$, Palm ($ng/cm^2$) | Time (minutes) | $M_f$, Cuff ($ng/cm^2$) | Average Time (minutes) | Average $M_f$ ($ng/cm^2$) |
| 5 | 0 | 14 | 1 | 10 | 1 |
| 35 | 2 | 44 | 3 | 40 | 3 |
| 65 | 3 | 74 | 4 | 70 | 3 |
| 95 | 4 | 104 | 5 | 100 | 4 |
| 125 | 5 | 134 | 6 | 130 | 5 |
| 155 | 6 | 164 | 7 | 160 | 7 |
| 185 | 7 | 194 | 9 | 190 | 8 |
| 215 | 9 | 224 | 10 | 220 | 10 |
| 245 | 11 | 254 | 12 | 250 | 12 |
| 275 | 14 | 284 | 14 | 280 | 14 |
| 305 | 17 | 314 | 16 | 310 | 17 |
| 335 | 21 | 344 | 18 | 340 | 19 |
| 365 | 24 | 374 | 21 | 370 | 22 |
| 395 | 27 | 404 | 24 | 400 | 26 |
| 425 | 30 | 434 | 27 | 430 | 29 |
| 455 | 34 | 464 | 29 | 460 | 31 |
| 485 | 37 | 494 | 31 | 490 | 34 |
| 515 | 40 | 524 | 33 | 520 | 36 |
| 545 | 42 | 554 | 35 | 550 | 38 |
| 575 | 44 | 584 | 36 | 580 | 40 |
| 605 | 45 | 614 | 38 | 610 | 42 |
| 635 | 46 | 644 | 40 | 640 | 43 |
| 665 | 47 | 674 | 41 | 670 | 44 |
| 695 | 49 | 704 | 42 | 700 | 45 |
| 725 | 50 | 734 | 43 | 730 | 47 |
| 755 | 51 | 764 | 45 | 760 | 48 |
| 785 | 52 | 794 | 46 | 790 | 49 |
| 815 | 53 | 824 | 47 | 820 | 50 |
| 845 | 54 | 854 | 48 | 850 | 51 |
| 875 | 55 | 884 | 49 | 880 | 52 |
| 905 | 55 | 914 | 50 | 910 | 53 |
| 935 | 56 | 944 | 51 | 940 | 54 |
| 965 | 57 | 974 | 52 | 970 | 55 |
| 995 | 58 | 1004 | 53 | 1000 | 56 |
| 1025 | 59 | 1034 | 54 | 1030 | 57 |
| 1055 | 60 | 1064 | 55 | 1060 | 58 |
| 1085 | 61 | 1094 | 56 | 1090 | 58 |
| 1115 | 61 | 1124 | 57 | 1120 | 59 |
| 1145 | 62 | 1154 | 58 | 1150 | 60 |
| 1175 | 63 | 1184 | 59 | 1180 | 61 |
| 1205 | 64 | 1214 | 60 | 1210 | 62 |
| 1235 | 65 | 1244 | 61 | 1240 | 63 |
| 1265 | 66 | 1274 | 62 | 1270 | 64 |
| 1295 | 67 | 1304 | 64 | 1300 | 65 |
| 1325 | 67 | 1334 | 65 | 1330 | 66 |
| 1355 | 68 | 1364 | 66 | 1360 | 67 |
| 1385 | 69 | 1394 | 67 | 1390 | 68 |
| 1415 | 70 | 1424 | 68 | 1420 | 69 |

**Table E- 2 North Viton Glove - Average GB Permeation**

| North Viton Glove | | | | | |
|---|---|---|---|---|---|
| Time (minutes) | $M_f$, Palm ($ng/cm^2$) | Time (minutes) | $M_f$, Cuff ($ng/cm^2$) | Average Time (minutes) | Average $M_f$ ($ng/cm^2$) |
| 6 | 1 | 15 | 4 | 10 | 2 |
| 36 | 7 | 45 | 17 | 40 | 12 |
| 66 | 12 | 75 | 78 | 70 | 45 |
| 96 | 16 | 105 | 6127 | 100 | 3071 |
| 126 | 63 | 135 | 18295 | 130 | 9179 |
| 156 | 164 | 165 | 30226 | 160 | 15195 |
| 186 | 278 | 195 | 41395 | 190 | 20836 |
| 216 | 385 | 225 | 51704 | 220 | 26044 |
| 246 | 480 | 255 | 60939 | 250 | 30709 |
| 276 | 564 | 285 | 69089 | 280 | 34826 |
| 306 | 640 | 315 | 76296 | 310 | 38468 |
| 336 | 711 | 345 | 82740 | 340 | 41726 |
| 366 | 781 | 375 | 88554 | 370 | 44667 |
| 396 | 853 | 405 | 93859 | 400 | 47356 |
| 426 | 931 | | | | |
| 453 | 1002 | | | | |
| 477 | 1059 | | | | |
| 501 | 1113 | | | | |
| 525 | 1166 | | | | |
| 549 | 1218 | | | | |
| 570 | 1261 | | | | |
| 591 | 1301 | | | | |
| 612 | 1339 | | | | |
| 633 | 1377 | | | | |
| 654 | 1413 | | | | |
| 675 | 1449 | | | | |
| 696 | 1484 | | | | |
| 717 | 1518 | | | | |
| 738 | 1551 | | | | |
| 759 | 1585 | | | | |
| 780 | 1618 | | | | |
| 801 | 1652 | | | | |
| 822 | 1685 | | | | |
| 843 | 1719 | | | | |
| 864 | 1753 | | | | |
| 885 | 1789 | | | | |
| 906 | 1825 | | | | |
| 927 | 1863 | | | | |
| 948 | 1901 | | | | |
| 969 | 1941 | | | | |
| 990 | 1983 | | | | |
| 1011 | 2025 | | | | |
| 1032 | 2070 | | | | |
| 1053 | 2117 | | | | |
| 1074 | 2164 | | | | |
| 1095 | 2213 | | | | |
| 1116 | 2264 | | | | |
| 1137 | 2317 | | | | |
| 1158 | 2373 | | | | |
| 1179 | 2429 | | | | |
| 1200 | 2487 | | | | |
| 1221 | 2547 | | | | |
| 1242 | 2609 | | | | |

| North Viton Glove | | | | | |
|---|---|---|---|---|---|
| Time (minutes) | $M_f$, Palm ($ng/cm^2$) | Time (minutes) | $M_f$, Cuff ($ng/cm^2$) | Average Time (minutes) | Average $M_f$ ($ng/cm^2$) |
| 1263 | 2672 | | | | |
| 1284 | 2736 | | | | |

Note: Sampling of cuff swatches was ended prior to 24 hours to enable MINICAMS™ to return to baseline following high vapor permeation.

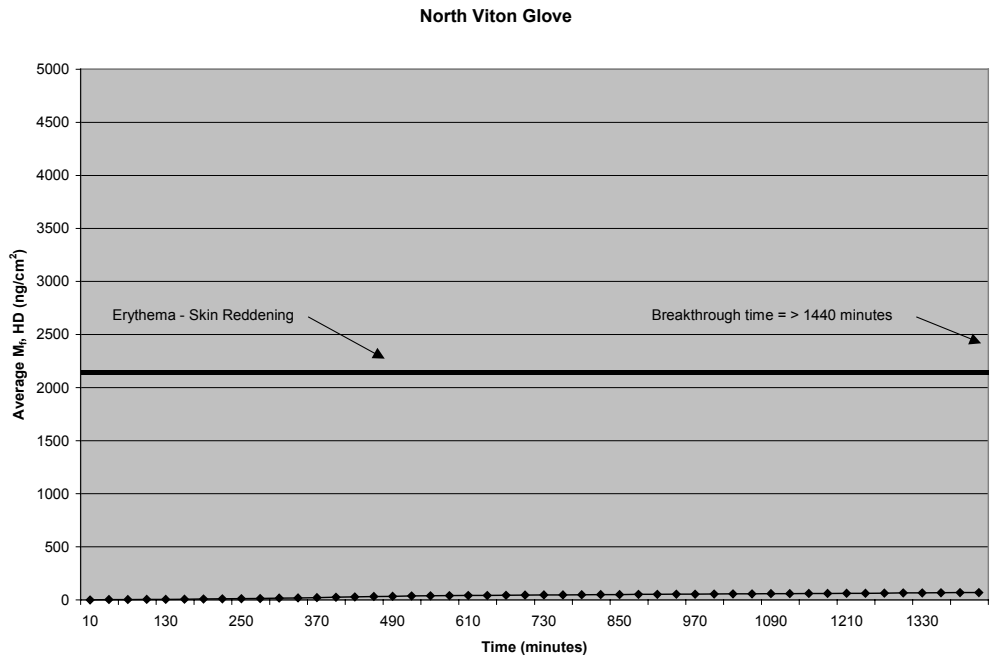


**Figure E- 2 North Viton Glove - Average HD Cumulative Permeation**

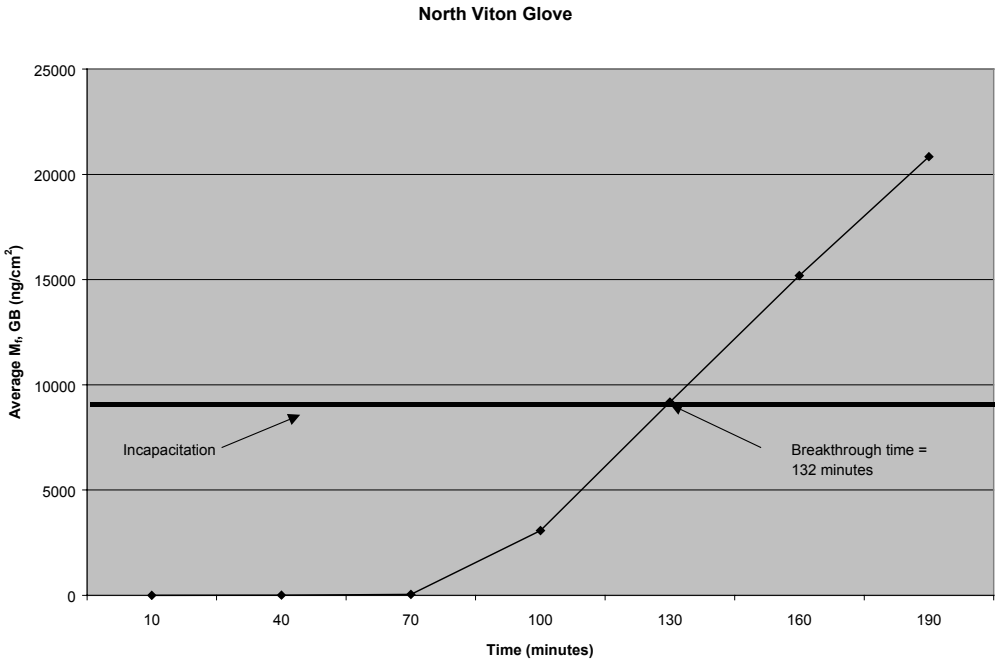


**Figure E- 3 North Viton Glove - Average GB Cumulative Permeation**

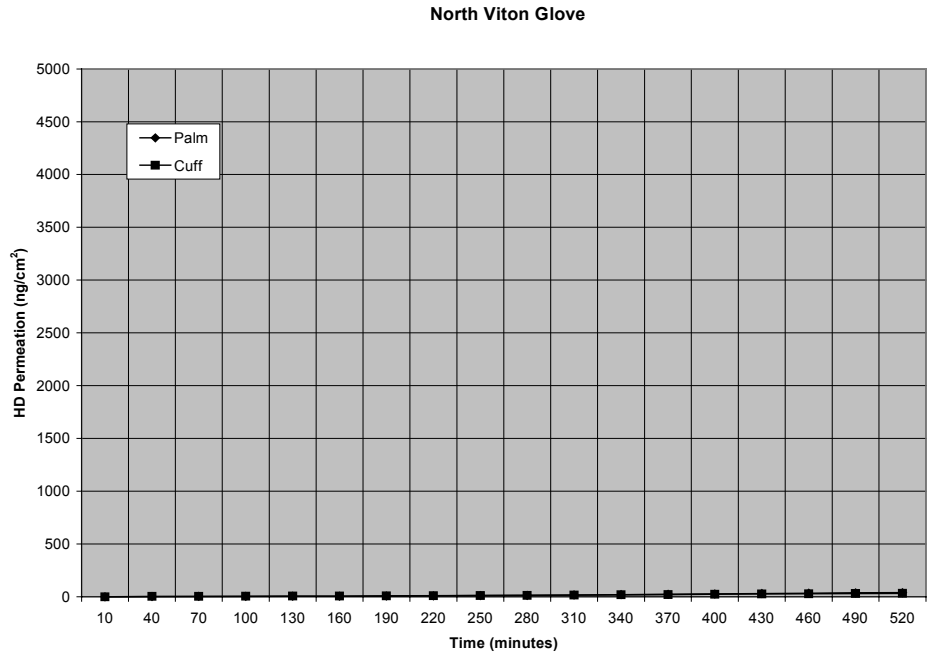


**Figure E- 4 North Viton Glove: HD Cumulative Permeation By Sampling Area**

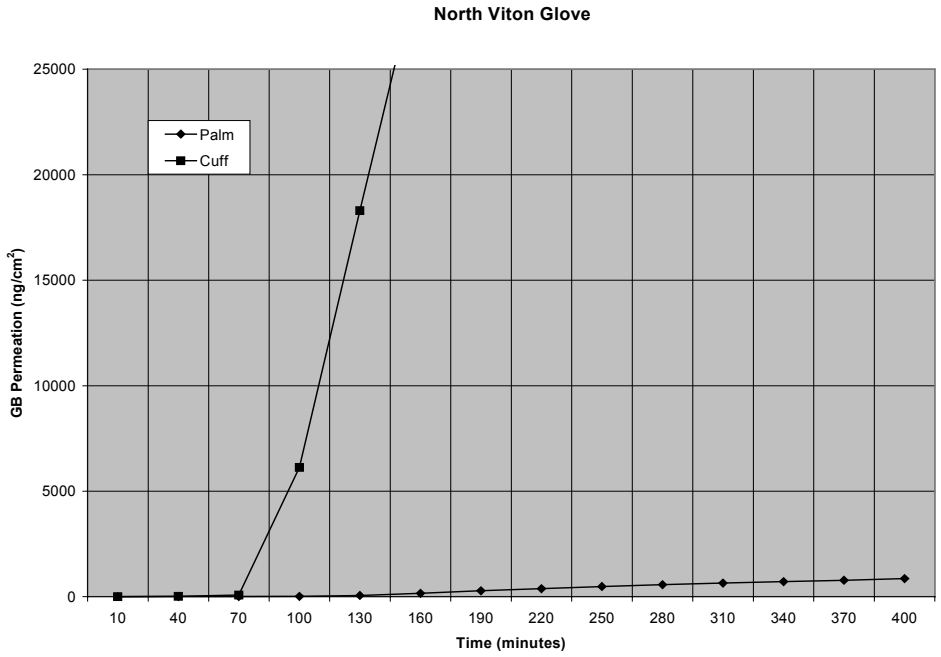


**Figure E- 5 North Viton Glove: GB Cumulative Permeation By Sampling Area**

Blank

## Appendix F
## North Silver Shield


**Figure F- 1 North Silver Shield Glove**

**Table F- 1 North Silver Shield Glove - Average HD Permeation**

| North Silver Shield Glove | | | | | |
|---|---|---|---|---|---|
| Time (minutes) | $M_f$, Palm ($ng/cm^2$) | Time (minutes) | $M_f$, Cuff ($ng/cm^2$) | Average Time (minutes) | Average $M_f$ ($ng/cm^2$) |
| 4 | 0 | 13 | 0 | 8 | 0 |
| 34 | 0 | 43 | 1 | 38 | 1 |
| 64 | 0 | 73 | 2 | 68 | 1 |
| 94 | 0 | 103 | 2 | 98 | 1 |
| 124 | 0 | 133 | 2 | 128 | 1 |
| 154 | 0 | 163 | 2 | 158 | 1 |
| 184 | 0 | 193 | 2 | 188 | 1 |
| 214 | 1 | 223 | 2 | 218 | 1 |
| 244 | 2 | 253 | 2 | 248 | 2 |
| 274 | 3 | 283 | 2 | 278 | 3 |
| 304 | 6 | 313 | 2 | 308 | 4 |
| 334 | 9 | 343 | 4 | 338 | 6 |
| 364 | 12 | 373 | 6 | 368 | 9 |
| 394 | 16 | 403 | 7 | 398 | 12 |
| 424 | 20 | 433 | 9 | 428 | 14 |
| 454 | 23 | 463 | 11 | 458 | 17 |
| 484 | 27 | 493 | 13 | 488 | 20 |
| 514 | 31 | 523 | 15 | 518 | 23 |
| 544 | 35 | 553 | 17 | 548 | 26 |
| 574 | 38 | 583 | 18 | 578 | 28 |
| 604 | 42 | 613 | 20 | 608 | 31 |
| 634 | 46 | 643 | 22 | 638 | 34 |
| 664 | 50 | 673 | 25 | 668 | 37 |
| 694 | 54 | 703 | 27 | 698 | 40 |
| 724 | 57 | 733 | 29 | 728 | 43 |
| 754 | 61 | 763 | 31 | 758 | 46 |
| 784 | 64 | 793 | 33 | 788 | 48 |
| 814 | 67 | 823 | 35 | 818 | 51 |
| 844 | 70 | 853 | 37 | 848 | 53 |
| 874 | 73 | 883 | 38 | 878 | 56 |
| 904 | 76 | 913 | 40 | 908 | 58 |
| 934 | 79 | 943 | 41 | 938 | 60 |
| 964 | 82 | 973 | 43 | 968 | 62 |
| 994 | 84 | 1003 | 44 | 998 | 64 |
| 1024 | 87 | 1033 | 45 | 1028 | 66 |
| 1054 | 89 | 1063 | 45 | 1058 | 67 |
| 1084 | 92 | 1093 | 46 | 1088 | 69 |
| 1114 | 94 | 1123 | 46 | 1118 | 70 |
| 1144 | 97 | 1153 | 47 | 1148 | 72 |
| 1174 | 99 | 1183 | 47 | 1178 | 73 |
| 1204 | 102 | 1213 | 48 | 1208 | 75 |
| 1234 | 104 | 1243 | 49 | 1238 | 76 |
| 1264 | 107 | 1273 | 50 | 1268 | 78 |
| 1294 | 109 | 1303 | 50 | 1298 | 80 |
| 1324 | 112 | 1333 | 51 | 1328 | 81 |
| 1354 | 114 | 1363 | 52 | 1358 | 83 |
| 1384 | 117 | 1393 | 52 | 1388 | 84 |
| 1414 | 119 | 1423 | 53 | 1418 | 86 |

**Table F- 2 North Silver Shield Glove – Average GB Permeation**

| North Silver Shield Glove | | | | | |
|---|---|---|---|---|---|
| Time (minutes) | $M_f$, Palm ($ng/cm^2$) | Time (minutes) | $M_f$, Cuff ($ng/cm^2$) | Average Time (minutes) | Average $M_f$ ($ng/cm^2$) |
| 4 | 1 | 13 | 8 | 8 | 4 |
| 34 | 13 | 43 | 46 | 38 | 29 |
| 64 | 23 | 73 | 82 | 68 | 53 |
| 94 | 32 | 103 | 112 | 98 | 72 |
| 124 | 40 | 133 | 139 | 128 | 90 |
| 154 | 48 | 163 | 163 | 158 | 106 |
| 184 | 55 | 193 | 186 | 188 | 120 |
| 214 | 62 | 223 | 207 | 218 | 135 |
| 244 | 69 | 253 | 227 | 248 | 148 |
| 274 | 76 | 283 | 246 | 278 | 161 |
| 304 | 83 | 313 | 264 | 308 | 174 |
| 334 | 89 | 343 | 283 | 338 | 186 |
| 364 | 96 | 373 | 302 | 368 | 199 |
| 394 | 102 | 403 | 320 | 398 | 211 |
| 424 | 108 | 433 | 336 | 428 | 222 |
| 454 | 114 | 463 | 350 | 458 | 232 |
| 484 | 119 | 493 | 364 | 488 | 241 |
| 514 | 123 | 523 | 377 | 518 | 250 |
| 544 | 128 | 553 | 389 | 548 | 259 |
| 574 | 133 | 583 | 402 | 578 | 267 |
| 604 | 137 | 613 | 413 | 608 | 275 |
| 634 | 141 | 643 | 425 | 638 | 283 |
| 664 | 146 | 673 | 436 | 668 | 291 |
| 694 | 150 | 703 | 446 | 698 | 298 |
| 724 | 154 | 733 | 457 | 728 | 305 |
| 754 | 158 | 763 | 467 | 758 | 312 |
| 784 | 162 | 793 | 477 | 788 | 319 |
| 814 | 166 | 823 | 487 | 818 | 326 |
| 844 | 169 | 853 | 496 | 848 | 333 |
| 874 | 173 | 883 | 505 | 878 | 339 |
| 904 | 177 | 913 | 514 | 908 | 345 |
| 934 | 180 | 943 | 523 | 938 | 352 |
| 964 | 184 | 973 | 531 | 968 | 358 |
| 994 | 188 | 1003 | 540 | 998 | 364 |
| 1024 | 191 | 1033 | 548 | 1028 | 370 |
| 1054 | 195 | 1063 | 557 | 1058 | 376 |
| 1084 | 198 | 1093 | 565 | 1088 | 381 |
| 1114 | 202 | 1123 | 573 | 1118 | 387 |
| 1144 | 205 | 1153 | 580 | 1148 | 393 |
| 1174 | 208 | 1183 | 588 | 1178 | 398 |
| 1204 | 211 | 1213 | 595 | 1208 | 403 |
| 1234 | 215 | 1243 | 603 | 1238 | 409 |
| 1264 | 218 | 1273 | 611 | 1268 | 415 |
| 1294 | 222 | 1303 | 619 | 1298 | 421 |
| 1324 | 225 | 1333 | 628 | 1328 | 426 |
| 1354 | 229 | 1363 | 636 | 1358 | 432 |
| 1384 | 232 | 1393 | 643 | 1388 | 438 |
| 1414 | 236 | 1423 | 650 | 1418 | 443 |

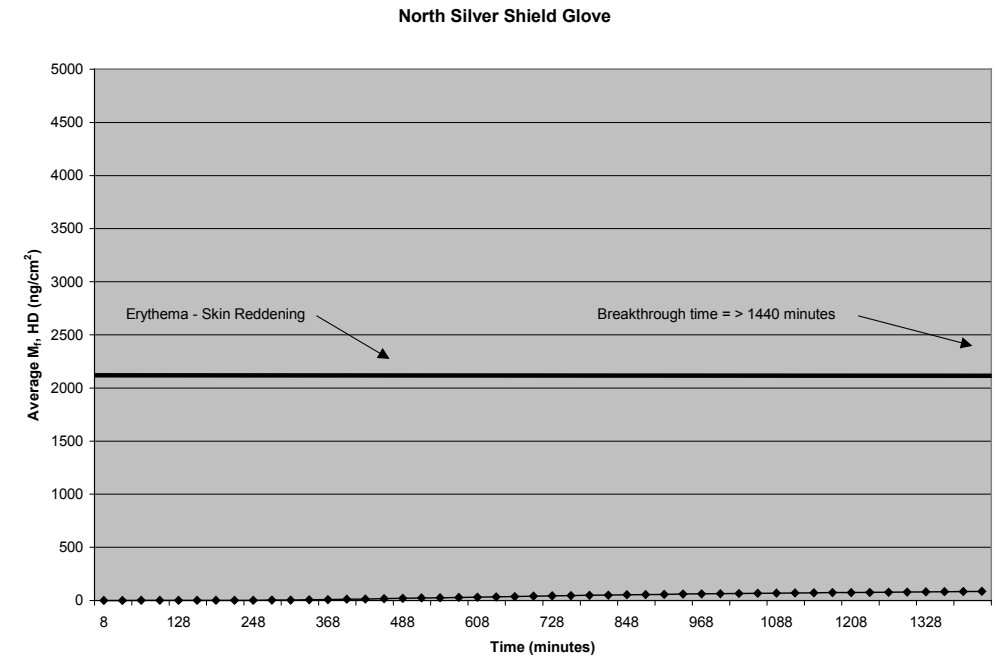


**Figure F- 2 North Silver Shield Glove - Average HD Cumulative Permeation**

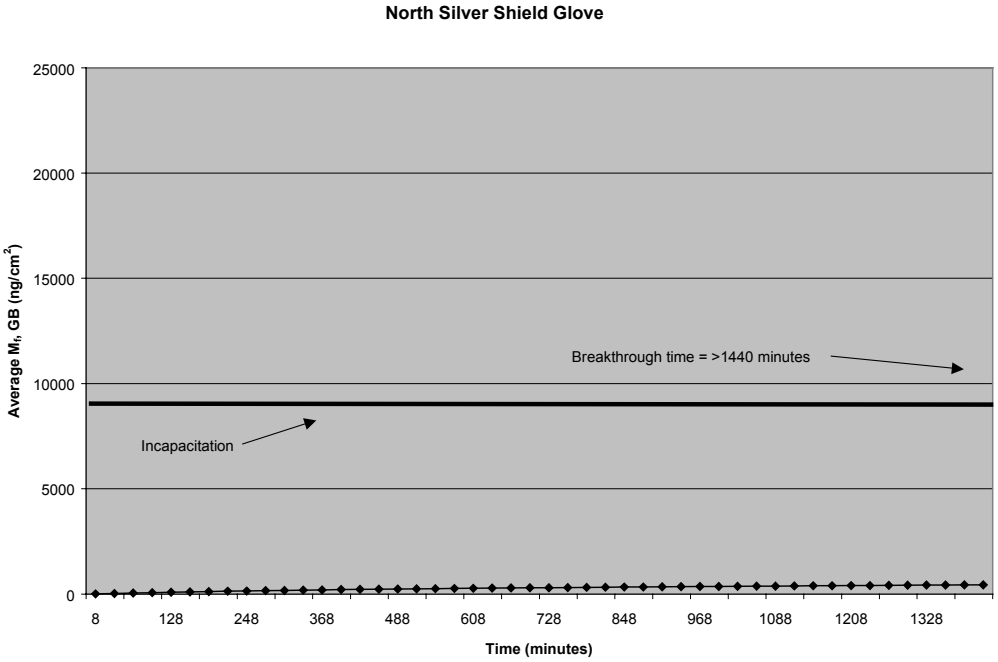


**Figure F- 3 North Silver Shield Glove - Average GB Cumulative Permeation**

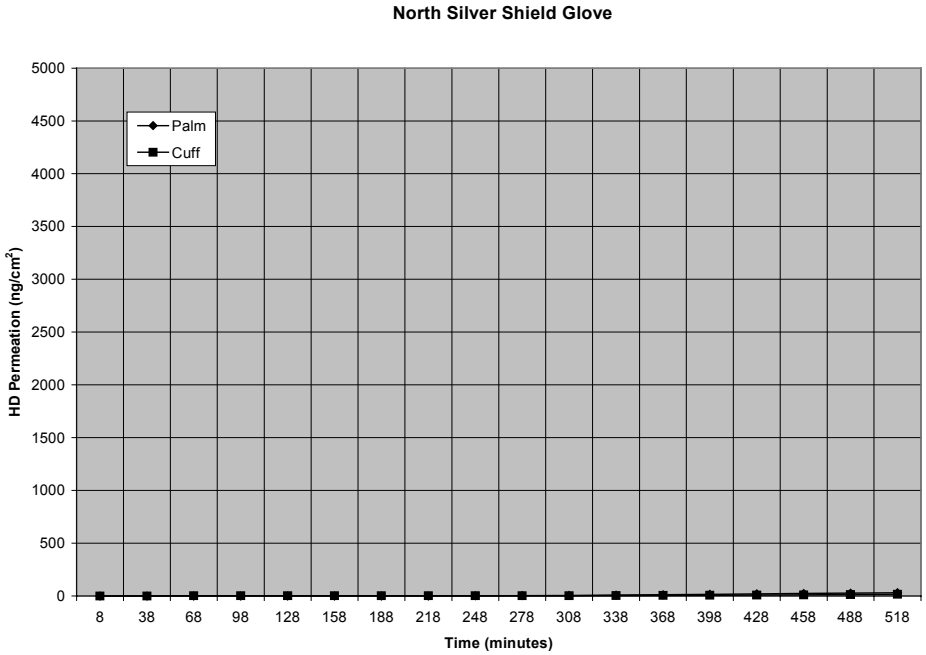


**Figure F- 4 North Silver Shield Glove - HD Cumulative Permeation by Sampling Area**

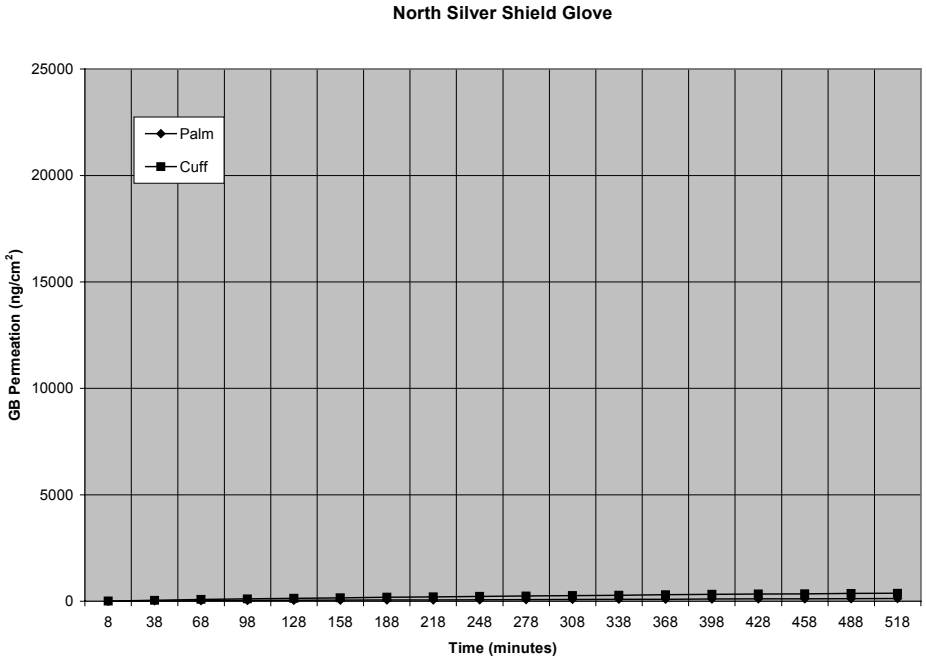


**Figure F- 5 North Silver Shield Glove - GB Cumulative Permeation by Sampling Area**

# Appendix G
# Overall Test Results

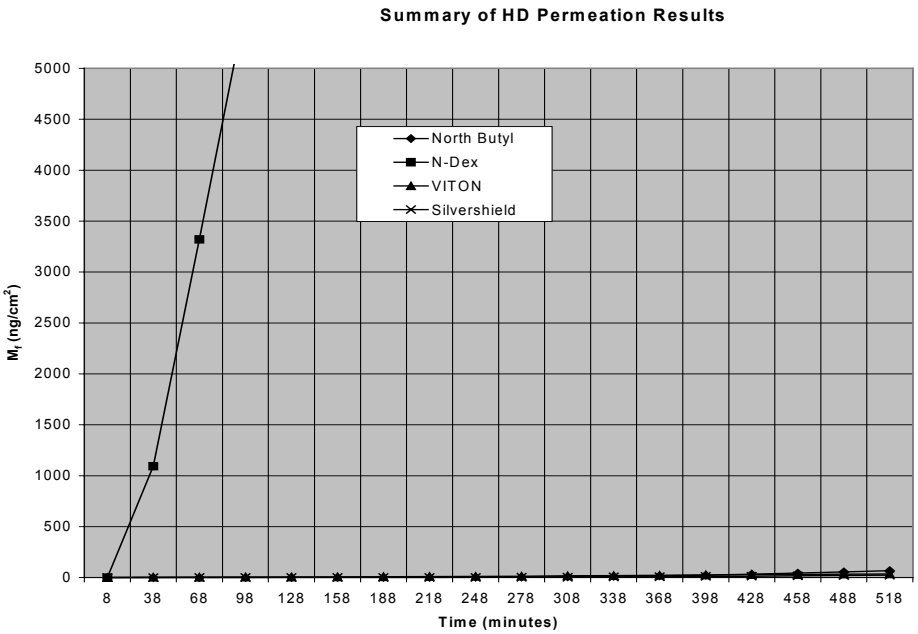


**Figure G- 1 Average HD Cumulative Permeation**

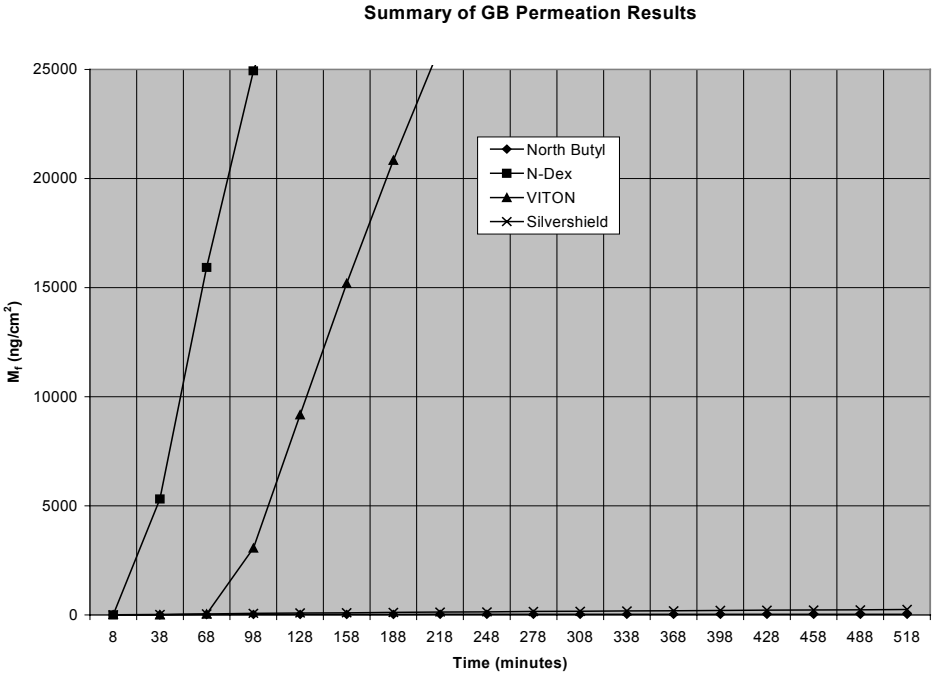


**Figure G- 2 Average GB Cumulative Permeation**