

**A GUIDE FOR EVALUATING THE PERFORMANCE OF  
CHEMICAL PROTECTIVE CLOTHING (CPC)**

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## ABSTRACT

In industrial environments where dermal exposure to hazardous chemicals can occur, engineering, administrative, and work practice controls can minimize the worker's contact with chemicals. Where these controls are inadequate, the use of chemical protective clothing (CPC) can minimize the risk of exposure and provide a last line of defense. This guide describes a method for an industrial hygienist or equivalent safety professional to select appropriate CPC. The steps in the selection process are (1) evaluating the workplace, (2) obtaining samples of candidate CPC, (3) testing the samples under the conditions in which they will be used, (4) select the best candidate CPC, and (5) monitoring the use of the CPC in the workplace. The decontamination and reuse of chemical protective clothing are discussed, and an example is given for using the selection process.



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## INTRODUCTION

Many chemicals known to be detrimental to health can be easily absorbed into the body. The respiratory tract is usually the major route of entry for volatile chemicals [Plog 1988]. Information to prevent chemical exposures via inhalation is readily available and can be effectively used to protect workers.

Chemicals can also enter the body through the skin. In some cases, skin absorption may contribute a significant portion of the total body exposure to a volatile chemical [NIOSH 1988; ACGIH 1989]. Intact skin can be an effective barrier to many chemicals; however, minor cuts and abrasions—common to industrial situations—can allow direct entry into the body.

In addition to being a potential route of entry for chemicals, the skin can be the target organ in the development of diseases such as dermatitis. Skin diseases can also increase the likelihood of percutaneous absorption. Skin disorders have been reported as the most prevalent occupational disease [BLS 1987; NIOSH 1988].

Until the mid-1970's, people assumed that "rubber" or liquid-proof gloves provided adequate protection for the hands. Since then, many studies have demonstrated that some chemicals can permeate all commercially used chemical protective clothing (CPC) [Schwope et al. 1987; Mickelsen and Hall 1987; Mickelsen et al. 1986; Sansone and Jonas 1981; Stampfer et al. 1984].

This guide is intended to help select CPC that will protect a worker's skin from contacting chemicals. The information is to be used by persons who are knowledgeable in industrial hygiene, chemistry, and safety principles and practices.

## **Information not Included in this Guide**

**This guide does not address several important areas in worker protection:**

- 1. This Guide does not provide instruction to determine whether CPC protection is necessary. In fact, CPC should be considered as the last line of defense to protect against accidental contact (e.g., spills, splashes). The use of engineering and work practice controls are the preferred methods to eliminate or minimize contact with the chemical and should be implemented and evaluated before using CPC.**
- 2. This Guide is not a CPC decision logic but does provide information relevant to the performance of CPC. If CPC is used, a program similar to that used for respirator selection and use should be developed by the employer [NIOSH 1987a; NIOSH 1987b]. Several useful publications and training programs are available to cover CPC use [Perkins 1988; Johnson 1989; Mansdorf 1988 and 1989].**
- 3. This Guide does not address a worker's use of CPC with unknown chemicals. The Guide is limited to situations where the chemicals can be identified and the CPC can be tested in a timely fashion. In emergency response to chemical spills and in chemical waste dump situations, the chemicals may not be identified or be only partially identified and immediate action may be required. NIOSH and others have published guidance for selecting CPC for these incidents [NIOSH 1984; NIOSH 1985; Schwowe et al. 1987].**
- 4. This Guide does not address how much of a chemical can safely contact the skin. Dermal exposure limits have not been established. Therefore, this guide assumes that chemical contact with the skin should be minimized. This Guide uses the permeation breakthrough time to indicate minimum exposure. Perkins suggests using the steady-state permeation rate to indicate minimum exposure [Perkins 1987]. Although**

this Guide will work with either breakthrough time or steady-state permeation rate, some material-chemical systems do not reach a steady-state permeation rate.

Should dermal exposure limits be established, the dose received by the CPC wearer could conceivably be estimated from the permeation breakthrough time, system sensitivity, steady-state permeation rate, exposed CPC area, exposed skin area, and skin permeation data.

### **General Considerations Concerning CPC Use**

Several important issues should be considered when selecting CPC.

1. Although the use of "impervious" clothing is frequently recommended, such clothing does not exist. All commercially available CPC tested will allow some chemicals to permeate in relatively short times.
2. Because all CPC is vapor resistant, evaporative cooling of the skin is prevented; without evaporative cooling, the skin temperature and moisture increase when wearing CPC. Under these conditions, detecting a permeated chemical is difficult unless sensory effects such as itching, discoloration, or burning result. Even when the CPC is removed, an exposure might not be recognized if an odor is not noticeable or the skin appearance has not changed. Furthermore, the warm, humid conditions under the CPC can increase the permeability of the skin.
3. When the CPC being used has not been tested under the expected conditions, the CPC may fail to provide adequate protection. In this situation, the wearer should observe the CPC during use and treat any noticeable change (e.g., color, stiffness, chemical odor inside) as a failure until proved otherwise by testing. If the work must continue, new CPC should be worn for a shorter exposure time, or CPC of a different generic material should be worn.

4. The same thickness of a generic material, such as neoprene or nitrile, supplied by different manufacturers may provide significantly different levels of protection because of variations in the manufacturing processes or in the raw materials and additives used in processing [Mickelsen et al. 1986].
  
5. Most permeation data have been produced by testing the CPC material while in continuous contact with the chemical. This method of testing is considered the "worst case" condition that produces the quickest breakthrough time. Although it appears this breakthrough time could be safely increased if intermittent contact is expected, researchers have shown that, in some cases, breakthrough times for intermittent exposure are similar to continuous contact [Sansone and Jonas 1981]. Breakthrough times for intermittent exposures can be estimated during testing of the candidate CPC by using intermittent chemical contact with the candidate CPC to simulate expected use.
  
6. Published permeation data of CPC tested against pure chemicals do not correlate with test data for those same chemicals in mixtures, and these data cannot be used to reliably predict breakthrough times for chemical mixtures [Mickelsen et al. 1986]. Unfortunately, mixtures of chemicals are usually encountered in the industrial setting. When data are not available for specific mixtures, the worst-case data for any component of the mixture should be used to select the candidate CPC.

## SELECTION PROCESS

The important elements for selecting CPC, shown in Figure 1, are discussed below.

### 1. Evaluating the Workplace

Systematic job review or analysis techniques such as an industrial hygiene survey, job safety analysis, or fault tree analysis should be used to determine the potential for chemical contact and the conditions that CPC must withstand. Information should be collected to answer the following specific questions for the selection of CPC:

a. Chemical identification. What are all of the components of each chemical mixture used in the workplace? The presence of less toxic chemicals may decrease the protection provided against the more toxic ones. A list of all chemicals and their concentrations contained in a product should be obtained from the Material Safety Data Sheets (MSDS), container labels, or manufacturer's product literature.

Confirmation of these chemicals can be ascertained by chemical analysis of the product.

b. Chemical state and properties. What are the state and properties of the chemicals used in the workplace? If a chemical is present as a vapor and the vapor exposure can be harmful, the worker should use whole body protection (e.g., EPA Level A ensemble [EPA 1984], a totally encapsulated suit with supplied air).

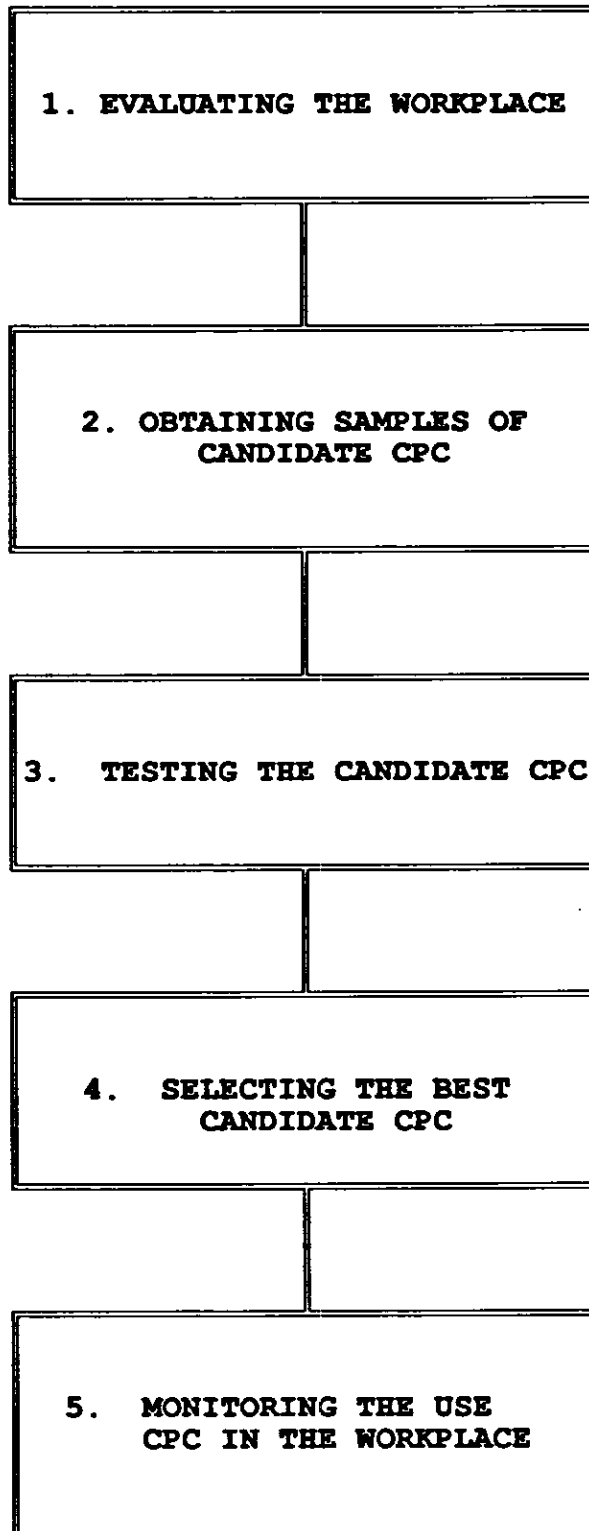


Figure 1. A logical method for evaluating the performance of CPC.

- c. Chemical contact sequence. Is the chemical contact limited to an occasional accidental splash, with the opportunity available to quickly change the CPC? Or is the CPC in continuous contact with the chemical for long periods of time? To simulate actual conditions, a realistic exposure sequence can be used during testing.
- d. Potential CPC use/reuse pattern. If CPC is to be removed after a short exposure time and then donned for another subsequent exposure time, can the worker be exposed as the result of handling, doffing, and donning the contaminated CPC?
- e. Environmental conditions. What is the temperature of the environment in which chemical contact may occur? With each 10°C rise in temperature, the permeation rate roughly doubles and breakthrough time significantly decreases [Comyn 1985]. Is there potential contact with open flame or will high environmental temperatures be encountered? Many CPC products are flammable.
- f. Contact location. What parts of the body can the chemical potentially contact? Some types of garments, such as boots, are available only in a few generic materials.
- g. Resistance to physical stress. Will the CPC be used in a workplace where abrasions, cuts, punctures, or tears may occur? Requirements for moving a 55-gallon drum are different from those for pouring liquid from one beaker to another.
- h. CPC interference with task. Does the work include delicate tasks such as handling very small parts that require high manual dexterity? Could the CPC catch on moving equipment to cause an injury? Is the work rate high enough to cause heat stress if large areas of the body are covered with a vapor barrier of CPC?

## **2. Obtaining Samples of Candidate CPC**

Because of manufacturing differences and unique workplace conditions, representative samples from specific garments being considered for use should be obtained and tested. CPC products already used for other purposes in the workplace could be considered as candidates. Specific products and generic polymer candidates can be identified from chemical resistance data. For example, several sources of chemical resistance data are described in Appendix B of this document. Also, many health and safety product manufacturers and vendors publish data in their literature and have current information available by telephone.

Physical resistance data for generic materials have been summarized in Appendix A of the present document. These data are not generally published for specific products, but are sometimes available from manufacturers and vendors. Types of physical tests performed for CPC are summarized in Appendix A.

Most types of garments are not manufactured from all generic materials. In Appendix C of Volume I of Guidelines for the Selection of Chemical Protective Clothing, sources are listed for specific garments made from generic polymers [Schwope et al. 1987]. For products that became available after 1986 (the last update of the publication), vendors should be consulted. This information is summarized in Appendix F.

EPA has defined CPC ensembles to provide levels of protection for various exposure situations [NIOSH/OSHA/EPA/USCG 1985]. These levels of protection and data sheets describing specific encapsulating ensembles are included in Volume I, Appendices G, H, and I of Guidelines for the Selection of Chemical Protective Clothing [Schwope et al. 1987].

## **3. Testing the Candidate CPC**

Before the candidate CPC is used in the workplace, it should be tested under the anticipated work conditions. This testing is necessary because of the differences in generic materials [Mickelsen and Hall 1987] and because



of the inability to predict mixture permeation characteristics from pure chemical data [Mickelsen et al. 1986]. The most important test parameter is how long the CPC will prevent chemical contact with the skin. This parameter can be estimated by the breakthrough time from a permeation test. The ASTM F 739 permeation test method is the consensus method for volatile or water soluble chemicals [ASTM 1985]. For a permeation test, the complete testing system (not just the analyzer) must be sensitive enough to indicate chemical breakthrough [Jamke 1989]. If the ASTM test method is not practical, three simplified permeation methods for volatile chemicals are outlined in Appendix C of this document. Another simple test method for volatile chemicals is currently being developed by the ASTM F23 Committee on Protective Clothing. This method estimates permeation using a balance to measure weight loss from a permeation test cup. Testing kits based on this method are commercially available from Arthur D. Little, Inc., and Texas Research Institute.

For low-volatile and low-water-soluble chemicals, breakthrough times can be estimated by analyzing periodic wipe samples from the inside surface of the CPC [Stampfer 1984]. Other ways to increase sensitivity would be by selecting a more sensitive analytical method (one that can concentrate periodic samples), by increasing the exposed material surface area, or by decreasing the collection volume.

Brief descriptions of some test methods used to evaluate CPC (chemical resistance, physical resistance, and ergonomic factors) are included in Appendix A. These test methods have not been verified by NIOSH. Laboratories that perform these tests on CPC for a fee are listed in Appendix E. Although chemical resistance is important, physical resistance and ergonomic factors can sometimes be as critical. Because few data are published on these factors, the user must select or devise tests to rank the candidate CPC.

Reuse of any CPC after decontamination is not recommended unless chemical resistance testing is conducted after decontamination. The test should evaluate (1) the adverse effect of the decontamination procedure on the CPC material and (2) the effectiveness of the decontamination procedure in removing the chemical from the material [Berardinelli and Hall 1989; Perkins 1987]. Any chemical and physical resistance tests should be

repeated after the CPC has undergone a number of chemical exposure and decontamination cycles. Information to consider in CPC reuse is presented in Appendix D of this document.

#### **4. Selecting the Best Candidate CPC**

The data generated in step 3 should be compared with the requirements established in step 1 to determine which candidate CPC to try in actual use situations.

#### **5. Monitoring the Use of CPC in the Workplace**

Once the CPC is selected, an initial evaluation of its use is necessary. Training the worker in the proper use and care of the clothing is important, and the training should include the reason for using the CPC. In this initial assessment, information from the CPC user is important to determine its effectiveness (e.g., has dermatitis been reduced?).

After the product is in routine use, the workplace should be periodically reviewed to ensure that nothing in the workplace or with the CPC has changed to invalidate the test results on which the selection was based. During its use or during its manufacture, the CPC's composition or resistance characteristics of CPC could have changed. Workers should also be evaluated periodically for adverse health effects such as skin or systemic diseases to confirm the effectiveness of CPC protection.

## **AN EXAMPLE USING THE SELECTION PROCESS**

In this example, some data have been fabricated to illustrate the selection process. Some of the decisions are subjective and could be interpreted differently by others. The hypothetical situation is as follows: A company manufactures plastic automobile supercharger carburetor kits for sale overseas. As the company's industrial hygienist, you have been requested to recommend protective clothing for a workers whose skin is exposed to a mixture of chemicals.

### **1. Evaluating the Workplace**

You evaluate the workplace. The operation is a chemical strengthening process in which small ceramic parts are removed from a hot dipping process. The task takes place over a draining table where the worker's hands and wrists are exposed to the chemical. There is a possibility of body exposure because of splashing. A rack of parts is unloaded in about 10 minutes. The worker receives about 3 racks per hour. A mixture of 1,1,2,2-tetrachloroethane and cyclohexane is used in the hot dip process. From chemistry and toxicological data, you judge that skin absorption results predominantly from exposure to liquid rather than to vapor. The parts have some sharp edges. Although some parts are small, dexterity with most gloves should not be a problem. The temperature of the parts is 25° to 40°C.

### **2. Obtaining Samples of Candidate CPC**

Because the hands and wrists are directly in contact with the chemicals, gloves are required. Furthermore, you decide that an apron should be worn to protect from accidental splashing. Two types of gloves are already stocked in the plant. One is a nitrile glove that is reused after being sent to a commercial laundry that cleans

them with hot, soapy water. The other is a disposable polyethylene glove. Butyl and neoprene aprons are also stocked. A review of the data from commercial sources (Appendix B), recent literature, and information supplied by manufacturers and distributors yield the information summarized in Table 1. The expected use time in column 4 is the smallest value for breakthrough time from columns 2 and 3. These values, obtained from the scientific literature, are used to rank the candidates for testing.

The data in Table 1 are grouped by general chemical resistance ranges. Group A could provide protection for half a shift or more. Group B could provide protection if replaced after a specified number of racks were unloaded. Group C is unlikely to provide adequate protection. Groups A and B are investigated to determine whether the necessary garments can be obtained. Table 2 was constructed with data from the sources listed in Appendix B and with data from suppliers of CPC.

The reasons for not considering some of the available products as candidate CPC for the initial testing are:

- The imported Material C glove supply cannot be guaranteed.
- None of the usual sources can supply the gloves of Material A, Material D, or Material E/chlorobutyl (if other candidate CPC does not work out, these could be reconsidered).
- Material A, Material E/chlorobutyl, and CPE are available only as full-suit garments.
- Gloves and aprons made from Material E are very expensive.
- The PVA polymer's cut resistance and dexterity are notably worse than other candidate CPC.

Table 1. Summary of published data

| Generic material           | Breakthrough time<br>(minutes) |                  | Expected<br>use time<br>(minutes) | Resistance<br>of CPC<br>to cuts | Dexterity<br>permitted<br>by CPC |
|----------------------------|--------------------------------|------------------|-----------------------------------|---------------------------------|----------------------------------|
|                            | Tetrachloro-<br>ethane         | Cyclo-<br>hexane |                                   |                                 |                                  |
| <b>Group A:</b>            |                                |                  |                                   |                                 |                                  |
| Material A                 | >1440                          | >1440            | >1440                             |                                 |                                  |
| Material B                 |                                | >360             | >360                              |                                 |                                  |
| Material C                 |                                | >240             | >240                              |                                 |                                  |
| Nitrile/PVC                |                                | 222              | 222                               | G*                              | G                                |
| Material D                 | >900                           | >200             | >200                              |                                 |                                  |
| Material E                 | >180                           | >420             | >180                              | G                               | G                                |
| Material E/<br>chlorobutyl | >180                           |                  | >180                              |                                 |                                  |
| <b>Group B:</b>            |                                |                  |                                   |                                 |                                  |
| Butyl/neoprene             |                                | 65               | 75                                |                                 |                                  |
| Material F                 | 75 to 303                      |                  | 75                                | F                               | F                                |
| Butyl                      | 276                            | 69               | 69                                | G                               | G                                |
| CPE                        | 64                             | >180             | 64                                | G                               | G                                |
| PVA                        | >480                           | 47               | 47                                | F                               | P                                |
| Nitrile                    | 22 to 74                       | 60-480           | 22                                | E                               | E                                |
| <b>Group C:</b>            |                                |                  |                                   |                                 |                                  |
| Material G                 | DG                             | 330              | <10                               |                                 |                                  |
| Neoprene                   | 6 to 18, DG                    | 6 to >156        | <10?                              | E                               | G                                |
| Natural rubber             | 6, DG                          | 2 to 41          | <10                               | E                               | E                                |
| Nat rub<br>+ neoprene      | 9                              | 5 to 9           | <10                               |                                 |                                  |
| Polyethylene               | 4                              | 1                | <10                               | F                               | G                                |
| PVC                        | 1 to 6, DG                     | 6 to 165         | <10                               | P                               | F                                |

\*DG = degrades, P = poor, F = fair, G = good, E = excellent, blank = no data.

Table 2. Availability of garments from candidate materials

| Material                                      | Availability |          | Comments                        |
|---|--------------|----------|---------------------------------|
|   | Gloves       | Aprons   |                                 |
| <b>Group A (replace after 1/2 + shift):</b>   |              |          |                                 |
| Material A                                    | No           | No       | In suits only                   |
| Material B                                    | Obtained     | No       | No comment                      |
| Material C                                    | Yes          | No       | Imported, supply not guaranteed |
| Nitrile/PVC                                   | ?            | ?        | Not available                   |
| Material D                                    | No           | Obtained | Not available                   |
| Material E                                    | Yes          | Yes      | Expensive                       |
| Material E/<br>chlorobutyl                    | No           | No       | In suits only                   |
| <b>Group B (replace after a few unloads):</b> |              |          |                                 |
| Butyl/neoprene                                | ?            | ?        | Couldn't locate                 |
| Material F                                    | No           | Obtained | Inexpensive, disposable         |
| Butyl   | Obtained     | Stocked  | Aprons in stock                 |
| CPE   | No           | No       | Suit material only              |
| PVA   | Yes          | Yes      | Poor physical resistance        |
| Nitrile                                       | Stocked      | Obtained | Have in stock                   |

Because a system for recycling nitrile gloves is currently being used, the nitrile apron is included as a candidate.

The nitrile gloves and butyl aprons are included because they are currently stocked for other purposes.

The candidate products selected for gloves are Material B, butyl, and nitrile; for aprons, Material D, Material F, butyl, and nitrile are selected.

### **3. Testing the Candidate CPC**

To screen unsuitable products cheaply and quickly, a visual and tactile degradation test is run. The samples are weighed, soaked overnight, patted dry, immediately reweighed, visually inspected, and compared with an unexposed sample for properties such as stretchability. Three individuals perform actual tasks using the gloves. Each individual compares the cut resistance of the gloves by making slices in the material with a razor blade and subjectively rating each sample material. Products with fewer visual, weight and other physical property changes generally provide longer protection against chemical permeation.

The more sophisticated and expensive ASTM F739 permeation test is performed on the selected CPC materials by an outside testing laboratory at 40°C using the actual chemical mixture. The butyl apron was included because it was already stocked. Because the Material B gloves are recommended as disposable, permeation tests after decontamination cycles are not performed. This also means that decontamination would not be a factor in the company's CPC program for Material B. The results of these tests are presented in Table 3.

To save expense and time, some of the tests are not performed on all of the candidate CPC. Cut and dexterity tests are not considered necessary for aprons. The more expensive permeation test is performed only after screening with the other less complicated and less expensive tests.

Table 3. Summary of test results for CPC candidates

| Product        | Degradation       |                      | Resistance to cuts | Dexterity permitted | Breakthrough time (minutes) | Breakthrough time after 10 decontaminations (minutes) |
|----------------|-------------------|----------------------|--------------------|---------------------|-----------------------------|---|
|                | Weight Change (%) | Visible Effects      |                    |                     |                             |   |
| <b>Gloves</b>  |                   |                      |                    |                     |                             |   |
| Material B     | 2                 | None                 | Good               | Fair                | >480                        | Not done  |
| Butyl          | 20                | Discoloration        | Poor               | Good                | Not done                    | Not done  |
| Nitrile        | 8                 | None                 | Good               | Fair                | 190                         | 180   |
| <b>Aprons:</b> |                   |                      |                    |                     |                             |   |
| Material D     | 12                | Surface crazing      | Not done           | Not done            | 100                         | Not done  |
| Material F     | --                | Separation of layers | Not done           | Not done            | 100                         | Not done  |
| Nitrile        | 10                | None                 | Not done           | Not done            | 500                         | Not done  |
| Butyl          | 20                | Discoloration        | Not done           | Not done            | 30                          | 32  |



#### **4. Selecting the Best Candidate CPC**

The Material B glove is the most chemically resistant (lasting an entire work shift) and the least expensive. The stocked butyl apron is judged to be adequate based on information gathered from observing the process and from interviews with workers confirming that exposure from splashes on the trunk are infrequent. The workers are instructed to begin each workshift with a decontaminated or clean apron and to replace the apron if contact with the chemicals occurs.

#### **5. Monitoring the Use of CPC in the Workplace**

A sufficient number of CPC products are purchased for trial use. Observations and discussions with the workers indicate that handling small parts is difficult with the Material B glove, apparently because of the poor fit or lack of dexterity it permits. An increase in the breakage of ceramic parts seems to confirm the problem. The butyl apron performs adequately.

The stocked nitrile gloves undergo a second trial. They are replaced every 2 hours and worker acceptance is good. The gloves are decontaminated through the currently used laundry process. The breakage rates do not increase. (The Material B glove is stocked for use during extended maintenance projects that involve contact with the same chemicals for more than 2 hours.)

When the performance of all CPC in use is reviewed a year later, it is noted that a new nitrile glove is being stocked. The purchasing agent found a another nitrile glove for half the price from local distributors. The workers like the new glove because they can feel the parts much better. Samples of the new and old gloves are sent to the laboratory for permeation testing. The chemical breakthrough time of the new glove is 20 minutes, whereas the old one is 190 minutes. After talking with the safety officer and the purchasing agent, the old glove is restocked because of the longer breakthrough time. A procedure is implemented requiring prior approval from

the safety officer before any safety equipment products are replaced. The purpose, use, and care of protective clothing is periodically discussed at the required worker safety meetings.

## **SUMMARY**

**A knowledgeable person can perform an industrial hygiene and safety survey of an industrial environment.**

**Where CPC use is necessary, published data can be used to select candidate products for evaluation. Samples of specific candidates can be ranked with the use of existing test methods. Initial and follow-up evaluations can verify whether the CPC in current use is protecting the workers.**

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## GLOSSARY

American Society for Testing and Materials (ASTM) is a non-profit organization that develops standard testing methods by the consensus of volunteers from manufacturers, users, and others.

Breakthrough time is the elapsed time between the initial contact of a chemical with the outside of CPC and the time at which the chemical is first detected on the inside surface of the material by means of the chosen analytical instrument.

Candidate product is a CPC product to be evaluated before use in the workplace.

CPC or chemical protective clothing is an item of clothing used to isolate parts of the body from direct contact with a potentially hazardous chemical.

Degradation is a deleterious change in one or more physical properties of a protective clothing material due to contact with a chemical.

Generic material is made from one type of polymer or polymer combination. Examples are neoprene, nitrile, and polyvinyl alcohol. When products are manufactured from the polymer, additions of other materials are included for various reasons during the manufacturing process.

Penetration is the flow of a chemical through closures, porous materials, seams, pinholes, or other imperfections in a protective clothing material on a non-molecular level.

Permeant is the chemical permeating through the CPC material.

Permeation is the process by which a chemical moves through protective clothing on a molecular level. It involves sorption of the chemical into the contacted material, diffusion of the chemical molecules in the material, and desorption from the opposite surface of the material.

Steady state permeation is the constant rate of permeation that occurs after the breakthrough when all forces affecting permeation have reached equilibrium.

System Sensitivity is the lowest concentration of a chemical that can be detected in the collection side of a permeation test cell. In addition to the analytical instrument sensitivity, other factors are the exposed area of the CPC material and either the collection volume (accumulation system) or the flow rate (single pass system).





## APPENDIX A. DESCRIPTION OF CHEMICAL PROTECTIVE CLOTHING

### PRODUCT EVALUATION DATA

Product evaluation tests are used to assess the performance and to control the manufacture of chemical protective clothing (CPC). A preliminary survey of manufacturers and others active in testing CPC identified a variety of tests being used. In this appendix, the data from these tests are discussed in relation to their use in selecting CPC. Most of the information presented here was derived from discussions with persons routinely performing the tests; these tests have not been verified by NIOSH testing.

Copies of the ASTM test methods can be obtained from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103; the Federal Test Methods (FTM) and NAVY, from National Technical Information Service (NTIS), Department of Commerce, Springfield, VA 22161.

Chemical resistance data are frequently published and available from many manufacturers and distributors for their products. Often unpublished data may be supplied by manufacturers upon request.

CPC product evaluation data can be divided into three categories—chemical resistance, physical resistance, and ergonomic factors. Chemical resistance is the ability of the CPC to protect users from chemicals. Physical resistance is the ability to retain physical integrity and, therefore, remain an effective chemical barrier with normal product wear. Ergonomic factors are relationships between the CPC and the user. Examples are fit, user comfort, donning or doffing difficulty, and exposure potential from doffing and donning.

## CHEMICAL RESISTANCE

### Permeation

Two different testing systems are used in permeation--accumulation and removal. Examples of accumulation systems are the closed loop (recirculating) system with a nondestructive analytical detector or a system with periodic removal of collection medium aliquots for analysis (usually replaced by fresh collection media). The accumulation methods allow the permeant to build up in the collecting medium, making them more sensitive in estimating the initial breakthrough time. Removal systems (open loop or single pass) continually remove the permeant with a stream of fresh collection medium.

Although the breakthrough time data from the two types of systems are not identical, they are close enough to compare when selecting candidate materials. For most chemical-CPC material combinations, the time between breakthrough and maximum permeation rate is short, which would result in very little differences between the accumulation and the removal methods. If the steady state permeation rate is low in relation to the test system sensitivity, however, the breakthrough time estimated in an accumulation system could be significantly lower than in a removal system. Such low steady state permeation rates occur sometimes in Teflon materials.

A permeation test produces the following data:

- a. Breakthrough time is the elapsed time between the initial contact of a chemical with the outside of CPC and the time at which the chemical is detected in the collection medium in contact with the inside surface of the sample CPC.

The analytical method and system sensitivity are important when comparing data from different sources. The actual breakthrough time could be much less than that measured if an inappropriate analytical method is used or if the system sensitivity is insufficient to detect permeation, especially if the permeation rate is low. A measured breakthrough time earlier than the actual time could occur because of system contamination or sample defects such as pinholes (which typically give very short breakthrough times and high steady state permeation rates).

If the sensitivity is reported in literature, it is usually that of the analytical detector, which is usually much lower than that of the system. The ASTM F23 committee is currently addressing this problem.

- b. Steady state permeation is the constant rate of permeation that occurs after the breakthrough when all forces affecting permeation have reached equilibrium. It does not occur for many chemical material testing combinations. If the breakthrough times of two products were similar, the one with the lower steady state permeation rate would allow less chemical exposure if the product was used beyond its breakthrough time.

## Degradation

Degradation is a deleterious change in one or more physical properties of a protective clothing material resulting from contact with a chemical. For example, a chemical can leach out part of the material's components essentially changing it into another material that probably has different chemical and physical resistance properties. Degradation data have been published since the early 1970s as "chemical resistance charts."

The test used is similar to the ASTM D 471, Standard Test Method for Rubber Property- Effect of Liquids. This method allows immersion or one-sided contact with the chemical for various

times. For CPC material, these times vary from 5 minutes to 48 hours instead of those recommended in the ASTM D 471. The size of the sample varies from 1 to 1.5 square inches. The quantitative results from the test include changes in weight, thickness, surface area, or volume. Another quantitative test is the ASTM D 412, Tensile Strength and Ultimate Elongation. This test may be performed immediately after chemical exposure (rough indication of performance during use) or after chemical evaporation (a indication of the permanent effect of the chemical on the material). In addition, qualitative data such as "feel" and visual changes are considered.

All of these results are generally combined on chemical resistance charts into nonstandard subjective ratings such as excellent, good, fair, poor, and not recommended. The quantitative data are generally not published; however, they are available by request from some manufacturers. When comparing degradation quantitative data from different sources, the following test conditions should be the same: single-sided chemical contact or total immersion, contact time, temperature, property measured (e.g. weight), and time after exposure (immediate or after recovery time) before the final data were collected.

The important facts about degradation data are these:

- a. Any product not in the highest rating category has demonstrated some signs of being changed by the chemical.
- b. A product with a top degradation rating does not guarantee that permeation will not occur.
- c. Different data from different sources cannot be reliably compared. Both the testing methods and the interpretation of the results vary from source to source.

- d. Some of the published chemical resistance charts are not specific for the manufacturer's products. Some charts from different suppliers are obviously from the same source. The data may describe degradation characteristics of the generic polymer rather than the specific material in the finished product. Finished CPC products contain additives to give the desired physical and chemical resistance properties.
  
- e. Degradation data are useful in eliminating products from further consideration. This may be the only chemical resistance data available for some chemical-material combinations if the material degraded considerably.

### **Penetration**

Penetration is the flow of a chemical through CPC product closures, seams, and imperfections (e.g., pinholes). Unlike permeation, in which a relatively small amount of chemical is transported to the inside of the CPC, penetration is bulk flow. Virtually all of the published penetration data were collected using the ASTM F 903, Penetration Test Method [ASTM 1984]. The output is a two-level pass/fail test. The first pass/fail level is no breakthrough indication after 5 minutes at 0 psig. Then 2 psig air pressure is applied for 10 minutes, and a second-level observation is made. Failure is determined by a visual indication (usually enhanced by an indicator) of chemical on the inside of the sample.

Although the data from this test do not provide an estimate of the time a product will protect a user, ASTM F 903 can demonstrate relative performance among products. It is recommended to evaluate closures and seams of CPC. One study demonstrated that seams were potentially a major problem with the CPC on the market at that time [Berardinelli and Cottingham 1986].

## PHYSICAL RESISTANCE

Most CPC manufacturers perform various physical tests in product development and in quality control during manufacturing. Although the results are seldom published, they may be available by customer request from some manufacturers. Unfortunately, data from different sources may not be comparable since there are many adjustable variables in the various test methods used. The results usually do not relate directly to actual use; however, they could be useful in relative ranking of candidates under consideration. Usually the tests for products made from supported (coated fabrics) and unsupported (films) materials are not comparable. Similarly, tests used for a type of product, such as gloves, can vary depending on the generic material used.

Physical resistance data should be obtained for the specific material being considered since it can vary widely for a given generic material (Table A1). Therefore, the best source of physical data is either the product manufacturer or the supplier.

Table A1. Summary of physical resistance data for CPC generic materials<sup>1</sup>

| Generic material | Abrade         | Cut | Tear | Puncture | Heat | Ozone | Flexible |
|------------------|----------------|-----|------|----------|------|-------|----------|
| Butyl            | F <sup>2</sup> | G   | G    | G        | E    | E     | G        |
| CPC              | E              | G   | G    | G        | G    | E     | G        |
| Natural rubber   | E              | E   | E    | E        | F    | P     | E        |
| NBR              | E              | E   | G    | E        | G    | F     | E        |
| Neoprene         | E              | E   | G    | G        | G    | E     | G        |
| Nitrile          | E              | E   | G    | E        | G    | F     | E        |
| Nitrile-PVC      | G              | G   | G    | G        | F    | E     | G        |
| Polyethylene     | F              | F   | F    | P        | F    | F     | G        |
| Polyurethane     | E              | G   | G    | G        | G    | G     | E        |
| PVA              | F              | F   | G    | F        | G    | E     | P        |
| PVC              | G              | P   | G    | G        | P    | E     | F        |
| SBR              | E              | G   | F    | F        | G    | F     | G        |
| Viton            | G              | G   | G    | G        | G    | E     | G        |

<sup>1</sup>Extracted from Guidelines for the Selection of Chemical Protective Clothing, 3rd Edition, Volume I, data Table 8.2 [Shwope et al. 1987].

<sup>2</sup>E = excellent, G = good, F = fair, P = poor. These are general ratings for the generic polymer and could vary significantly for the material in a specific product.

## **Tear**

CPC can fail by snagging and tearing and thus allow direct chemical contact with the skin. Manufacturers can introduce additives and change the degree of polymer cure (cross-link density) to increase resistance to tearing. Some manufacturers measure CPC tear resistance with the use of the ASTM D 624, Standard Test Method for Rubber Property--Tear Resistance. This method allows three different dies to cut the sample, which is then nicked so it will tear from that location. The measurement provided is the force to start the tear (breaking force) when stretched divided by the sample thickness. Other methods include ASTM D 1424, Test Method for Tear Resistance of Woven Fabrics by Falling Pendulum (Elmendorf) Apparatus (replaced FTM 191A 5132, falling pendulum); ASTM D 2261, Test Method for Tearing Strength of Woven Fabrics by the Tongue (Single Rip) Method using CRE Tester (unsupported materials); and ASTM D 2582, Standard Test Method for Puncture Propagation Tear Resistance of Plastic Film and Thin Sheeting.

## **Cut**

CPC can fail when sliced on sharp surfaces allowing chemicals to penetrate easily. No standard test method exists at this time, although the ASTM F23.20 Committee on Protective Clothing, Subcommittee on Physical Hazards, is considering a cut test method which is now being used by some manufacturers and the National Fire Protection Association (NFPA)

## **Puncture**

A hole punched in CPC allows chemicals to penetrate easily and results in skin exposure. Several custom tests are used. NFPA requires a penetration or puncture test for firefighters gloves, a test from a NIOSH report [NIOSH 1977]. Another standard test is the ASTM D 2582 mentioned under TEAR.



## **Strength**

A measure of the strength of CPC is the force required to break a strip by stretching.

ASTM D 412, Standard Test Methods for Rubber Properties in Tension, is used by some manufacturers. It provides data on tensile stress, tensile strength, and ultimate elongation.

For supported materials, the polymer is removed from the backing before testing. Variables in the test include the die used, the orientation of the sample cut from the product, extension rate, temperature, humidity, and sample preconditioning.

## **Abrasion**

Some manufacturers measure how well a product will wear with the use of ASTM D 3389, Test Method for Coated Fabrics Abrasion Resistance (Rotary Platform, Double Headed Abrader). Two different values can be obtained: the number of cycles until the support fabric is exposed and the weight loss after a specified number of cycles. Variables are grit size and condition of the abrasion wheel, weight applied, and number of cycles. Other standard tests used include ASTM D 3884, Test Method for Abrasion Resistance of Textile Fabrics (Rotary Platform, Double Headed Method), and ASTM D 4157, Standard Test Method for Abrasion Resistance of Textile Fabrics (Oscillatory Cylinder or Wyzenbeck Method).

## **Aging**

Material aging is simulated using ASTM D 573, Standard Test Method for Rubber-Deterioration in an Air Oven. Other tests to estimate aging or the effect of storage conditions are ASTM D 865, Standard Test Method for Rubber--Deterioration by Heating in Air (Test Tube Method); ASTM D 1149, Test Method for Rubber Deterioration--Ozone Cracking in a Chamber; NAVY GA 2242C (tension before and after hot water exposure); and custom tests using heat (100° to 200° C for 48 or 72 hours).

## **Flammability**

Standard test methods for flammability include ASTM D 568, Test Method for Rate of Burning and/or Extent and Time of Burning of Flexible Plastics in a Vertical Position, and FTM 191A 5903, Flame Resistance of Cloth; Vertical. The NFPA has draft standards for Vapor (NFPA 19XXA) and Liquid Splash (NFPA 19XXB) Protective Suits for Hazardous Chemical Emergencies. These methods propose the use of a slightly modified FTM 191A 5903.

## **Leakage**

Gloves and fully encapsulating suits can be checked for pinholes and integrity of seams and closures by inflating the product. Pressures used include 0.5 psig for unsupported gloves, 1 psig for supported gloves, and 3 psig for encapsulated suits. Leakage can be measured by a change in pressure with time, immersion in water, or applying a soap solution to the surface. A draft test in the ASTM F23.50 Subcommittee on Ensemble Performance, Committee on Protective Clothing, proposes a leak test of fully encapsulating suits: pressurizing to the maximum allowable pressure (minimum of 3 psig), reducing to the test pressure (2 psig minimum), and checking the pressure after 3 minutes (must be 80% of test pressure). When evaluating the integrity of a Level A (totally encapsulating) suit [EPA 1984], OSHA 29 CFR 1910.120, Appendix A Regulations for Hazardous Waste Operations, require the use of this test or a qualitative test employing ammonia to detect leaks.

## **Cold or Heat Resistance**

Tests used to evaluate performance under cold conditions are ASTM D 1790, Test Method for Brittleness Temperature of Plastic Sheeting by Impact (cold crack), and ASTM D 2136, Test Method for Testing Coated Fabrics- Low-Temperature Bend Test (cold flexibility).

Custom tests such as heat exhaustion with use or degradation after elevated temperatures are used to evaluate the effects of heat. Frequently military contracts describe and require heat and cold tests as part of the purchasing contracts.

## **ERGONOMIC FACTORS**

### **Flexibility**

Flexibility can be estimated from tensile stress measurements determined from the ASTM D 412 method, which is used by many manufacturers in quality control testing. The sample is stretched a specified percentage of its initial length, typically 300% or 500%. A high tensile value means the material is less flexible and could cause more fatigue when using the product. The percentage of elongation is a variable, in addition to those discussed under STRENGTH.

Other tests used include FTM 191 5204, Standard Test Method for Stiffness of Cloth, Directional; Self Weighted Cantilever Method; ASTM D 392, Static Bending Testing of Metallic Bone Plates (radiation gloves); ASTM D 747, Standard Test Method for Apparent Bending Modulus of Plastics by Means of a Cantilever Beam; ASTM D 2097, Test Method for Flex Testing of Finish on Upholstery Leather (Newark flex); and ASTM D 2137, Standard Test Method for Rubber and Rubber Coated Products- Brittleness Temperature by Impact.

To estimate the effect of gloves on performing tasks, apparatus to perform tasks such as placing nuts on bolts are available and used occasionally [Bennett 1981]. Similar tests can be conducted by users performing the expected tasks.

### **Donning and Doffing**

A user may be exposed when doffing exposed CPC or donning previously exposed CPC. Standard tests are not available for measuring the likelihood of this occurrence. The user, however, can design simple tests such as a "crawl" test to determine if a glove can be donned with one hand. The glove is laid on a table to see if it can be donned by sliding the hand into it without use of the other hand. User education in proper procedures is the most effective control against this type of exposure.

### **Comfort and Fit**

Comfort in wearing CPC is important to obtain the workers' compliance in using the product properly. Standard tests do not exist to measure comfort. Subjective user responses are probably the most effective way to rate comfort.

Heat stress from covering large areas with CPC is a recognized problem [White and Hodous 1987]. The work rate, work/rest time ratio, and the environmental conditions—especially temperature—are factors that can contribute to heat stress with full ensembles. The vapor barrier and extra weight of CPC places an additional burden on the body. Another important consideration is that CPC can restrict the range of motion or vision, which may interfere with performing the required task. Proper sizes may not be available in all clothing, and the improper size affects comfort, the shape of the CPC can also affect the task performance; a cupped, hand-shaped left or right hand glove is more comfortable than a flat one for either hand.

## APPENDIX B. SOURCES OF CPC DATA

The addresses of the specific databases discussed are given at the end of this Appendix.

### CHEMICAL RESISTANCE DATA

For several years, manufacturers of CPC have published degradation data that indicate changes in CPC properties. These CPC were rated as "Excellent/Good/Poor/Not Recommended." These ratings were derived by exposing a sample to the chemical and observing (dissolves, discolors, cracks) or measuring (weight, thickness, volume) changes in the CPC. Sometimes the ratings were determined using the generic polymers rather than the final product that may include additives. These subjective data have not been compiled or summarized in this document.

Chemical resistance data have been published in technical journals (such as the American Industrial Hygiene Journal and Applied Industrial Hygiene), government reports (usually available from NTIS), and manufacturer's product brochures. Approximately 500 pure chemicals and 100 chemical mixtures have been published, mostly from testing gloves. Very few are from testing footwear. Data for fully encapsulated suits are for the suit material only and do not include closures/seams and other exposed components such as visors and exhalation valves. These published data have been compiled by two sources and presented in common formats. The two sources are:

1. Arthur D. Little compiled information for the Environmental Protection Agency (EPA, Edison) and U. S. Coast Guard.
  - a. Guidelines for the Selection of Chemical Protective Clothing, 3rd. Edition, is available from NTIS (report numbers AD A179 516 and AD A179 164) and from ACGIH (publication No. 0460). EPA anticipates the 4th. edition will be available in 1990.

In addition to permeation data, some degradation data (quantified volume and weight change) are included in the guidelines. The guidelines also contains information that is not compiled elsewhere such as names and addresses of suppliers, fully encapsulated suit specifications and levels of protection definitions. Locating specific information is sometimes difficult; codes are used to link information over many data tables and are not always conveniently sorted; a cross reference chart for the specific pieces of data in each data table is not provided. The chemical resistance tables for generic materials are summarized for specific chemicals and chemical classes based on the quantity and consistency of the data. The data are current through February, 1987.

- b. CPCbase® is a computer program for IBM® PC and compatible computers. The data are accessed through a "run time" version of DataFlex, a database application development software. With the custom menu provided, programing and software knowledge are not required. Data are searched and reported by specific pure chemical; chemical mixture data are not included. Additional data can be entered in supplemental files. The can be exported as several relational files in a form usable by other database software such as dBASE®. The manufacturer and address of the product tested and references are provided in a complete well-formatted printed report. The data was current through early 1988. Release 3 is expected in 1990.
  - c. A pilot version of the Guidelines is being tested as an on-line system using an EPA (Washington, D.C.) mainframe computer. Telephone access is through an EPA computer account. The data are current through early 1989.
2. Krister Forsberg (Royal Institute of Technology) has compiled a Swedish permeation database on a Mackintosh® computer using a word processor.
    - a. An English version of Forsberg's Chemical Protective Clothing Performance Index is

available for the IBM PC and compatible computers from Instant Reference Sources. An IBM PC or compatible computer (with 640 K internal memory, DOS 2.0 or later, and 2 floppy drives a hard disk is recommended) are required to run this and GlovES+ described below. The index is also supplied by American Congress of Governmental Hygienist (ACGIH), The National Safety Council, American Chemical Society (ACS), and several commercial safety equipment distributors.

ZenWord®, an ASCII® word processor, is provided in the index. While the copyrighted data is provided in a ASCII file, it is in a form not readily usable by other nonword-processing software such as dBASE. Because ZenWord® operates on documents that are totally contained in a maximum usable 640 kilobytes of computer memory (RAM), data searches can require loading (a slow process) of several files to obtain desired information. Knowledge of the chemical classification system that is used and which data is stored in the various files is effective in reducing searching time. The database contains some data on chemical mixtures and provides the model and manufacturer of the specific product tested. Chemical Abstract Services (CAS) numbers are not usually included for components of a mixture. Searches may be made for any character string (including a material) but printing the selected information in report format is difficult. Product manufacturer address, telephone, and contact persons are provided in a tutorial accompanying the database. The data are current through early 1990.

- b. GlovES +® is an IBM and compatible computer program provided free with Performance Index. It was developed by Radian for the National Toxicology Program (NTP) using Rulemaster® software to produce a "run time" program. Defined rules were applied to the pure chemical data from the Performance Index to provide data applicable to specific situations. The output of this report is filtered using task criteria and chemical toxicology ratings. Therefore, data on products that would not meet the specified situation requirements is not presented; these data would be useful in identifying inappropriate

products. The data are current through 1989.

- c. HyperCPC® Stacks is a computer program equivalent to those described in a and b above for Macintosh computers. A Macintosh Plus, SE, Portable, or Macintosh II computer, HyperCard version 1.2 or greater, and a hard drive are required. The HyperCard stacks system allows more effective searching and reporting than the PC version. The data was updated in 1990 and future updates are planned.
- d. The printed version of the Chemical Protective Clothing Performance Index is published by John Wiley and Sons. The data are current through 1988.
- e. An English version of the Quick Selection Guide to Chemical Protective Clothing is a simple, pocket-size summary of 11 generic CPC materials tested against 420 chemicals. The permeation data are a color-coded rating system and include health risk information on the chemicals. This guide is published by Van Nostrand Reinhold. The data are current through 1989.

#### **PHYSICAL RESISTANCE AND ERGONOMIC FACTORS DATA**

Physical resistance data and ergonomic factors are seldom published. These data are sometimes available from the manufacturers and suppliers upon request. Physical resistance data and ergonomic factors have not been compiled or summarized for specific products.

#### **OTHER NIOSH INFORMATION**

NIOSH has several publications listed below that could be useful in selecting CPC in hazardous chemical spill incidents (HAZMAT) and chemical waste dump cleanups. These three publications suggest using the Guidelines for the Selection of Chemical Protective Clothing (Item 1. above) to select the proper garment. If the chemical or the chemical class is unknown, a butyl suit is recommended. A suit of Viton® is recommended in situations where butyl is known to fail based upon chemical



degradation (not permeation) data available in 1986. Most failure situations can be identified using a suggested Draeger® gas detector tube chemical class identification scheme. These NIOSH publications, based on degradation data available in 1984, preceded the introduction of new suit materials such as the Chemfab Challenge® and Chemron Chemrel®.

The user should be aware that the recommended suits are selected on the basis that they are not known to fail; this does not guarantee that they will provide adequate protection in all exposure incidents.

1. **Personal Protective Equipment for Hazardous Materials Incidents: A Selection Guide.** Available from NTIS (PB 85-222 230) and ACGIH (Publication Number 0860).
2. **A Hazardous Waste Supplement to Personal Protective Equipment for Hazardous Materials Incidents: A Selection Guide.** Available from NTIS (PB 86-130 697).
3. **Selection Program for Personal Protective Equipment for Hazardous Material Incidents** (5.25" 360K floppy disk for the IBM PC or clone).

## **SOURCES OF CPC PRODUCTS**

Locating sources to purchase CPC for evaluation and use is sometimes difficult even though the product is identified. In addition to the above sources, a compiled database of CPC suppliers in the United States is available from the EPA, Washington, DC. The EPA database, **Personal Protective Equipment for Pesticide Applicators: A Guide to Sources**, was developed from contacting safety equipment suppliers for the personal protective clothing and equipment (respirators) they supplied. The data were updated through early 1988.

NIOSH also compiled bibliographies on protective equipment that could be useful to those selecting CPC:

1. A computerized listing of references is available on an IBM PC and compatible computers. This contains about 100 references to permeation of the skin and CPC material. The complete database references about 7500 articles in categories of decontamination, fire, suit physiology, water spray for HAZMAT, contact lens, confined spaces, emergency (for firefighters), films, and training. The original database used SAVVY® database software which is no longer commercially available. The data files can be converted to Sci-Mate,® software similar to SAVVY.® The database is available on PC disks without SAVVY® or Sci-Mate.® Specific searches and printouts can be requested.
2. A Selected Bibliography for HAZMAT Responders is available from the NIOSH library. HAZMAT refers to hazardous materials spill incidents. This is current through 1988.

## OTHER CPC ORGANIZATIONS

Several groups are active in studying, developing, and using CPC:

1. In 1977, the American Society for Testing and Materials (ASTM) formed the F23 Committee on Protective Clothing for the purpose of developing standard testing methods, specifications, and practices for CPC. The committee meets twice a year and has sponsored three international symposia on protective clothing. Test methods published or under development include virtually all phases of CPC usage. The committee also works in the area of heat protection.
2. The American Industrial Hygiene Association (AIHA) Personal Protective Clothing and Equipment Committee meets twice a year (once at the AIHC), and has developed a textbook Chemical Protective Clothing that is used for a one-day personal development course, Chemical Protective Clothing. The committee also sponsors a presentation session at the American Industrial Hygiene Conference (AIHC) on protective equipment and clothing. The AIHA also sponsors a 3-day chemical protective clothing workshop several times a year around the country.
3. The National Fire Protection Association (NFPA) formed a subcommittee on Hazardous Chemical Protective Clothing in 1986 under the Technical Committee on Protective Equipment for Firefighters. The committee meets several times a year to develop manufacturing specification standards for chemical protective suits worn by emergency response personnel. NFPA 1991, standard on Vapor-Protective suits for Hazardous Chemical Emergencies and NFPA 1992, Standard on Liquid Splash Suits for Hazardous Chemical Emergencies, and NFPA 1993, Standard on Single Use Splash-

Protective Suits for Non-flammable Hazardous Chemical situations, have been adopted. Other standards are being developed for gloves and boots against chemicals and CPC against biological agents in liquids.

4. The Federal Interagency Work Group was established in 1986 to coordinate federally funded CPC research projects. The organizations that are active in this working group are the U.S. Coast Guard, U.S. Environmental Protection Agency (EPA), U.S. Fire Administration, National Institute for Occupational Safety and Health (NIOSH), Occupational Safety and Health Administration (OSHA), and Department of Energy/Los Alamos National Laboratory. This group maintains a mailing list of those persons interested in federally funded research on CPC. The group publishes a bulletin that contains information on CPC research, training, meetings, and notes. The group also publishes a document entitled "Federal Research on Chemical Protective Clothing and Equipment," that summarizes the research of each organization. This annual summary report is also available from NTIS.
5. The Federal Emergency Management Agency (FEMA) sponsors satellite television conferences for firefighters. Many of these conferences have been about CPC. Viewers are encouraged to videotape and distribute the conferences. Videotapes (Beta, VHS, and 3/4") and transcripts of past conferences are available.
6. The National Toxicology Program (NTP) recommends gloves for use in their national repository laboratories which deal with very toxic, restricted chemicals.

## ADDRESSES

American Chemical Society  
Distribution Office  
Department 25  
P.O. Box 57136  
West End Station  
Washington, DC 20037  
800-227-5558

American Congress of Governmental Industrial Hygienists  
Building D-7  
6500 Glenway Avenue  
Cincinnati, OH 45211-4438  
513-661-7881

American Industrial Hygiene Association  
475 Wolf Ledges Parkway  
Akron, OH 44311-7294  
216-762-7294

American Society for Testing and Materials  
1916 Race Street  
Philadelphia, PA 19103  
215-299-5490

Arthur D. Little, Inc.  
Center for Protective Clothing  
15/224 Acorn Park  
Cambridge, MA 02140  
617-864-5770

EPA/RREL/STDD (MS-104)  
Release Control Branch  
Woodbridge Avenue  
Edison, NJ 08837.  
201-321-6626 (FTS: 340-6626)

EPA  
401 M Street, SW  
Washington, DC 204602  
202-556-7410

Genium Publishing  
1145 Catalyn  
Schenectady, NY 12303  
518-377-8855

Federal Emergency Management Agency  
Emergency Education Network  
National Emergency Training Center  
K-009  
Emmitsburg, MD 21727  
301-447-1068

Instant Reference Sources, Inc.  
7605 Rockpoint Drive  
Austin, TX 78731  
512-345-5267

John Wiley and Sons, Inc.  
605 Third Avenue  
New York, NY 10158-0012  
212-850-2499

National Fire Protection Association  
Battery March Park  
Quincy, MA 02269  
617-770-3000

National Institute for Occupational Safety and Health  
Division of Safety Research  
944 Chestnut Ridge Road  
Morgantown, WV 26505-2888  
304-291-4595

National Toxicology Program  
Box 12233  
Research Triangle Park, NC 27709  
919-541-3355 (FTS: 629-3395)

National Safety Council  
444 N. Michigan Avenue  
Chicago, IL 60611-3391  
312-527-4800

National Technical Information Service  
Department of Commerce  
5285 Port Royal Road  
Springfield, VA 22161  
703-487-4600

Occupational Safety and Health Administration  
Department of Labor  
Room N-3651  
200 Constitution Avenue  
Washington, DC 20210  
202-523-7065

Radian Corporation  
P.O. Box 201088  
Austin TX 78720-1088  
512-454-4797

Royal Institute of Technology  
Department of Work Sciences  
S100 44 Stockholm  
Sweden

Van Nostrand Reinhold  
Mail Order Department  
P.O. Box 668  
Florence, KY 41022-0668  
606-525-6600





## APPENDIX C

### 1. A SIMPLIFIED TEST METHOD FOR MEASURING BREAKTHROUGH OF VOLATILE CHEMICALS THROUGH CHEMICAL PROTECTIVE CLOTHING

Michael Roder\* and Rotha Hall\*

#### INTRODUCTION

A consensus test method, the ASTM F 739, Standard Test Method for Resistance of Protective Clothing Materials to Permeation by Liquids or Gases [ASTM 1985], will provide those selecting chemical protective clothing (CPC) with an estimate of the length of time a garment will protect the worker. Because of the complexities necessary to perform this test, a simplified procedure has been developed and evaluated in the laboratory.

#### LIMITATIONS

This method has several limitations:

1. It provides a measure of the breakthrough time only and depends only on the qualitative nature of the detector tubes.

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\*Protective Equipment Section, Injury Prevention Research Branch, Division of Safety Research, National Institute for Occupational Safety and Health, December 4, 1987.

2. The chemical detected must be volatile and must provide a visible indication on the detector tube used.
3. The detector tube must be sensitive enough to detect the chemical at breakthrough.

## EQUIPMENT

1. The garments being evaluated. Samples should be taken from relatively flat areas representative of the part that will contact the chemical. For gloves, the palm and back are suggested.
2. A sample of the chemical mixture.
3. Permeation test cells. The ASTM F 739 test cell and AMK test cells were used with equal success. Other cells with more than  $3/4$  in<sup>2</sup> of the specimen exposed should perform adequately. A 50- or 100-cc syringe is suggested for introducing the chemical into the test cell.
4. Detector tubes. The Draeger Polytest tube, model CH 28401, was evaluated and appears to be sensitive enough to detect many hydrocarbons. It is based on a generalized iodine pentoxide reaction. Other gas detector tube manufacturers provide similar tubes.
5. A timer. One timer is adequate if concurrent cells are started together or the start time is noted for each. Time to the nearest minute is sufficient for most applications.
6. A pressurized source of collection gas, pure air, or nitrogen. If a pressurized source is unavailable, an air pump capable of pulling 100 to 500 cc/min is required. Some means of regulating the flow is required; Tylan mass flow controllers were used in these evaluations.

## PROCEDURE

1. Check the sensitivity. To determine if the analyzer will react, break the ends off the detector tube and draw a sample of gas through the tube from the head space over a sample of the liquid chemical mixture. For a gaseous challenge chemical, force a few liters through the tube. The flow rate is not critical. A vacuum source or a gas detector tube pump will work. If no visible reaction occurs, this test cannot be used. Note the initial color change in the tube. Sometimes the discoloration is very faint. It helps to compare the tube to an unexposed one.

To check if the detector tube is sensitive enough to detect breakthrough, inject a volume of the chemical into the collection stream of gas before it enters the tube at the flow rate to be used for sampling, typically 500 to 1000 cc/min. A suggested volume is:

$$V = \frac{1.5 \times EL \times A_c}{d \times A_g} \quad \text{where:}$$

V =  $\mu$ L of the liquid chemical to inject

EL = exposure limit (e.g., REL, PEL, TLV) in mg/m<sup>3</sup>

d = density of the chemical in g/mL

A<sub>c</sub> = material area exposed in the test cell in cm<sup>2</sup>

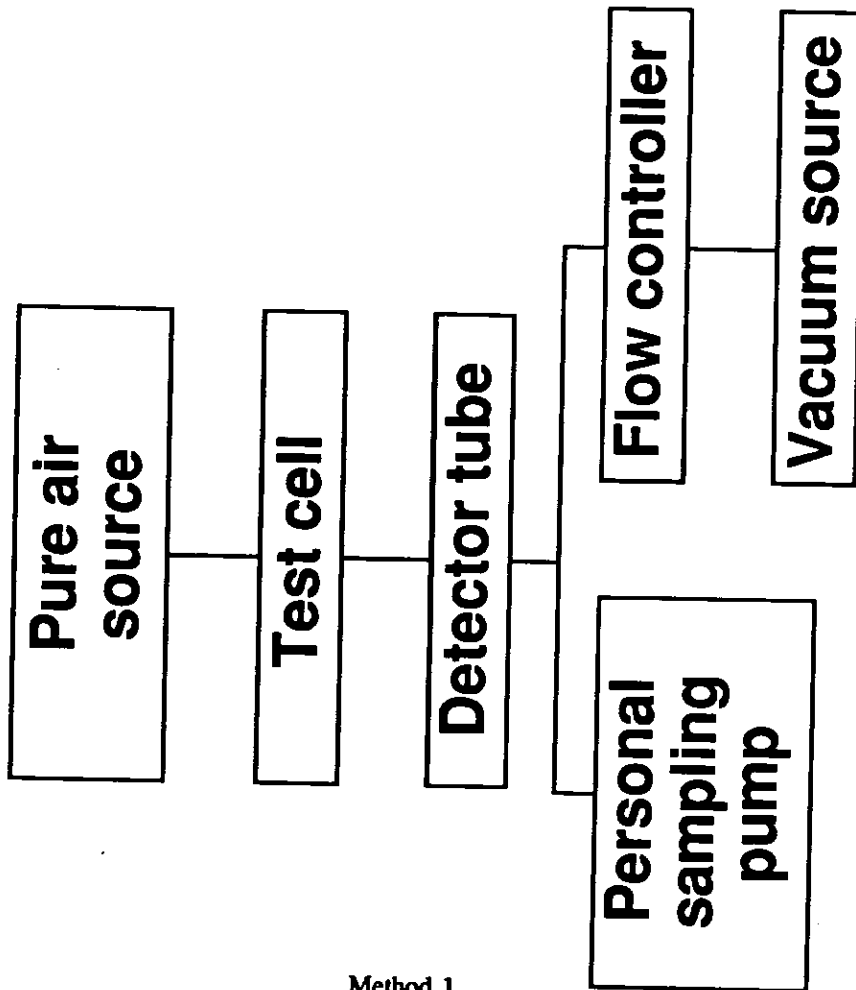
A<sub>g</sub> = expected exposed area of the garment (a hand would be about 350 cm<sup>2</sup>).

2. Assemble the test cells. Because of variability in the permeation test, the test should be run in triplicate. Since determining the breakthrough time to the nearest minute is adequate to compare different products, one person can observe several simultaneous tests. An assembled test cell without addition of the chemical challenge should be run as a blank. Contamination in the air source used or off gassing from the material being tested may cause an indication on the gas

detector tube. Generally, the time significant breakthrough occurs can be detected by comparing the test sample with the blank.

3. Set the air or vacuum source to 500 to 1000 cc/min. All of the cells should have approximately the same collection flow rate.
4. Break the ends from the detector tube and connect it to the test cell in the order in Figure C1. Flow through the gas detector tube can be reversed for a second sample if the entire reaction bed has not been discolored. Compare it with an unexposed tube since the discoloration may be very faint.
5. Using the large syringe, charge enough of the liquid challenge chemical to cover the material sample. Immediately start the timer or note the starting time.
6. Monitor the tube to determine when the discoloration occurs. If an unused tube is used for comparison, the fainter stains may be detected more easily. Because of the sensitivity of the Draeger Polytest tube, a narrow band of light gray, green, or tan may develop very early in the test. It does not increase in size or change color. This is probably contamination and should not be considered breakthrough. Contamination could be in the air source or outgassing from the material sample. Usually at breakthrough, the stain will deepen to a dark brown, green, or purple color and rapidly begin to lengthen.
7. Record the time that breakthrough occurs.

## Vacuum System



## Pressure System

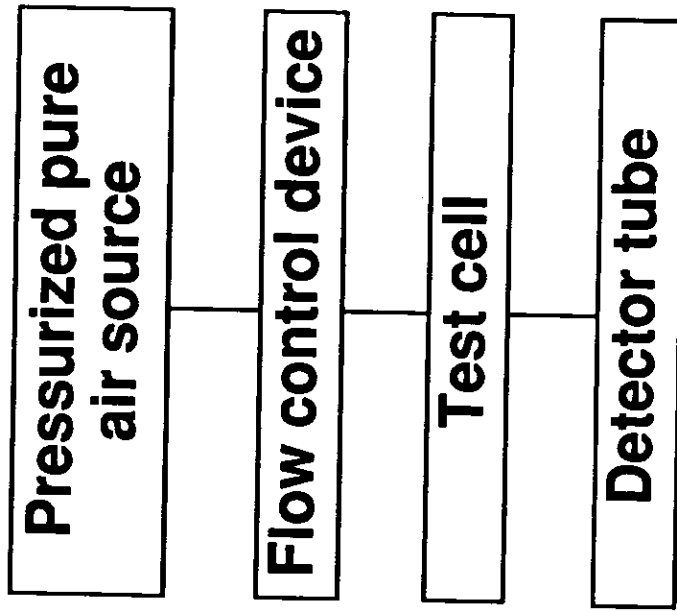


Figure C1. Detector tube testing setups.

## 2. ASI-052.1 PERMEATION FIELD TEST METHOD USING A FINGER COT OF A GLOVE

R.L. Mickelsen\* and M.M. Roder\*

### INTRODUCTION

This test method can be used in the field to supplement laboratory testing of chemical protective clothing (CPC) for evaluating breakthrough times when exposed to a constant liquid hazard.

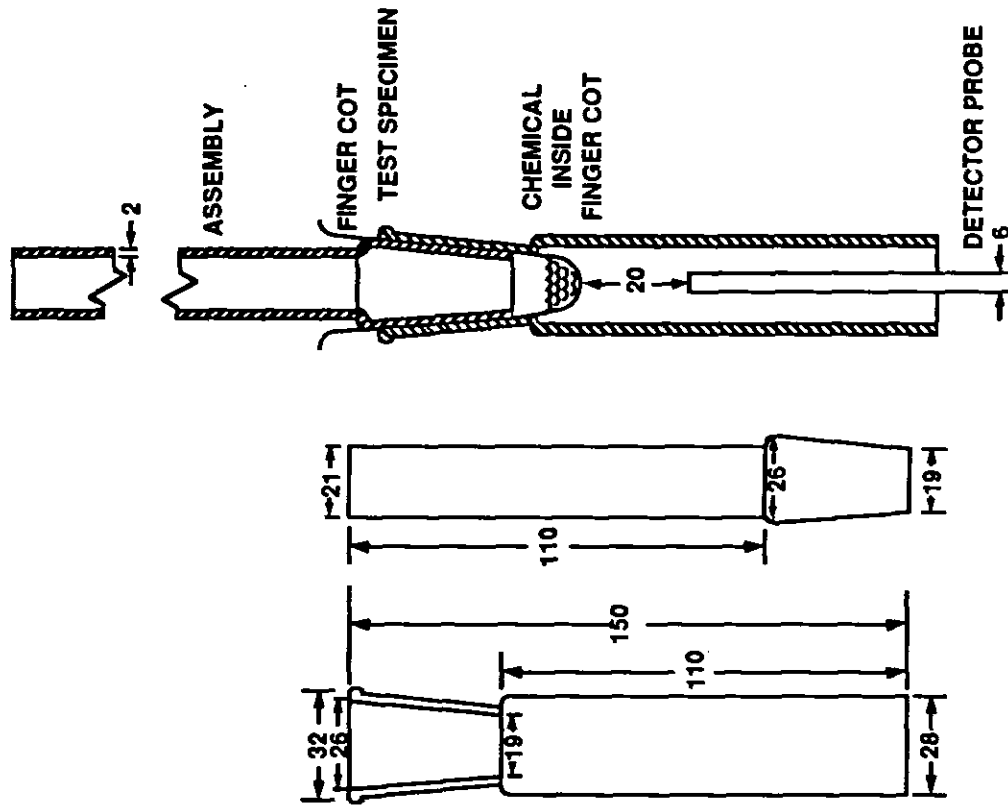
### EQUIPMENT

The two pieces of commercially available equipment shown in Figure C2 provided the test cells; other readily available equipment completed the system used.

- Standard taper outer joint; Pyrex, No. 24/40, length 150 mm (Corning 6580)
- Standard taper inner joint No. 24/40
- Detector; H-NU Photoionization, PI-101, or other direct-reading instrument
- Ring stand
- 2 clamps
- Chart recorder (optional)
- Timer
- 50-ml beaker
- Micrometer

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\*Protective Equipment Section, Injury Prevention Research Branch, Division of Safety Research, National Institute for Occupational Safety and Health, March 1985.



**Figure C2. Finger cot permeation test cell. All measurements are in mm; glove material thickness can vary from 0.001 to 1.0 mm; and standard glass taper is 24/40.**

## PROCEDURE

Check the detector manual to ensure that it will respond to the chemical in question. Place 1 ml of the liquid in question into a 50-ml beaker. Using the detector, sample the vapor near the top of the beaker. If a response is detected, you may proceed. If there is no response (a) a different detection method must be used or (b) the chemical is not volatile enough. Another detector may be tried or the test discontinued.

Cut the finger (approximately 5 cm long) from a glove used by workers handling the chemical in question. Using the micrometer, take 10 thickness measurements at different locations on the finger (Fed. Std. No. 191, Method 5030.2, Measurement of the Thickness of Materials). Turn the finger inside out. Place the open end of the finger onto the ground glass of the inner joint; then place the finger/inner joint into the outer joint (see Figure C1). Mount the assembly vertically, outer joint on bottom, onto the ring stand. Place the detector probe into the bottom of the assembly approximately 2 cm from the tip of the finger. Zero the detector, add 1 ml of chemical into the top of the assembly and monitor the response versus time. Record the elapsed time from the addition of chemical until the first detector response to permeating chemical.

Depending on your choice of detectors, makeup air may come in the bottom of the assembly. Care must be taken so that no contaminants enter during the test. It is recommended that fresh makeup air be provided to the bottom of the assembly at a rate greater than or equivalent to that used by the detector.

Run the test until the chemical is detected or a prespecified time has elapsed with no chemical breakthrough.

## EXPERIMENTAL RESULTS

Repetitive samples of a commercially available gloves were tested (Table C1). The mean thickness is an average of 10 measurements on the finger cot sample.



In Figure C3, the breakthrough time appears to vary with sample thickness. The 0.85 R Squared in Table C1 indicates a strong correlation of breakthrough time with thickness. A 17% coefficient of variation (COV) was calculated for the breakthrough time; if the first point is rejected, this is reduced to a 11% COV. This is comparable to the 15% COV normally found with the ASTM F 739, Standard permeation test method for neoprene-acetone system [ASTM 1985].

Table C1. Results from 10 test runs of breakthrough times using an H-NU PI-101 PID detector. Edmont 29-870 Neoprene inverted thumb cots were tested; Fisher Acetone (99% pure), Lot 724057, was the chemical employed.

| Run | Mean Thickness (mm) | Breakthrough time (mm) |
|-----|---------------------|------------------------|
| 1   | 0.473               | 8.2                    |
| 2   | 0.496               | 16.0                   |
| 3   | 0.431               | 12.4                   |
| 4   | 0.452               | 13.2                   |
| 5   | 0.517               | 15.7                   |
| 6   | 0.415               | 12.2                   |
| 7   | 0.443               | 12.4                   |
| 8   | 0.422               | 11.7                   |
| 9   | 0.448               | 14.5                   |
| 10  | 0.434               | 12.3                   |
| EOV | 8%                  | 17%(12%)*              |

\* Excluding Run 1

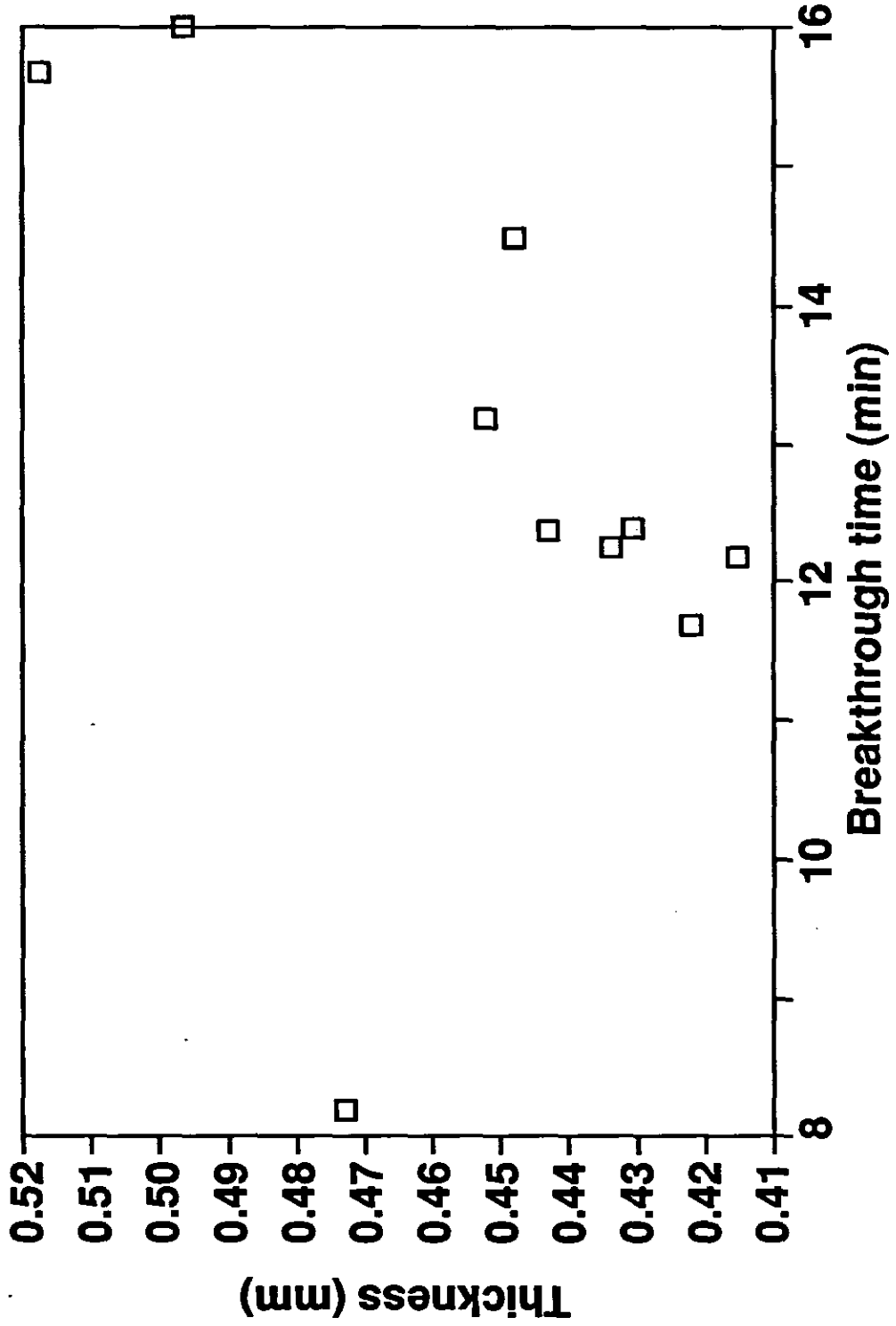


Figure C3. Variation in breakthrough time due to thickness.

## CONCLUSIONS

This is a relatively simple method that employs easily obtained equipment to provide a rough estimate of the time it would take a chemical to break through gloves actually being used. For gloves manufactured by the same process, the relative breakthrough should be useful. The following precautions should, however, be considered in using the data.

1. The finger of a glove may not be representative of the entire glove performance. Because of the manufacturing dipping process, the fingers are one of the thickest parts and indicate a longer breakthrough time than would actually occur in practice [Berardinelli 1985]. The fingers could also provide a greater variation in the results because of variations in thickness.
2. Since ambient air is drawn into the sampling side of the cell, outside air contamination could provide a short, false breakthrough time. If possible, clean makeup air should be provided to the collection side of the cell at a rate near to the analyzer sampling rate.

### 3. FIRST APPROXIMATIONS: CHEMICAL RESISTANCE TEST METHODS

S.P. Berardinelli, Ph.D.\*

With the use of several different testing methods adapted for nonlaboratory situations, three different approaches were developed to rank candidate CPC products: test methods for degradation, penetration, and permeation. The permeation methods can be applied to a liquid chemical with a vapor pressure of 10 torr or above or a vapor pressure below 10 torr or to a gas or vapor. These procedures were evaluated in the field.

#### a. TEST METHOD FOR RESISTANCE OF PROTECTIVE CLOTHING MATERIAL TO DEGRADATION BY LIQUID CHEMICALS

##### INTRODUCTION

The resistance of protective clothing to chemical degradation can be evaluated by an easily performed, inexpensive test method. This test method determines the resistance of protective clothing materials to degradation by liquid chemicals under the condition of continuous liquid contact. One side of the fabric is exposed to a challenge liquid for a known period of time. At the end of this known time, changes are noted in visual appearance, thickness, and weight of specimens of the clothing material. This test, therefore, is a measure of chemical compatibility between a challenge liquid and fabric. Chemical degradation data do not indicate chemical penetration or permeation. This test method aids in the selection of candidate materials for further testing, i.e., penetration and permeation testing. The chemical degradation test method is a modified version of the ASTM F23.30.03 Committee draft standard test method under consideration in 1984.

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\*Protective Equipment Section, Injury Prevention Research Branch, Division of Safety Research, National Institute for Occupational Safety and Health, 1

## EQUIPMENT

The chemical degradation tests apparatus is constructed from two rectangular polyethylene plates that hold the test specimen in the glass test cells (Figure C4). Three test specimens can be evaluated simultaneously. The test apparatus can be purchased from Radian Corporation, 8501 Mo-Pac Blvd., Austin, TX 78766.

## PROCEDURE

The following procedure is used to identify changes in appearance, and to measure changes in weight and thickness of material specimens after contact by a liquid chemical.

1. Use material specimens with a minimum dimension of 64 mm (2.5 in.). A 70-mm square is convenient.
2. Measure the thickness of each specimen at the 3, 6, 9, 12 o'clock, and center positions to the nearest 0.01 mm (or nearest 0.001 in.) and record. Compute the mean.
3. Weigh the specimen to the nearest 1.0 mg and record.
4. Mount the specimens in the test cell and assemble (refer to Figure C4).
5. Quickly, but carefully, charge the liquid chemical into the test cell and begin timing the test. Cover the test cell with a watch glass.

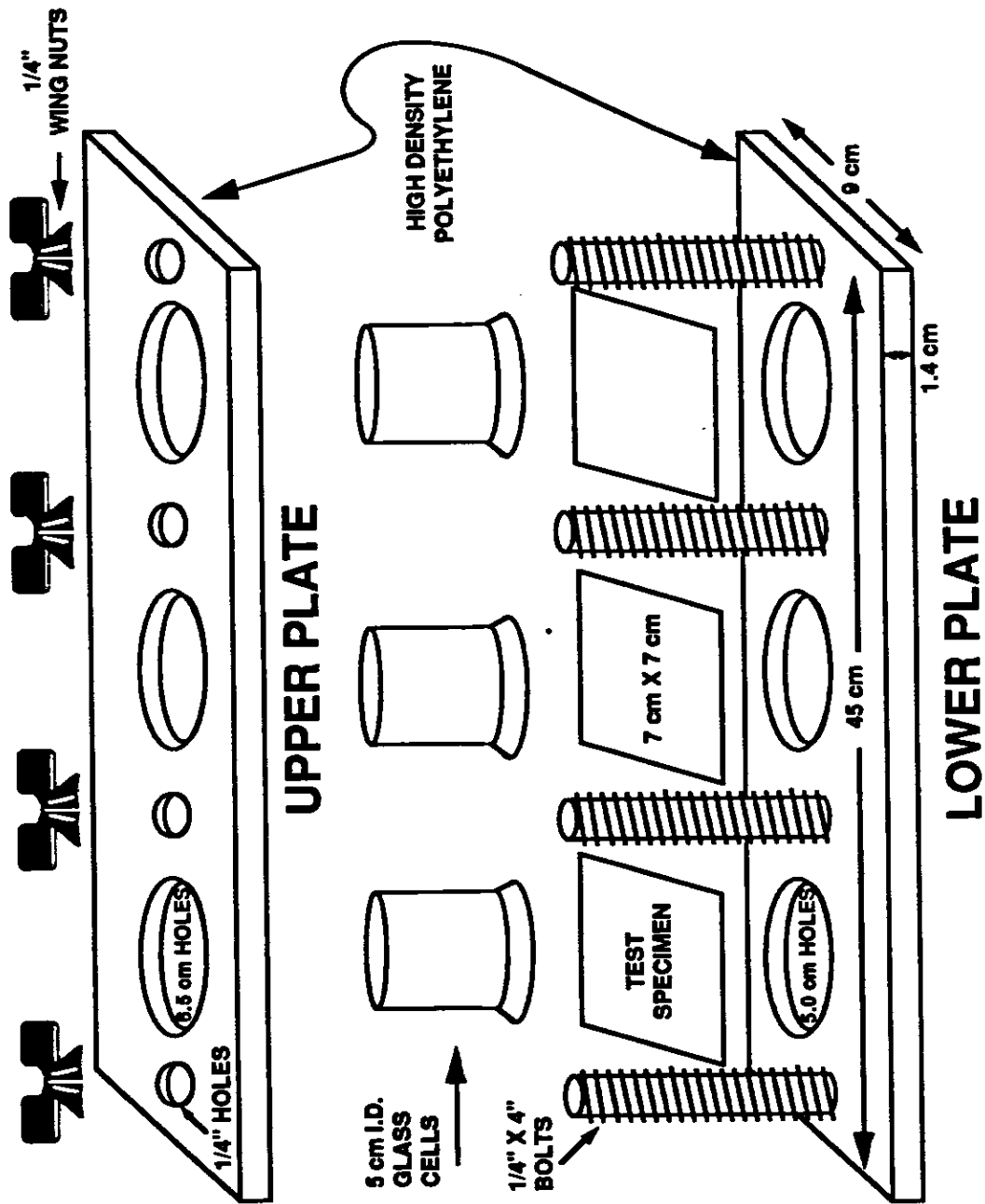


Figure C4. Chemical degradation test apparatus.

6. Record the appearance of the material specimen at 5 min, 30 min, 1 hr, and 4 hr.
7. End the test after 4 hr. The test may be ended at less than 4 hr if the specimen shows visible signs of disintegration.
8. On removal of the material specimen from the test cell, pat the tested specimen dry with a paper towel to remove excess liquid chemical. Record the appearance of the specimen and note discoloration, swelling, wrinkling, cracking, delamination, disintegration, or other changes. Quickly reweigh and remeasure thickness. Then flex the tested specimen by hand and compare changes in the specimen, such as tearing and cracking, with the condition of an untested, flexed specimen.

**NOTE:** Some chemicals, such as acids, may damage the balance or the thickness gauge. A weighing bottle or piece of plastic is used to protect the balance. Two pieces of plastic with the exposed specimen sandwiched in the middle are used to protect the thickness gauge. Be sure to subtract the extra weight due to the bottle or plastic from the total weight. Similarly, be sure to subtract the thickness of the two plastics from the total thickness determination.

9. After the first test run, disassemble the test cell, thoroughly clean it, and prepare for another test.
10. Test a minimum of three specimens.
11. Record the test temperature (ambient temperature).

## **REPORT**

For each protective clothing material tested, prepare a report that describes:

1. the liquid chemical used;

2. the garment material manufacturer, stock number, lot number, and generic chemical composition;
3. the mean thickness of the specimens to the nearest 0.01 mm (or the nearest 0.001 in.);
4. the mean weight or mean thickness change.

Describe visual changes in appearance in subjective terms (e.g., bleached, swollen, disintegrated), and rate the performance of each specimen using the following scale.

| <u>Rate the material</u> | <u>Visual changes in sample after</u> |
|--------------------------|---------------------------------------|
| 1                        | 5 min                                 |
| 2                        | 30 min                                |
| 3                        | 1 hr                                  |
| 4                        | 4 hr                                  |

Chemical protective materials that receive a 1 or 2 rating or exhibit more than 20% weight or thickness change are considered unacceptable; no further testing is warranted.

**b. TEST METHOD FOR RESISTANCE OF PROTECTIVE CLOTHING TO PENETRATION BY LIQUID CHEMICALS**

**INTRODUCTION**

The test method for resistance to chemical penetration by protective clothing is a modified version of the ASTM F23 Committee F 903 standard test method [ASTM 1984; Berardinelli and Cottingham 1986]. Test specimens without discontinuities should be evaluated for quality assurance (e.g. pinholes). Discontinuities such as zippers and seams, should be tested as well, to evaluate their penetration resistance.



The resistance of a protective clothing material to penetration by a liquid is determined by the penetration of visible liquid through the material when a specimen is subjected to the liquid under atmospheric pressure and then at a specified pressure of 13.8 kPa (2 psig).

## EQUIPMENT

The test system uses a test cell where a liquid contacts the specimen, under pressure, on the specimen's normal outside surface. It has a viewing port on the specimen's normal inside surface. Details of the test cell are shown in Figure C5. Two possible sources for this test system are the Wilson Road Machine Shop, 1170 Wilson Rd., Rising Sun, MD 21911, and the Kent Machine Co., 4445 Allen Road, Stow, OH 44224.

## PROCEDURE

1. Use material specimens with a minimum dimension of 64 mm (2.5 in.). A 70-mm square is convenient.
2. Measure the appropriate thickness of each test specimen at the 3, 6, 9, 12 o'clock, and center positions to the nearest 0.01 mm (or nearest 0.001 in.) and record. Record each reading and include the site from which measurement was made (zipper, zipper fabric, seam, fabric beside seam, etc.). Compute the mean.
3. Place a 10- $\mu$ L droplet of the test liquid on the normal inside surface of a specimen of the material to be tested. The droplet must be easily visible to ensure that a droplet that penetrates the material will be detected. If the droplet is not visible, the following method of enhancing droplet visibility has usually been effective: for water soluble chemicals, use food coloring or an acid-base indicator, such as methyl orange; for organic liquids, Oil Red EGN is recommended. Oil Red EGN is available from various sources, one of which is Matheson, Coleman and Bell, Cincinnati, OH. The test specimen used in this step is discarded. This visible test need only be conducted once for each material.

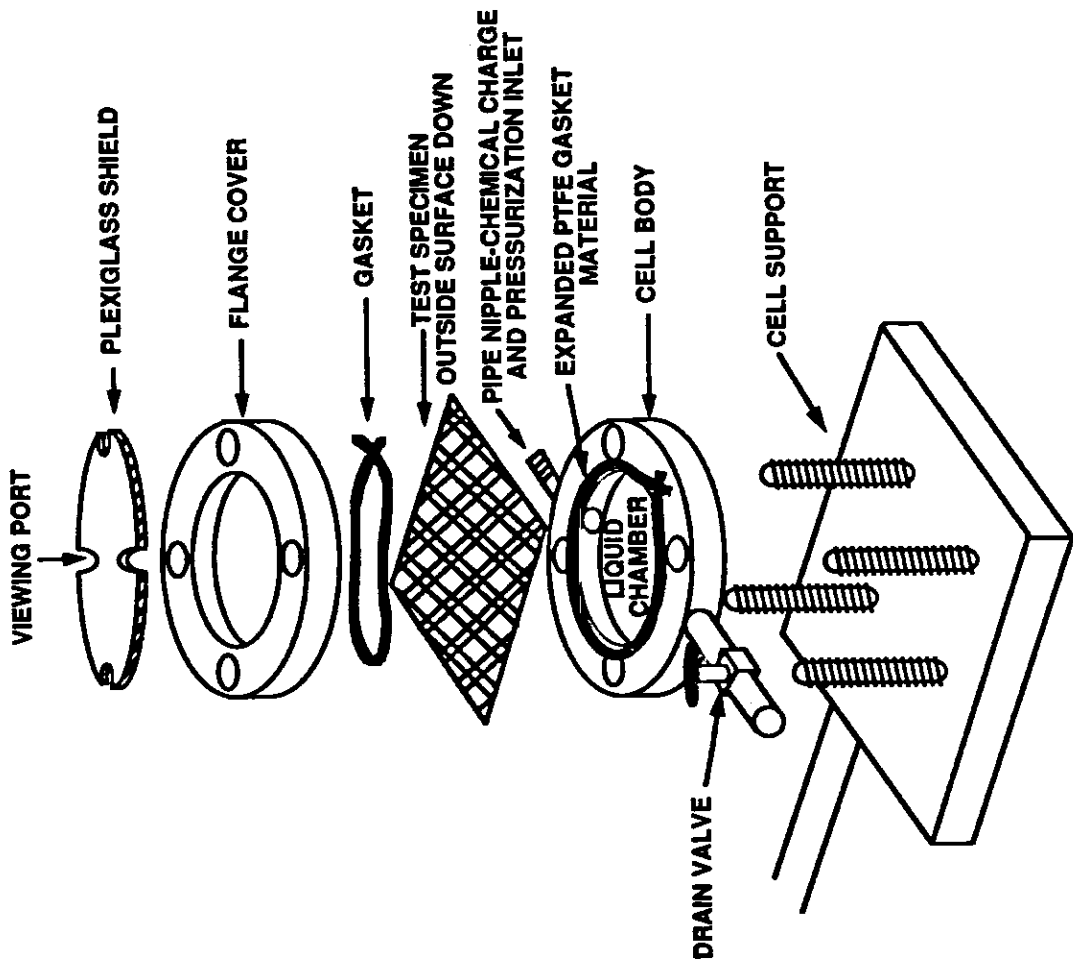


Figure C5. Chemical penetration test cell.

4. Mount the specimen in the test cell and assemble it as shown in Figure C5. Coat the entire specimen's viewed surface with the recommended dye, if necessary, as determined by Step 3. A small brush is used to apply the dye.
5. Remove the male air line connector from the pipe nipple on the test cell. Carefully charge the liquid into the chamber of the test cell allowing air to vent. A funnel or a large syringe (50 or 100 ml) may be useful.
6. Screw on the air line connector, and connect it to the pressure regulator on the air cylinder making sure the valve is in the vent position.
7. Set the pressure regulator to 0 kPa (0 psig) pressure, and close the cell vent valve.
8. Wait 5 min, and then apply the test pressure of 13.8 kPa (2 psig) at the rate of no more than 6.9 kPa/sec (1 psig/sec).
9. Hold the 13.8 kPa (2 psig) constant (within 1.38 kPa), and monitor the viewed surface of the material specimen for the appearance of liquid.
10. Terminate the test at the appearance of liquid, or the appearance of discoloration, or 10 minutes after pressure has been applied, whichever comes first.
11. At the conclusion of the test, relieve the test pressure and drain the test fixture. Flush the fixture with an appropriate wash liquid to remove or render harmless any traces of the liquid. Remove the specimen from the cell and discard it and the used gasket. Clean any external parts of the test cell that may have been touched by the liquid.
12. Test a minimum of three specimens.

## REPORT

For each protective clothing material specimen tested, prepare a report that describes:

1. the manufacturer, stock number, lot number, and the generic chemical composition of the material tested;
2. the type of discontinuity tested and its position on the garment;
3. the mean thickness to 0.01 mm;
4. the challenge liquid used;
5. the temperature at which the test was performed; and
6. the type, composition, and application procedure of the dye indicator (if used).

The penetration test results should be reported as pass or fail. Specimens leaking within the 5-min period before pressure is applied shall be reported as failing during atmospheric testing. Specimens that leak during the pressure test shall be reported as failing during pressure testing. The specimen must pass both atmospheric and pressure tests to be acceptable.

- c. **TEST METHOD FOR RESISTANCE OF PROTECTIVE CLOTHING MATERIALS TO PERMEATION BY LIQUID CHEMICALS**

## INTRODUCTION

The chemical permeation field test method is the most complicated of these three tests to rank candidate CPC. In the permeation test apparatus, the clothing material acts as a barrier separating the liquid chemical from an air stream that sweeps the permeating chemical vapor to a detector for measurement. The collecting medium, which is air, is sampled and analyzed quantitatively to measure the concentration of challenge chemical and, thereby, the amount of hazardous chemical that has permeated the barrier as a function of time.

Specifically, the resistance of a protective clothing material to permeation by a liquid chemical is characterized by measuring two parameters: the breakthrough time and the subsequent steady state permeation rate of the liquid through the clothing material. Only breakthrough time is discussed.

Breakthrough time is used to estimate how long the CPC provides maximum protection while in continuous contact with the test liquid. Breakthrough time is defined as the elapsed time between initial contact of the hazardous liquid chemical with the outside surface of a protective clothing material and the time at which the chemical can be detected at the inside surface of the material by means of the analytical technique.

Selecting a chemical permeation field test method depends on the challenge chemical state (gas, liquid, solid) and the vapor pressure. The methods described here are good examples; other methods may perform equally well.

Liquid chemical with a vapor pressure 10 torr or above--

## EQUIPMENT

Permeation Test Cell - The cell, as shown in Figure C6, is constructed of two sections of straight glass pipe, each 25 mm (1.0 in.) in diameter. When assembled, the two glass sections are joined by an aluminum or stainless steel clamp. A specimen is positioned between the two Teflon rings as shown in Figure C6. When the specimen is in

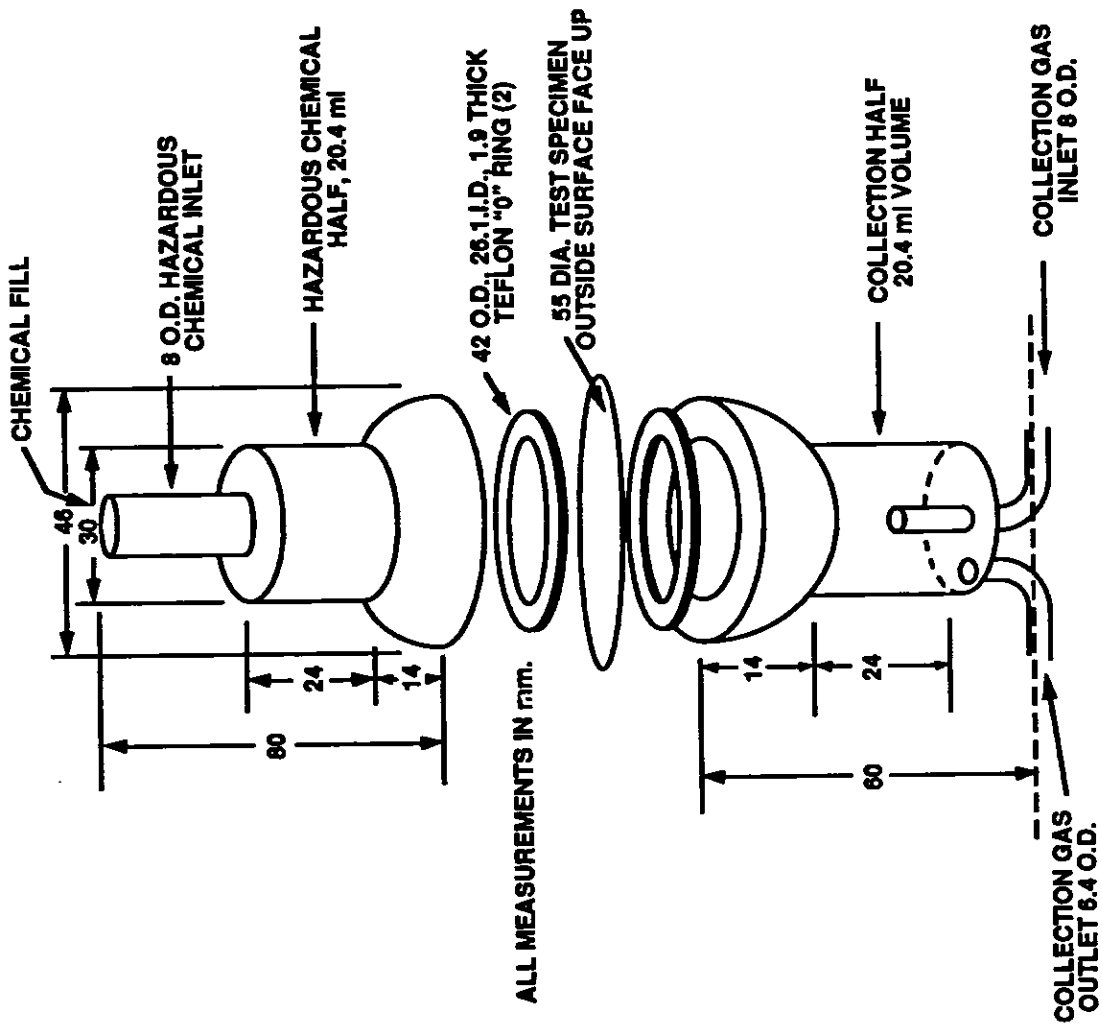


Figure C6. Chemical permeation test cell.

place, the test cell is divided into two chambers. Polytetrafluoroethylene (PTFE) gaskets (Teflon rings) are used in all joints. This cell is commercially available from AMK Glass Co., 610 South 3rd Ave., Vineland, NJ 08360.

A horseshoe clamp is supplied with the cell.

Analytical Equipment - Any direct reading detector that detects the chemical can be used. The following detectors were used in developing this method:

- (1) The H-NU Model PI101 (photoionization detector), H-NU Corporation, 160 Charlemont St., Newton, MA 02161, is non-specific; that is, chemicals are not separated. The observed detector response could be due to a single gaseous chemical or several gaseous chemicals.
- (2) The Century OVA 108 (organic vapor analyzer), the Foxboro Co., 180 Water St., South Norwalk, CT. 06856, uses a flame ionization detector. This instrument can function as a total organic vapor analyzer or as a portable gas chromatograph (GC) operating at ambient room temperature. Only the total organic analyzer mode will be discussed here. The chemical permeation field test apparatus is shown in Figure C7.

Tubing - Teflon tubing is used throughout; connections are Teflon. Teflon Swagelok fittings are used as connectors.

Battery Powered Air Pump - A DuPont P-4000 pump or equivalent is used to circulate air through the chemical permeation test cell.

## PROCEDURE

1. Sensitivity Check - For the H-NU or OVA 108, place the probe tip over the challenge liquid. A large response must be obtained. 75% full scale is good; 100% is better. The OVA 108 or H-NU calibration/span knob setting may be moved to increase the scale reading.

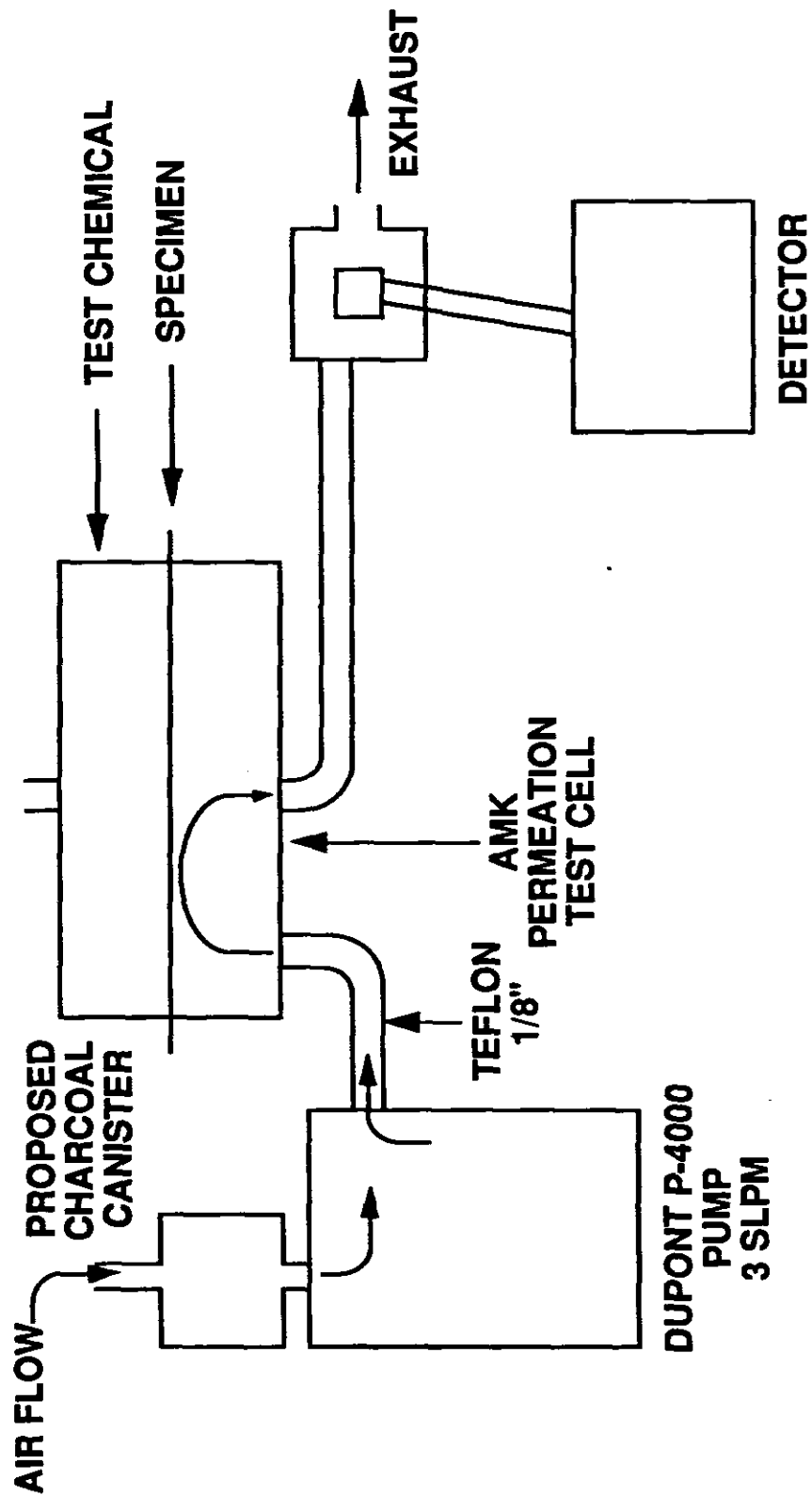


Figure C7. Chemical permeation test system (open loop).



This is a head space response (concentration gas/vapor). If no response is observed or if a poor response (<50% full scale) is observed, then the direct reading detector cannot be used and permeation will not be measured.

2. Use material specimens with a minimum cross dimension of 38 mm (1.5 in.). A 55-mm diameter (1.6 in.) circle is convenient.
3. Measure the thickness of each specimen at the 3, 6, 9, 12 o'clock, and center positions to nearest 0.01 mm (or nearest 0.001 in.) and record. Compute the mean.
4. Assemble the permeation test system using Figure C7 as a guide.
5. Calibrate the DuPont P-4000 pump via a bubble meter. This pump will push air through the collection side of the permeation cell. The OVA 108 operates at 2000 ml/min; hence, the DuPont pump must be calibrated at 2500 ml/min flow rate. H-NU operates at a much lower flow rate; therefore, 600 ml/min can be used.
6. Mount a specimen in the permeation test cell so the normal outside surface of the CPC will contact the liquid. The cell must be clamped together using a stainless steel horseshoe clamp.
7. Start the calibrated DuPont P-4000 pump.
8. Obtain a 10 to 30 minute base line (test system operational without challenge chemical).
9. Fill the permeation cell (see Figure C6) with the challenge liquid (8 ml), and start the timer.

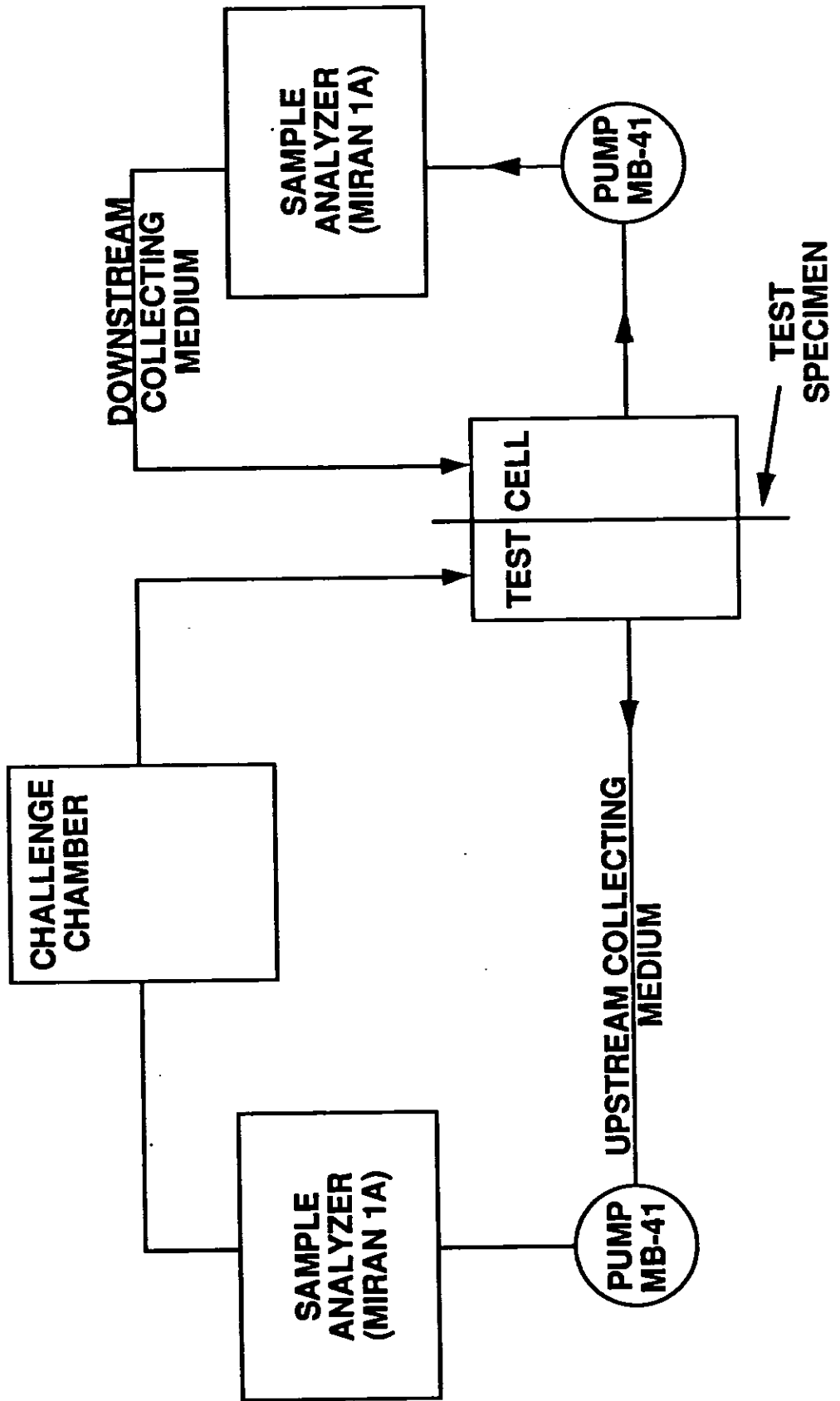


Figure C8. Vapor permeation test system (closed loop).

10. Record time versus concentration (detector meter reading) for 4 hr, then terminate test. (Longer or shorter test times may be selected as determined by the potential exposure time.) A recorder connected to the direct reading detector will plot meter reading versus time quite conveniently. Be sure to mark start time on recorder paper.
11. Test a minimum of three specimens.

## REPORT

For each protective clothing material specimen tested, prepare a report that describes:

1. the protective clothing material by manufacturer, stock number, lot number, and generic chemical composition;
2. the liquid chemical used;
3. the thickness of each material specimen to the nearest 0.01 mm (or nearest 0.001 in.);
4. the mean thickness of the specimens tested for each material type;
5. the breakthrough time, in minutes, for each material specimen (breakthrough time is that time when the meter reading or concentration leaves the base line);
6. the mean breakthrough time of the specimens tested for each material type;
7. when a protective clothing material degrades rapidly after initial liquid contact so that no meaningful permeation data could be obtained; and

8. for each protective clothing material tested, the analytical technique (including its sensitivity) used.

Liquid chemical less than 10 torr vapor pressure--

## EQUIPMENT

Permeation Test Cell - No cell is used. A finger or swatch of material is formed into a pouch and filled with liquid, then sealed by a tie. An electrical tie works well.

Analyzer - Gas chromatography and a detector are typically used. Direct reading instruments are usually not employed.

## PROCEDURE

1. Sensitivity check - A chemist must be consulted for the correct analytical equipment to be used and exact procedure for its use.
2. Cut a 7.6 by 7.6 cm (4 by 4 in.) specimen of material or cut a finger off a glove.
3. Measure the thickness of the specimen. The accurate measurement of a finger cot may be difficult if a larger gauge presser foot is used.
4. Fashion a small pouch from the garment material or use a finger of a glove. The finger should be inverted, or the pouch made so that the outside CPC surface is inside the pouch.
5. Fill the pouch or finger with liquid, quickly seal via a tie, and start the timer. The specimen may be hung on a clothesline.

6. Use a wipe (e.g., Kimwipe) lightly moistened with a solvent that will dissolve the liquid chemical.
7. Lightly wipe the specimen with the moistened wipe. Note the exact time.
8. Extract the liquid chemical using a suitable technique (e.g., Soxhlet extract).
9. Analyze the liquid chemical via the method recommended by the consulting chemist. Typically, GC/ECD or GC/FID is used for organic liquids.
10. Record the concentration and time associated with each extraction. Plot concentration versus time.
11. Breakthrough time, the first detectable concentration above background, is obtained from the plot.
12. Test a minimum of three specimens.

## REPORT

Follow the reporting methods listed in the previous section.

### Gas or vapor

## EQUIPMENT

Permeation Test Cell - The cell, as shown in Figure C6, is constructed of two sections of straight glass pipe, each 25 mm (1.0 in.) in diameter. When assembled, the two glass sections are joined horizontally by an aluminum or stainless steel clamp. A specimen is positioned between the two Teflon rings as shown in Figure C6. When the specimen is in place, the test cell is divided into two chambers. Polytetrafluoroethylene (PTFE) gaskets (Teflon

rings) are used in all joints. This cell is commercially available from AMK Glass Co., 610 South 3rd Ave., Vineland, NJ 08360.

**Analyzer** - A Miran 1A direct reading detector is used. A Miran 1A General Purpose Infrared Gas Analyzer is a single-beam, variable filter spectrometer capable of scanning the infrared spectral range between 2.5 and 14.5  $\mu$ m. The detector is equipped with a gas cell having variable path length between 0.75 and 20.25 m. As shown in Figure C8, two Miran 1As are needed - one for the upstream or vapor gas challenge, the other for downstream or permeant.

**Tubing** - Teflon tubing is used throughout; connections are Teflon.

**Swagelok fittings** - Teflon fittings are used as connectors.

**Pumps** - Two stainless steel pumps, Model MB-41 manufactured by Metal Bellows Corporation, 1075 Providence Highway, Sharon, MA 02067, producing a flow rate of approximately 8 sLpm are used.

#### Sensitivity check

The infrared (IR) instrumental conditions of the Miran 1A instrument are set to handle the specific concentration range of interest (usually from 0.2 to 20 ppm). The IR is first zeroed and then calibrated by injecting known concentrations of the contaminant into a calibrated IR loop. The absorbency is monitored as a function of concentration. In some cases, the IR will not be suitable if the IR has poor sensitivity for the chemical's gas or vapor.

## PROCEDURE

As shown in Figure C8, the upstream chamber is purged with dry air and the contaminant introduced by means of a syringe. The upstream loop is then allowed to equilibrate. The upstream vapor concentration is continually monitored by means of the Miran 1A infrared detector. Additional contaminant is introduced into the upstream loop until the desired concentration is obtained. Immediately downstream of the specimen is another closed loop that contains the other IR detector to monitor the breakthrough permeation concentration as a function of exposure time. Metal Bellows stainless steel pumps in the upstream and downstream loops produce an 8 sLpm flow rate.

The specimen is placed in the permeation cell and the cell is connected to the downstream closed loop. When all the final adjustments have been made, the upstream closed-loop vapor-containing system is placed on line and the timer is actuated. Downstream data (concentration of permeant versus time) is conveniently plotted. The breakthrough time is determined from the graph.

## REPORT

Follow the report requirements of the first section (liquid chemical with a vapor pressure 10 torr or above).





## APPENDIX D. INFORMATION TO CONSIDER IN CPC REUSE

When CPC is disposed of within the estimated safe-use time, the selection process is simple. Disposable garments may, however, not be practical in some cases—their cost may be too great or there may be technical problems in disposing of contaminated products. In these cases, decontaminating the CPC and reusing it may be more practical. If the CPC is to be reused, additional testing must be done to evaluate the following:

1. Is the CPC adversely affected by the decontamination process? The physical or chemical resistance may be affected by heat or chemicals used to clean the CPC. The best way to measure any effect is to subject the CPC to a number of exposure-decontamination cycles and to retest it by repeating the tests suggested in "Test the Candidates Under Expected Conditions" step (see page 18).
2. Is the decontamination process effective? There is some indication that volatile, small molecule chemicals may be successfully removed from the CPC with the use of heat [Berardinelli 1985; Perkins 1987]. No standard method is available, however, to determine whether a product is decontaminated. Repeating the permeation test after decontamination may detect low-level-matrix release phenomenon which could expose users.
3. Can the decontamination process cause exposures? Any chemicals used in the process must be evaluated to ensure they do not result in unacceptable exposures—either during the decontamination process or when CPC is reused.

The recommendation to evaluate reused products necessitates performing the tests on virgin samples and repeating them after a number of exposure and decontamination cycles. Occasional testing of a product that has been in the use/reuse process for a time near the expected product life would provide greater confidence in its effectiveness.



## APPENDIX E. CHEMICAL PROTECTIVE CLOTHING TESTING LABORATORIES

The following is a partial list\* of laboratories that do permeation testing on CPC for a fee. The cost could vary considerably from the typical cost listed; the chemical analytical method, number of materials tested against a chemical, the degree of test automation, and the availability or applicability of standard test methods could easily cause a tenfold increase in the cost of a chemical-material test. Most laboratories offer volume discounts.

Arthur D. Little  
Center for Protective Clothing  
15/224 Acorn Park  
Cambridge, MA 02140

617-864-5770  
Arthur Schwoppe  
\$750 plus permeation; penetration;  
degradation, particulates, sizing, dexterity, physical properties;  
specialize in the more difficult analyses, such as pesticides  
and mixtures (verified 2/88).

Better Fabrics Testing Bureau  
101 W. 31st. Street  
New York, NY 10001-3583

212-868-7090  
Richard Ruperford  
Fire/flammability tests; fire fighting clothing and fabrics  
(5/88).

Geomet Technologies  
8577 Atlas Drive  
Gaithersburg, MD 20877

301-963-3993 or 301-428-9898  
John M. Smith  
\$175-950 permeation; handles RECA class A poisons; runs 48  
simultaneous tests to ASTM or CRDC-SP-84010  
Specifications (10/87).

Lawrence Livermore Laboratories  
Hazard Control Department  
P.O. Box 5505, L-386  
Livermore, CA 94550

415-422-5265  
Dr. James Johnson  
Pressure testing and chemical exposure  
of totally encapsulated suits (10/87).

Los Alamos National Laboratory  
Group HSE-5, M/S M986  
Los Alamos, NM 87545

505-667-7342  
Dr. J. F. Stampfer  
\$100,000-\$180,000/person year; research-oriented difficult  
tests such as low-volatile, low-soluble chemical analysis  
(10/87).

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\*Other organizations that wish to be added to future editions of this volume should provide the author with information similar to that given above.

S.Z. Mansdorf & Associates  
2000 Chestnut Boulevard  
Cuyahoga Falls, OH 44223-1323

216-928-5434  
Zack Mansdorf (10/87).

Miller-Nelson Research  
P.O. Box 2258  
Caramel Valley, CA 93924

408-659-0469  
Gary O. Nelson  
\$250 permeation (10/87).

National Testing Standards  
877 South Rose Place  
Anaheim, CA 92805

714099105520  
Lewis West  
\$400 permeation; physical testing.

Protech Scientific  
Two Cielo Center, 3rd Floor  
1250 Capital of Texas Highway  
Austin, TX 78746

512-329-2552  
Bruce Sorenson  
\$175-\$650 permeation;  
degradation; permeation systems (1/88).

Radian Corporation  
P.O. Box 201088  
Austin, TX 78720-1088

512-454-4797 ext 5956  
Rollen Anderson  
\$300-\$600 permeation; \$100-\$150 degradation; penetration;  
very toxic and radio-labeled chemicals, pesticides, and  
PCBs.(2/88)

Reaction Instruments  
2635 Sherwood Drive  
Wilmington, DE 19808

302-995-2276  
Dr. Stanley F. Sarnar  
\$200-\$250 permeation; \$25+ degradation (2/88).

Southern Research Institute  
2000 9th Avenue, South  
P.O. Box 55305  
Birmingham, AL 35255-5305

205-581-2000  
Dr. Ralph B. Spafford  
\$200-\$400 permeation; degradation;  
penetration; physical  
properties; very toxic, chemical surety materials, explosive  
chemicals (2/88).

Texas Research Institute  
9063 Bee Caves Road  
Austin, TX 78733-6201

512-263-2101  
Karen L. Verschoor  
\$150-\$600 permeation; <\$100 penetration; degradation;  
physical property testing (10/87).

U.S. Testing Company  
1415 Park Avenue  
Hoboken, NJ 07030

800-777-8378  
Melissa Foflom  
Permeation testing; physical properties (5/88).

APPENDIX F. SUMMARY<sup>1</sup> OF AVAILABLE TYPES OF GARMENTS FOR GENERIC MATERIALS<sup>2</sup>

| Type of garment            | Generic material |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
|----------------------------|------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|                            | ACR              | BUT | CAC | CPE | CPP | CR  | CRB | FAB | NBR | NEO | NIT | PE  | PP  | PST | PU  | PVA | PVC | SBR | SLV | SRN | TEF | VIT |     |
| Gloves                     | No               | Yes | No  | --  | No  | No  | No  | Yes | Yes | Yes | Yes | --  | --  | --  | Yes | Yes | Yes | --  | Yes | Yes | Yes | Yes | Yes |
| Coat or jacket             | No               | --  | No  | Yes | No  | No  | No  | Yes | Yes | Yes | Yes | Yes | --  | --  | Yes | --  | Yes | Yes | --  | --  | Yes | Yes | Yes |
| Coveralls                  | No               | --  | No  | Yes | No  | No  | No  | Yes | --  | Yes | --  | Yes | Yes | --  | Yes | --  | Yes | --  | --  | --  | Yes | --  | --  |
| Apron                      | No               | Yes | No  | Yes | No  | No  | No  | Yes | Yes | Yes | Yes | Yes | --  | --  | --  | --  | Yes | Yes | --  | --  | Yes | Yes | Yes |
| Pants or bib overalls      | No               | Yes | No  | Yes | No  | No  | No  | Yes | --  | Yes | --  | Yes | --  | --  | Yes | --  | Yes | Yes | Yes | --  | Yes | Yes | Yes |
| Hood                       | No               | Yes | --  | Yes | --  | No  | No  | Yes | Yes | Yes | --  | Yes | --  | --  | Yes | --  | Yes | Yes | Yes | --  | Yes | --  | --  |
| Shoe cover                 | No               | Yes | No  | --  | No  | No  | No  | Yes | Yes | Yes | --  | Yes | --  | --  | --  | --  | Yes | --  | --  | --  | --  | --  | --  |
| Boot                       | No               | Yes | No  | --  | No  | No  | No  | --  | Yes | Yes | Yes | --  | --  | --  | --  | --  | --  | --  | --  | --  | --  | --  | --  |
| Face shield                | Yes              | No  | Yes | --  | Yes | Yes | Yes | --  | No  | No  | No  | --  | No  | Yes | --  | --  | --  | --  | --  | --  | --  | No  | --  |
| Suit material <sup>3</sup> | No               | Yes | --  | Yes | --  | No  | --  | Yes | Yes | Yes | --  | Yes | No  | --  | Yes | --  | Yes | --  | No  | --  | Yes | Yes | Yes |

Dash indicates data not available.

2 ACR = acrylic  
 BUT = butyl  
 CAC = cellulose acetate  
 CPE = chlorinated polyethylene  
 CPP = cellulose propionate  
 CR = face shield material  
 CRB = polycarbonate  
 FAB = nonwoven fabric  
 NBR = natural rubber  
 NEO = neoprene  
 NIT = nitrile  
 PE = polyethylene  
 PP = polypropylene  
 PST = polyester  
 PU = polyurethane  
 PVA = polyvinyl alcohol  
 PVC = polyvinyl chloride  
 SBR = styrene butadiene  
 SLV = Silver Shield  
 SRN = Saran (PE/polyvinylidenechloride/PE)  
 TEF = Teflon  
 VIT = Viton

<sup>1</sup>Extracted primarily from "Guidelines for the Selection of Chemical Protective Clothing," Volume I, Appendix C, 3rd edition, Schwowe 1987.

<sup>3</sup>A fully encapsulated suit contains parts made of other materials exposed to the atmosphere. These include face shield (or respirator), gloves, boots, and exhalation valves.





