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.

CONTENTS

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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; Schwope 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 pemeated 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).

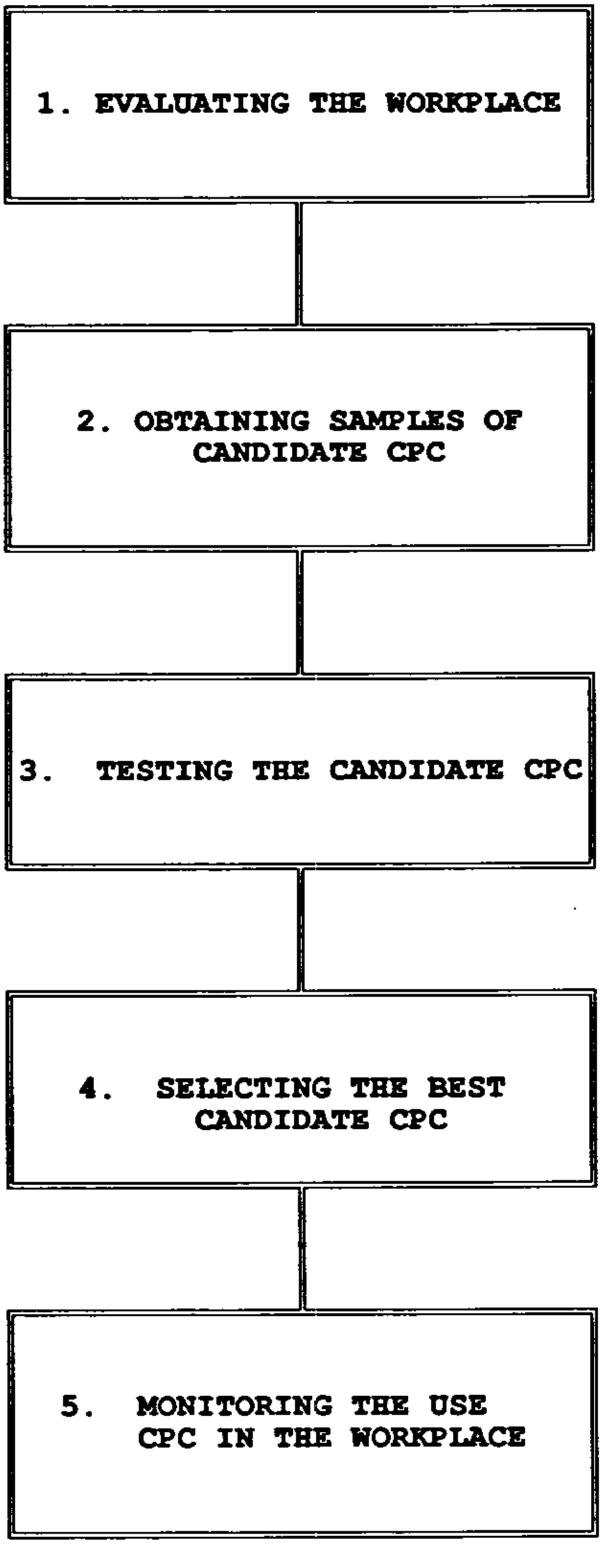

Figure 1. A logical method for evaluating the performance of CPC.

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 (minutes) Tetrachloro-ethane	Cyclo-hexane	Expected use time (minutes)	Resistance of CPC to cuts	Dexterity permitted by CPC
Group A:					
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/ chlorobutyl	>180		>180		
Group 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
Group C:					
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 + 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	
Group A (replace after 1/2 + shift):			
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/ chlorobutyl	No	No	In suits only
Group B (replace after a few unloads):			
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 Weight Change (%)	Degradation Visible Effects	Resistance to cuts	Dexterity permitted	Breakthrough time (minutes)	Breakthrough time after 10 decontaminations (minutes)
Gloves						
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
Aprons:						
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).