QUICK SELECTION GUIDE TO CHEMICAL PROTECTIVE CLOTHING
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Sixth Edition

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Important instructions and limitations

This guidebook contains information on hazardous chemicals and recommendations for the selection of chemical protective clothing materials based on published and unpublished scientific test data. Most of the chemical resistance data are generated in accordance to the standardized test methods. NO attempt has been made to ensure either the accuracy or precision of these compiled data. The guide also does not take into consideration the intended use or physical demands (resistance to tear, puncture resistance, etc., or heat and flames) of the chemical protective clothing. These factors are critical in the selection process. A person competent in the selection of chemical protective clothing such as a Certified Industrial Hygienist (CIH) or a Certified Safety Professional (CSP) with training in this area MUST review ALL selections based on this guide.

The Guide only addresses chemical protective clothing against chemical hazards and exposures. Clothing without barrier materials such as laboratory coats is not included in this guide.
NFPA Standards (http://www.nfpa.org) 252
EN Standards (http://www.cen.eu) 253

ISO Standards (http://www.iso.org) 255

SECTION VII  Manufacturers of Chemical Protective Clothing 257
The sixth edition of the *Quick Selection Guide to Chemical Protective Clothing* has been significantly revised, and updated, to include many new chemicals along with selection recommendations as compared with the previous edition. Also included in the sixth edition are recommendations for many chemical mixtures and commercially available chemicals. These new additions have been organized in 10 of the categories, the 600 series.

The chemical index now includes approximately 1000 chemicals/chemical brands or mixtures of chemicals, additional synonyms, CAS numbers, and risk codes to alert the user, which may be of most concern for user protection.

The Trade Name Table containing 9 generic materials listings and 32 proprietary composition materials versus a test battery of 21 chemicals. The Trade Name Table includes several multi-layers of generic materials not included in the Master Chemical Resistant Table.

The color-coded recommendations in the Master Chemical Resistant Table now contain 27 representative barrier materials. We believe these barrier listings include a wide range of gloves and suits on the market.

New features have been added to meet the users’ needs and expectations. The number of tested chemicals in the sixth edition is more than twice as much as in the first edition. We hope that this revised edition will receive the same enthusiastic response as the prior editions. The purpose is to arm supervisors, industrial hygiene and safety professionals, hazardous materials spill responders, and others with sufficient knowledge and insight in selecting and using the right CPC (chemical protective clothing). Selecting the most appropriate CPC can be an effective and efficient action preventing illnesses and injuries from hazardous chemical exposure where other control methods are not feasible.

Write to us if you have any questions or comments on the 6th edition of this Guide.

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Acknowledgments

The authors wish to acknowledge Ms. Erjka Mäkelä, Specialized occupational hygienist, Finnish Institute of Occupational Health. Ms. Brenda Hinds Pool, MSPH, CIH (Retired, 6/1998-1/2013), Simms Mountain Services, Summerville, Georgia, ccc.smga@gmail.com

Mr. Lawrence H. Keith, PhD, Instant Reference Sources Inc, Monroe, Georgia, larrykeith@earthlink.net for their contribution in reviewing this latest edition. We also thank the manufacturers of the chemical protective clothing for providing us with test reports and technical assistance.
Introduction to the Quick Selection Process

The intent of the *Quick Selection Guide to Chemical Protective Clothing* is to assist workers, supervisors, safety and health professionals, spill responders, industrial hygienists, and others in the initial selection of protective clothing materials against specific chemical challenges on the job. This is accomplished by use of the color-coded tables, which summarize the chemical breakthrough performance of 27 common barrier materials against approximately 1000 chemicals organized in 98 chemical classes based on functional groups and 10 categories of multicomponent/commercial chemicals.

**How to Use This Guide**

The three-step process in this guide completes the selection of barriers offering the best chemical resistance (see Figure 1).

First, the chemical name or synonym is found in the alphabetically sorted chemical index. The second step is to use the chemical class number, which appears to the left of the chemical name to search the selection recommendations tables. The master chemical resistance table is in numerical order by the chemical class. The final step is to find the chemical within the class listing and note the color-coded recommendations by barrier material. For example, to find the recommendations for protection from acetaldehyde, the user must first find the chemical class number in the Chemical Index section. We find the chemical acetaldehyde listed first in the chemical index in Section III. This listing shows a class number of 121. This is the chemical class for aldehydes (aliphatic and alicyclic) under the ASTM F-1186, *Standard Classification System for Chemicals According to Functional Groups*. This listing also
<table>
<thead>
<tr>
<th>Class #</th>
<th>Chemical name or synonym</th>
<th>Chemical number (and synonyms)</th>
<th>CAS #</th>
<th>Risk code</th>
</tr>
</thead>
<tbody>
<tr>
<td>121</td>
<td>Acetaldehyde (Ethanol)</td>
<td>75-07-0</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>102</td>
<td>Acetic acid</td>
<td>64-19-7</td>
<td>Cx</td>
<td></td>
</tr>
<tr>
<td>161</td>
<td>Acetic anhydride (Acetyl acid) (Acetone ethoxane) see Dimethoxane</td>
<td>104-24-7</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>391</td>
<td>Acetone (2-Propanone)</td>
<td>67-64-1</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>313/431</td>
<td>Acetonecyclohydrin (2-Methyllactonitrile)</td>
<td>75-86-5</td>
<td>Tx</td>
<td></td>
</tr>
<tr>
<td>431</td>
<td>Acetonitrile (Methyl cyanide)</td>
<td>75-05-8</td>
<td>TCancer</td>
<td></td>
</tr>
<tr>
<td>392/393</td>
<td>Acetophenone (1-Pentylethanone)</td>
<td>98-86-2</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>111/222</td>
<td>Acetoxyacetyl chloride</td>
<td>13831-31-7</td>
<td>C</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1. What barrier material offers the best chemical resistance?
shows the chemical abstract service (CAS) number assigned to acetaldehyde as 75-07-0. The main purpose for listing the unique CAS number is to be sure that this chemical is the one that we are interested in and not another chemical by a similar name. The next column lists the “Risk Code” for hazard ratings. For acetaldehyde, it is listed as an “X”. This means that the chemical has received a designation of “harmful” to skin. The next step is to go to the selection recommendations tables in Section IV and find chemical class number 121 in the master chemical resistance table. Acetaldehyde is listed first within this group. Reading the color codes from left to right, we find, for example, butyl rubber as the recommended barrier (color coded green) with “>8” representing greater than 8-hours resistance to acetaldehyde.

This three-step process is your fast track to the barrier offering the best chemical resistance against a chemical of interest. The full process from assessment of hazards to disposal of the protective clothing is described in Section II. In Section II you will also find the concept of “Penetration, Degradation and Permeation” described.

You have to be aware that skin is a significant route of chemical entry into the body, which may promote cancer or genetic damage. Chemical exposure also relates to skin irritation, burns, and sensitization. Hazards from chemical exposure are described in Section III.

Hazards are not limited to different types of chemical exposure. In the selection of the most appropriate protective clothing, biological and thermal exposure may be assessed as well.
SECTION II

Selection and Use of Chemical Protective Clothing

This section elaborates on the selection process of all types of CPC (chemical protective clothing). First, the concept of chemical resistance is explained along with some important standards and requirements. Then, there are some reflections on the different steps in the selection process itself. Finally, some notes on the correct use, care and maintenance, and disposal of the CPC are introduced. Both experienced users and users with little or no experience in selection of CPC can read this section.

Chemical Resistance of Protective Clothing – What Does It Mean and How to Evaluate It

The Quick Selection Guide to Chemical Protective Clothing is a tool, which, together with CPC’s manufacturers’ websites and selection tables, further assists you in determining the correct barrier materials for the chemicals to be used.
The selection recommendations are based on permeation and degradation data generated under laboratory conditions.

Comparing permeation data has become, and is probably, the most logical and convenient way to evaluate protective materials and to determine the most appropriate material for a given application.

In order to interpret chemical-resistant data correctly, we should first understand the different ways in which a chemical can pass through a protective material’s barrier and get in contact with the skin.

The most commonly known way by which a chemical can pass through a protective barrier is through **penetration**. Penetration occurs through a pinhole, stitched seams between zipper teeth, a tear, a rip, or other imperfections of the material. The chemical simply flows through that imperfection.

An illustration of penetration can be found in Figure 1.

Imperfection in the material could be related to production defects, or due to damages occurring during usage. Some of the imperfections might even not be visible to the naked eye.

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**Figure 1.** Penetration.

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CPC manufacturers have quality control systems in place to avoid defect products, such as pinholes, reach the market. However, as with every industrial manufacturing process, a defect might pass the quality checks in place. Therefore, it is recommended that the users perform a simple visual inspection of each CPC before donning.
The simplest way to determine imperfections affecting barrier properties is to inflate the garment with air and check where the air passes out of the garment. When the design of the suit does not allow inflation testing, the seams, interfaces, and material can be inspected with a strong light inside the garment while looking for the light from the outside surface.

There is also the phenomenon called **degradation**. This involves a deleterious change in the physical properties of the protective material. Signs of degradation are discoloration, swelling, and occurrence of cracks, hardening, and flaking or even decomposition. Increase and decrease in weight along with visual inspection are the simplest ways to determine degradation of a protective material. EN 374-4 describes standard test methods for determination of resistance to degradation by chemicals.

For corrosive chemicals, degradation is an important factor to consider in selection of chemical-resistant gloves. Results from the permeation test may indicate a relative long breakthrough time, while results from degradation tests may indicate severe physical changes early. Figure 2 visualizes degradation.

**Permeation** is a more complex process, whereby the chemical diffuses through the protective barrier on a molecular level. The process involves absorption of the chemical by the barrier material, saturation of the barrier material, and eventually desorption of the material from the unexposed surface as the chemical concentration in the barrier materials increases. The diffusion is not visible by the naked eye. An illustration can be found in Figure 3.
The chemical will then move through the barrier material at a speed that is called the permeation rate measured in $\mu g/cm^2/min$.

The permeation breakthrough time is the time it takes the chemical to break through the barrier at a specific permeation rate. By specifying the breakthrough time as time to achieve a specific rate of permeation, the results are “normalized” allowing more accurate comparison of results between materials and laboratories.

In 1881, ASTM (American Society for Testing and Material) was the first to adopt the permeation test cell as shown in Figure 4, and a standard test method for determination of permeation resistance (ASTM F 739).

An example of breakthrough of two different chemicals through one protective clothing material is shown in Figure 5. This example demonstrates how complex it can be to select the most appropriate barrier material for a certain work. The difference in performance may vary from minutes to hours.

The permeation breakthrough time is defined under specific laboratory conditions. A CPC sample is mounted in a test cell between two compartments (see Figure 4). One compartment contains the test chemical; an absorption medium (usually gas or liquid) is led to flow through the other compartment to collect any permeated substance. A detection device is connected to the second compartment, which is monitored for the concentration of the chemical over time, continuously monitoring the permeation rate of any chemical seeping through.
Figure 4. Permeation test cell Schematic.

Figure 5. An illustration of two types of permeation behaviors from two different chemicals tested against the same glove material. The dotted line indicates the level from which the standardized breakthrough time is measured. Permeation rate is expressed in \( \mu g/cm^2/min \). The arrows show the normalized breakthrough times in minutes.
Standards and Requirements Related to CPCs

In this subsection are listed the published standards and guidelines relevant in the selection process of CPCs.

Standards describing permeation breakthrough time tests

How the permeation breakthrough time is measured has been described. There are two main systems, which differ in the fixed permeation rate or in the design of the test cell.

In Figure 4, a scheme of the test cell used in ASTM F739 and ISO 6529 is shown.

The ASTM F739 standard records the standardized breakthrough time when the permeation rate achieves 0.1 μg/cm²/min, whereas the EN 374-3 standard records the normalized breakthrough time when the permeation rate reaches 1 μg/cm²/min. The EN ISO 6529 standard allows one to choose the normalized breakthrough time to be measured either when the permeation rate reaches 0.1 or 1 μg/cm²/min. The ASTM D6978 is meant for the measuring of the permeation of chemotherapy drugs through glove material, and according to the standard the breakthrough time is recorded when the permeation rate reaches 0.01 μg/cm²/min.

Please note that there will be a new European standard (EN 16523) replacing EN 374 in the near future. The EN ISO 6529 will cease to be European EN standard.

American Protection Levels and Performance Requirements

Environmental Protection Agency (EPA) and National Institute for Occupational Safety and Health (NIOSH) have developed...
selection schemes for personal protective equipment in hazardous waste operations and emergency response

The HAZWOPER standard defines the OSHA/EPA Protection Levels A, B, and C as follows:

**Level A**: To be selected where the hazards are unknown or unquantifiable or when the greatest level of skin, respiratory, and eye protection is required.

**Level B**: The highest level of respiratory protection is necessary but a lesser level of skin protection is needed.

**Level C**: The concentration(s) and type(s) of airborne substances is known and the criteria for using air-purifying respirators are met.

The National Fire Protection Association (NFPA) develops, publishes, and disseminates consensus codes and performance standards intended to minimize the possibility and effects of fire and other risks. The standards are listed in Section VI. NFPA 1991 sets the performance requirements for HAZMAT response vapor and Level A suits and NFPA 1992 for HAZMAT response liquid and Level A suits.

NIOSH has developed Guidance on Emergency Responder Personal Protective Equipment for Response to CBRN Terrorism Incidents where the NFPA 1994 Standard sets the performance requirements for protective ensembles used in response to CBRN terrorism incidents. The standard defines three classes of ensembles (Classes 2, 3, and 4) based on the protection required for different hazard types (vapors, liquids, and particulates) and airborne contaminant levels.

**European Types of Chemical Protective Clothing**

The European CPC standards are based on a process in which the first step is to decide which parts of the body the clothing has to cover. The next step is to decide the level of inward leakage protection. In EN and ISO CPC specification, the suits are divided into six types, with different kinds of structure and total leakage properties. When the type has been selected, the material of the clothing is selected by comparing the chemical permeation and degradation properties. The permeation tests are required from chemical protective gloves [standard EN 374-1], chemical protective suit types 1–4, and footwear highly resistant to chemicals.
EN 13832-3. Usually, the CPC are suits, but types 3, 4, and 6 suits can also be protective clothing that only covers a part of the body: aprons, coats, sleeves, etc.

The CPC can be meant for limited use (or single use) or they can be reusable. The clothing needs to be of adequate mechanical strength to fit to the task to be carried out. Maintenance and user comfort are not to be overlooked in the selection process. If there is a risk of fire, the flame-protective CPC should be selected.

**Type 1 CPC**, vapor-protective suits are divided into subtypes. Type 1a has a breathable air supply inside the chemical protective suit. The air supply can be, for example, self-contained open-circuit compressed air breathing apparatus. In type 1b, the breathable air supply is worn outside the CPC. To type 1c positive pressure of breathable air is provided via air hose [standard EN 943-1]. Types 1a-ET and 1b-ET are meant for emergency teams [EN 943-2]. Type 1 CPC is meant against hazardous gases, liquids, aerosols, and solid particles. The chemicals may be very hazardous such as dimethyl sulphate, ammonia, chlorine, cyanogen chloride, hydrogen cyanide, sulphur mustard, and Sarin.

The leak tightness for the type 1a, and for the types of 1b in which the facemask is permanently joined to the suit, is ensured with a test that measures how pressurized air is held by the suit. The type 1b suits, which have facemasks that are not permanently joined to the suits, have to be tested with the same pressure test but also inward leakage test. The inward leakage shall not be greater than 0.05% when measured in the ocular cavity of the mask. The inward leakage test is also used for type 1c and type 2 suits.

**Type 2 CPCs** are not gas tight and positive pressure of breathable air is provided into the suit via air hose. The suits can be used against aerosols, sprays, or gases, for instance, in the manufacture of drugs or other hazardous materials, if the task does not require the employee to move around a lot [EN 943-1].

**Type 3 CPC** (and protective clothing that partly covers the body) has liquid-tight connections between different parts of the suit. The CPC can be used in tasks where the contaminants are not airborne, chemicals may splash with pressure, or the space to work is confined and the employee has to lean on contaminated surfaces. The type 3 CPC is not tested for leakage of a gas or particles, but
it is jetted with water [EN 14605]. The materials can be the same as for the type 1 or 2 CPC.

**Type 4 CPC** (and protective clothing that partly covers the body) has spray-tight connections between different parts of the suit. The CPC can be used in tasks where the contaminants are not air-borne, splashes of chemicals may exist, but the splashes are not pressurized, and the space to work is not confined. The liquid splash protection of the type 4 CPC is tested with a spray of water [EN 14605]. The materials can be the same as for the type 5, but the seams are taped.

**Type 5 CPC** is meant for protection from air-borne solid particles such as asbestos, lead dust, and other hazardous dusts. For the leak tightness of the suit there are two criteria. The second is total inward leakage (TIL), that is, the overall mean penetration through the suit while worn by test persons in a sodium chloride aerosol atmosphere. The TIL can be used as a laboratory-based efficacy measure for the CPC. It is required from the type 5 CPC that the TIL has to be less than 15v% for 8 test persons out of 10 [EN ISO 13982-1]. That should be severely considered while selecting the type 5 against hazardous chemicals.

**Type 6 CPC** (and protective clothing that partly covers the body) is meant for tasks where limited protection against liquid chemicals is needed. The overall efficacy of the suit is tested with a spray test at 10% of the liquid load used in type 4 [EN 13034]. The material efficacy against chemicals is measured using percentages, while types 1–4 are measured using the permeation rate. Chemical penetration of 5% is acceptable for type 6 CPC. This is a reason for the type 6 CPC to be recommended for use against small and rare splashes of irritant substances.

Further information on selecting CPC fulfilling the European requirements can be found in Technical report CEN/TR 15149 “Protective clothing – Guidelines for selection, use, care and maintenance of chemical protective clothing.”

ISO 16602, *Protective Clothing for Protection against Chemicals – Classification, labelling, and performance Requirements*, utilizes a six-tier system similar to that found in the CEN standards. While there are subtle differences between the ISO and CEN requirement, garments will generally, but not always, meet the requirements of a given level in strategies.
Standards for Third-Party and Independent Testing of CPCs

Both in the United States and in Europe, a number of specific standards and guidelines exist that rely on third-party certification and independent testing. In Section VI of the guide you will find information on the standards organizations and links to their web sites.

In the United States, the National Fire Protection Association (NFPA) has developed the following standards for protective clothing in industrial applications:

- NFPA 1994, *Standard on Protective Ensembles for First responders to CBRN Terrorism Incidents*

Only products that are annually tested and certified by an independent agency can be labeled as compliant with these standards.

In Europe, all CPC falls under the Directive 89/686/EEC on Personal Protective Equipment (PPE). The directive has been transposed into member state legislation. PPE products are categorized in three risk categories ranging from minimal risks to mortal or irreversible risks.

Contact with chemicals is being considered as a mortal or irreversible risk, which is Category III. Such PPE has to pass certification by a notified body, recognized by carrying a CE-mark visible on the garment followed by four digits (the code of the notified body which is responsible to control that the manufactured products are homogeneous and in accordance with the certified type (Figure 6).

Marking of the garment includes pictograms indicating specific protection performance, The following pictograms in figure 6

It is important to pay attention to this specific CE-marking, as there are often similar products on the market, which are not considered or certified as Category III PPE, and hence, these are only allowed to carry the CE-mark without additional digits.
are examples used in clothing for protection against heat and flame, chemicals, and microorganism.

In Section VI you will find the ASTM, NFPA, ISO, and EN standards related to CPC listed.

The Selection Process

A fixed path can be followed in the selection process of applications involving CPC. Here are listed the basic steps and some important notes for the general selection process of CPC (Figure 7).

A certified CPC product may have been tested in an accredited laboratory against only a few chemicals. A certified product does not give protection against all chemicals.
Assessment of hazards and exposure time

Hazards

Chemical resistance requirements

Breakthrough times
Standards

Application requirements other than chemical resistance

User requirements

Selection of CPC barrier material

Selection of CPC product

Dispose

Care maintain

Use

Train

Figure 7. A scheme overviewing the process of selection, use, care, and disposal of CPC.