

---

---

**Personal safety — Personal protective  
equipment — Guidelines on  
compatibility testing of PPE**

*Sécurité personnelle — Équipement de protection individuelle —  
Lignes directrices pour les essais de compatibilité des PPE*

STANDARDSISO.COM : Click to view the full PDF of ISO/TS 20141:2022



STANDARDSISO.COM : Click to view the full PDF of ISO/TS 20141:2022



**COPYRIGHT PROTECTED DOCUMENT**

© ISO 2022

All rights reserved. Unless otherwise specified, or required in the context of its implementation, no part of this publication may be reproduced or utilized otherwise in any form or by any means, electronic or mechanical, including photocopying, or posting on the internet or an intranet, without prior written permission. Permission can be requested from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office  
CP 401 • Ch. de Blandonnet 8  
CH-1214 Vernier, Geneva  
Phone: +41 22 749 01 11  
Email: [copyright@iso.org](mailto:copyright@iso.org)  
Website: [www.iso.org](http://www.iso.org)

Published in Switzerland

# Contents

	Page
<b>Foreword</b> .....	<b>v</b>
<b>Introduction</b> .....	<b>vi</b>
<b>1 Scope</b> .....	<b>1</b>
<b>2 Normative references</b> .....	<b>1</b>
<b>3 Terms and definitions</b> .....	<b>1</b>
<b>4 Compatibility</b> .....	<b>3</b>
4.1 General.....	3
4.2 Combination of items of PPE known to create problems.....	3
4.3 Multiple hazard compatibility.....	5
4.4 Consideration of environmental compatibility.....	5
4.5 Thermal protection compatibility.....	5
4.6 Chemical protection compatibility.....	5
4.7 Mechanical protection compatibility.....	6
4.8 Examples of issues.....	6
4.8.1 General.....	6
4.8.2 Examples of compatibility situations.....	7
4.9 Applicability of test methods to ensembles.....	12
4.9.1 General.....	12
4.9.2 Specific combinations.....	12
4.10 Applicability of test methods for compatibility of PPE items.....	15
<b>5 Principles of compatibility testing</b> .....	<b>15</b>
5.1 General.....	15
5.1.1 Selection of the components of an ensemble.....	15
5.1.2 Selection of test persons.....	16
5.1.3 Reports.....	18
5.2 Guidelines for setting acceptance criteria.....	18
5.2.1 General.....	18
5.2.2 Principal factors to be considered.....	18
<b>6 Guidelines for practical performance tests</b> .....	<b>19</b>
6.1 General.....	19
6.2 Donning and doffing items of PPE in an ensemble.....	19
6.2.1 Procedure.....	19
6.2.2 Observations.....	19
6.2.3 Report.....	19
6.3 Head bending forward/backward and left/right.....	19
6.3.1 Procedure.....	19
6.3.2 Observations.....	20
6.3.3 Report.....	20
6.4 Head shaking 'no' and nodding 'yes'.....	20
6.4.1 Procedure.....	20
6.4.2 Observations.....	21
6.4.3 Report.....	21
6.5 Hands reaching above the head.....	21
6.5.1 Procedure.....	21
6.5.2 Observations.....	22
6.5.3 Report.....	22
6.6 Torso flexing.....	22
6.6.1 Procedure.....	22
6.6.2 Observations.....	24
6.6.3 Report.....	24
6.7 Repeated bending movements of the arm.....	24
6.7.1 Procedure.....	24

6.7.2	Observations.....	24
6.7.3	Report.....	24
6.8	Lifting the upper legs.....	25
6.8.1	Procedure.....	25
6.8.2	Observations.....	25
6.8.3	Report.....	25
6.9	Grabbing and pinching.....	25
6.9.1	Procedure.....	25
6.9.2	Observations.....	26
6.9.3	Report.....	27
6.10	Walking on a flat surface.....	27
6.10.1	Procedure.....	27
6.10.2	Observations.....	27
6.10.3	Report.....	27
6.11	Walking up and down a ladder and stairs.....	28
6.11.1	Procedure.....	28
6.11.2	Observations.....	28
6.11.3	Report.....	28
6.12	Bending over.....	29
6.12.1	Procedure.....	29
6.12.2	Observations.....	29
6.12.3	Report.....	29
6.13	Crawling.....	29
6.13.1	Procedure.....	29
6.13.2	Observations.....	29
6.13.3	Report.....	30
6.14	Reading instruments and instructions.....	30
6.14.1	Procedure.....	30
6.14.2	Observations.....	30
6.14.3	Report.....	30
6.15	Handling tools.....	30
6.15.1	Procedure.....	30
6.15.2	Observations.....	31
6.15.3	Report.....	31
6.16	Operation of PPE with electronic safety equipment.....	31
6.16.1	Procedure.....	31
6.16.2	Observations.....	31
6.16.3	Report.....	31
6.17	Multiple eye and face PPE and prescription spectacles.....	32
6.17.1	Procedure.....	32
6.17.2	Observations.....	32
6.17.3	Report.....	32
<b>Annex A (informative) Experimental design and statistical testing.....</b>		<b>33</b>
<b>Bibliography.....</b>		<b>39</b>

## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see [www.iso.org/directives](http://www.iso.org/directives)).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see [www.iso.org/patents](http://www.iso.org/patents)).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see [www.iso.org/iso/foreword.html](http://www.iso.org/iso/foreword.html).

This document was prepared by Technical Committee ISO/TC 94, *Personal safety — Personal protective Equipment*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at [www.iso.org/members.html](http://www.iso.org/members.html).

## Introduction

When, following a risk assessment, users are required to wear more than one type of personal protective equipment (PPE) to minimise the risk to their safety, health and well-being, it is important that there are no negative interactions between wearers and the PPE, between the items of PPE and between the PPE and other necessary items to the operations and processes.

Any item of PPE introduces some barrier between part(s) of the body and the environment. This barrier is essential for protection, but it is recognized that this can have unwanted side-effects on the wearer in terms of imposing additional physical effort, hindering movement, impairing sensory perception or causing discomfort. Such side-effects can reduce the efficiency and accuracy of task performance and/or discourage the user from wearing the PPE and, consequently compromising the level of protection afforded.

This document deals with the identification of issues and provides guidance for test procedures to assess the compatibility of items of PPE worn together in an ensemble and between the PPE and the operating environment and processes.

International standards for PPE and requirements and test methods are generally related to individual items of PPE and only a few, for instance ISO 10333-1, ISO 16073-2 and ISO/TS 11999-2, include the assessment of interactions with other items of PPE. For instance, the interface between PPE items at the neck, wrist and ankle needs to provide the appropriate coverage and functionality to protect the wearer from hazards.

The ultimate responsibility for protective equipment is with the wearers' employer, however there may be different levels of shared responsibility with manufacturers and/or wearers themselves. The employer is also the authority on their individual operating environment and processes

Since it is expected that a wide range of equipment may be used by personnel, it is important to note that most PPE are not approved as an ensemble. It is the responsibility of those selecting the equipment to determine if the selected PPE items are compatible and do not impair the performance of other PPE nor impede the ability of the wearer to conduct their activities safely. Given the importance of compatibility, those selecting the PPE ensemble should also be responsible for, or in close coordination with those responsible for the respiratory protection program. Suitability factors should include, but not be limited to issues such as correct use of each item of PPE, mobility, dexterity, field of view and clarity of vision. Heat stress is an issue too but it is not addressed in this document.

# Personal safety — Personal protective equipment — Guidelines on compatibility testing of PPE

## 1 Scope

This document describes compatibility for ensembles of personal protective equipment (PPE) to be used by personnel where operating situations and processes require more than one piece of PPE. Where there is more than one risk to health and safety, it is necessary to wear or use more than one item of PPE at the same time. Such equipment should be compatible and continue to be effective to minimise the risks.

This document includes examples of interactions between items of PPE, between PPE and the operating environment and the effects of PPE on the correct functioning of integrated sensors and electronic devices.

This document provides suggestions of test procedures to assess the effects of any interactions and identify unacceptable restrictions to safe operations.

**NOTE** The principles of this document are also applicable to assessment of interactions with other items in an ensemble that are necessary to the work and that are not PPE, for example cap lamps, instruments, tools.

This document is also intended to be a general guideline for writers of performance requirements standards and test methods for PPE. This document can also be used by PPE manufacturers, distributors, solutions providers, purchasers, wearers and employers as guidance in PPE design and selection.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 374-1, *Protective gloves against dangerous chemicals and micro-organisms — Part 1: Terminology and performance requirements for chemical risks*

ISO 374-2, *Protective gloves against dangerous chemicals and micro-organisms — Part 2: Determination of resistance to penetration*

ISO 4007, *Personal protective equipment — Eye and face protection — Vocabulary*

ISO 16972, *Respiratory protective devices — Vocabulary and graphical symbols*

ISO/TR 11610, *Protective clothing — Vocabulary*

ISO/TR 19591, *Personal protective equipment for firefighters — Standard terms and definitions*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 374-1, ISO 374-2, ISO 4007, ISO 16972, ISO/TR 11610, ISO/TR 19691 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

**3.1 compatibility (of PPE)**  
situation where two or more elements of personal protective equipment may be used together and perform appropriately without modification, adaption or mutual interference.

**3.2 electronic safety equipment**  
**ESE**  
products that contain or have associated electronics that provide enhanced safety functions for wearers during use

**3.3 ensemble**  
combination or assembly of multiple items that are individually compliant with a standard that provide protection to the head, upper torso including arms and hands and the lower torso including feet  
[SOURCE: ISO/TR 19591:2018, 3.95]

**3.4 harm**  
injury or damage to the health of people, or damage to property or the environment  
[SOURCE: ISO/IEC Guide 51:2014, 3.1]

**3.5 hazard**  
potential source of *harm* (3.4)  
[SOURCE: ISO/IEC Guide 51:2014, 3.2]

**3.6 interface**  
common boundary or interconnection between systems, equipment, use environment or human beings

**3.7 latin square design**  
 $n \times n$  array filled with  $n$  different symbols, each occurring once only in each row and once only in each column and which is used especially in the statistical design of experiments

**3.8 personal protective equipment**  
**PPE**  
any device or appliance designed to be worn or held by an individual for protection against one or more health and safety hazards  
[SOURCE: ISO 11660-1:2008, 3.1.15]

**3.9 practical performance test**  
test procedure with wearers of PPE ensembles moving under specified conditions

**3.10 risk**  
combination of the probability of occurrence of harm and the severity of that harm  
[SOURCE: ISO/IEC Guide 51:2014, 3.9, modified — Note 1 to entry has been deleted.]

**3.11 use conditions**  
conditions and processes for which an ensemble of PPE is used, including environmental and climatic circumstances

## 4 Compatibility

### 4.1 General

Compatibility is an issue when different types or combinations of PPE in an ensemble are worn together. This may mean that each item of PPE will not be compatible with each other or may interfere with each other. This may lead to protection being compromised and/or restrictions caused by the PPE that may impede the ability to carry out the tasks. When considering compatibility of items of PPE, there are three main criteria that need to be evaluated in the interest of safety:

- Interfaces – interface between PPE need to ensure that whatever the movement of the person (see [Clause 6](#)) does not cause a movement restriction or a lack of protection.
- Performance – the PPE that is used needs to provide the same minimum protection and it is necessary to identify the weakest item of PPE in the ensemble and how this may affect the user (can he/she realise when an item of PPE is about to fail). There are different tests that exist to permit testing of a full ensemble to understand the weakest link (for example chemical, heat and flame). (See [4.4](#) and [4.5](#)).
- Use condition are related not just to the expected movements of the user but also related to the length of time the PPE is intended to be worn, the spatial conditions the wearer is in, but also the climatic conditions (humidity, temperature, rain, etc.) of the use environment.

Compatibility is also an issue when PPE forms an interface with the user, the environment in which it is used and any integrated and external devices used including electronic.

While product standards can address the first two, the third remains an important consideration in the application of a dynamic risk assessment process and the safe use of PPE. These considerations need to cover the PPE and any ancillary or associated equipment, which is used in conjunction with each other for the holistic and overall protection of the user.

This document and other documents that cover at least partially compatibility, like ISO 16073-2, ISO 17723-1, ISO 18639-1, ISO/TS 11999-2, can only address the issue in general terms as guidance. The compatibility of a particular PPE ensemble can only be assessed by personnel familiar with the needs, processes and use conditions at which the tasks are carried out and set of activities. This will require an assessment of the required components of an ensemble and the potential compatibility issues, based on a risk assessment of the tasks and processes involved.

Any user, manufacturer or any test laboratory, that wishes to assess compatibility of a particular ensemble in a specific application under specific use conditions or compare the functioning of different ensembles, will need to be guided on the selection and design of appropriate test protocol(s) that ensure reproducibility of the results, but also includes hazards and risks to which the user is exposed including the use conditions in which the tasks and activities are carried out.

### 4.2 Combination of items of PPE known to create problems

The compatibility of the combination of PPE items should be tested. The easiest way to assess compatibility of your PPE items is to undertake an audit. The compatibility test should cover the items of PPE required and be cross-referenced against users' needs, use conditions at which the tasks are carried out, and the set of activities. A comprehensive audit will optimise user acceptance and wearing time. [Table 1](#) identifies the interfaces known to create potential problems (identified as "x").

**Table 1 — Possible interfaces between items of PPE worn together as an ensemble**

x indicates those items of an ensemble that may have compatibility issues. This is not an exhaustive list of all possible interfaces and PPE items

Item of PPE	Head/skull physical impact protective devices	Head/face protective devices	Eye/face protective devices	Hearing protective devices	Respiratory protective devices	Torso and arms protective devices	Hand protective devices	Foot and leg protective devices	Protective clothing	Fall arrest devices	Personal flotation devices	Electronic safety equipment
Electronic safety equipment	x	x	x	x	x	x	x	x	x	x	x	x
Personal flotation devices	x	x	x	x	x	x	x	x	x	x	x	x
Fall arrest devices	x	x	x	x	x	x	x	x	x			
Protective clothing	x	x	x	x	x	x	x	x	x			
Foot and leg protective devices						x		x				
Hand protective devices						x	x					
Torso and arms protective devices	x	x	x		x	x						
Respiratory protective devices	x	x	x	x								
Hearing protective devices	x		x									
Eye/face protective devices	x	x	x									
Head/face protective devices	x											
Head/skull physical impact protective devices												

STANDARDSISO.COM · Click to view the full PDF of ISO/TS 20141:2022

NOTE ISO 19734 contains advice on compatibility between prescription spectacles and eye/face protection.

### 4.3 Multiple hazard compatibility

Establish whether a combination of PPE (for example, harness, RPD) has the potential for a negative effect on other items of PPE (for example, garment) and the protection that the other PPE needs to provide (for example, chemical, heat and flame) or presents other risks due to compression, creation of folds, etc.

### 4.4 Consideration of environmental compatibility

- Establish appropriate PPE compatibility in the use environment based on an environmental risk assessment to achieve a sufficient level of protection.
- In the case of using a combination of PPE in a certain use environment, establish that each item of PPE and/or combination of PPE meets the appropriate level of protection to avoid interference between items of PPE and with the use environment.
- Combinations of items of PPE should be ergonomically appropriate (not too hot, not too humid, not too heavy, etc.) for the wearer to complete the mission objective or practical performance test

### 4.5 Thermal protection compatibility

The thermal protective properties of a different PPE should be reviewed so that the overall protection is not disproportional for one part of the body or cause a risk of failure of critical equipment. In addition, overprotection of certain body parts would increase the thermal physiological impact of the PPE on the wearer. Wearers should also be aware of the materials of the underclothing when using protective clothing against heat and flame to consider the probable melting properties of underwear.

ISO 13506-1 and ISO 13506-2 can be used to assess heat and flame ensembles to identify any weaknesses to the full system.

### 4.6 Chemical protection compatibility

The chemical protective properties of the outer layer are critical in providing chemical protection for the user whether this is purely chemical or dual protection (for example, chemical in combination with heat and flame).

Repellency of chemicals, in garment such as for structural firefighting, station wear, rescue clothing, needs to be ensured after cleaning through re-impregnation. If not, the garment could absorb or let through chemicals during an incident or cleaning operations. Some chemicals (for example, solvent, oil) may have a negative impact the heat and flame protection of the garment, glove, boot, etc.

Wear and tear, and specifically abrasion, can negatively impact the chemical protection of boots, gloves and garments. Helmets may lose their robustness if exposed to chemicals (for example, solvents, acids).

Chemical protection of the ensemble needs to ensure that, if one part for example, gloves, protect against a specific chemical, set of chemicals or mixtures, then the other parts (for example, boots, garments, RPD, visor) provide smaller protection.

- ISO 17491 series can be used to assess chemical protection of ensembles against liquids, gases and particulates to identify weaknesses in the full system.
- ISO 17491-1 for gas ingress.
- ISO 17491-2 for particulates testing.
- ISO 17491-3 Liquid jet resistance.
- ISO 17491-4 (Method B) Liquid spray (high level spray) resistance.

- ISO 17491-4 (Method A) Liquid mist (low level spray) resistance.
- ISO 17491-5 Manikin liquid spray resistance.

These tests should not be seen as being hierarchical. Tests from ISO 17491-3 through ISO 17491-5 are water-based tests at various pressures, liquid volumes, angles and surface tensions.

**4.7 Mechanical protection compatibility**

The mechanical protective properties of the outer layer are critical to providing protection of user. The mechanical properties can have different functions:

- Mechanical protection;
- Longevity of the PPE (maintaining the integrity of the PPE);
- Avoidance of snagging.

Therefore, the specific function of the mechanical properties is critical when assessing them as a user.

**4.8 Examples of issues**

**4.8.1 General**

It is important that each item of PPE complies with the relevant requirements in the specific product standard(s) and is selected and used in accordance with the relevant document(s) (if published). ISO 11999-1, ISO 16073-1, ISO/TR 21808 refer to PPE in general and [Table 2](#) contains examples of standards and documents published by ISO and IEC applicable to components of an ensemble. This list is not guaranteed to be exhaustive nor current.

**Table 2 — Possible interfaces between items of PPE worn together as an ensemble**

PPE component	Requirements	Guidance
Head/skull physical impact protective devices	ISO 3873, ISO 11999-5, ISO 16073-5, ISO 18639-5	
Head/face protective devices	ISO 11999-9, ISO 16073-9, ISO 16602 and ISO 17723-1	
Eye/face protective devices	ISO 16321-1 to ISO 16321-3, ISO 16073-7, ISO 19818-1, IEC 61331-3	ISO 19734
Hearing protective devices	ISO 16073-8,	
Respiratory protective devices	ISO 16975-3, ISO 17420 series,	ISO/TS 16975-1 & 2
Torso and arms protective devices	ISO 11393-6	
Hand protective devices	ISO 374-1, ISO 374-2, ISO 374-4 and ISO 374-5, ISO 11393-4, ISO 11999-4, ISO 13999-1 and ISO 13999-2, ISO 15383, ISO 16073-4, ISO 18639-4, ISO 18889, ISO 21420, ISO 23407, ISO 23388	
Foot and leg protective devices	ISO 4643, ISO 11393-2, ISO 11393-5, ISO 11999-6, ISO 16073-6, ISO 17249, ISO 18639-6, ISO 20345, ISO 20346, ISO 20347, ISO 20349-1 and ISO 20349-2	ISO/TR 18690
Protective clothing	ISO 11611, ISO 11612, ISO 11613, ISO 11999-3, ISO 13688, ISO 13982-1, ISO 14116, ISO 14877, ISO 15384, ISO 15538, ISO 16073-3, ISO 16602, ISO 17723-1, ISO 18639-3, ISO 20471, ISO 21942, ISO 27065, IEC 61331-3, IEC 61482-2	ISO/TR 2801
Fall arrest protective devices	ISO 10333-1	
Personal flotation devices	ISO 12402-2 to ISO 12402-6,	ISO 12402-10

**NOTE** Users of this document should check that these documents are current or if further relevant standards have been created since publication.

For some applications, there are other guidance documents related to compatibility that should be read in conjunction with this document. These include ISO 16703-2, ISO 17723-1, and ISO/TS 11999-2.

If there is an issue that donning and doffing the PPE with appropriate convenience and speed, it may require the creation of instructions on the method and, in particular, the orders of donning or doffing the PPE.

#### 4.8.2 Examples of compatibility situations

In the following figures several examples of compatibility are given to illustrate possible issues.



**Figure 1 — Respirator, head/skull impact and eye protection**



**Figure 2 — Respirator and head/skull impact**



**Figure 3 — Head/skull impact and hearing protection**

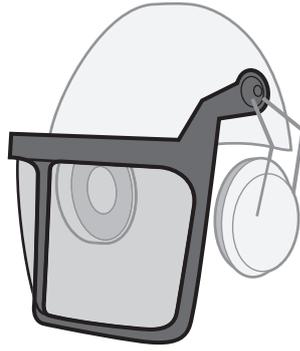


Figure 4 — Head/skull and eye/face protection

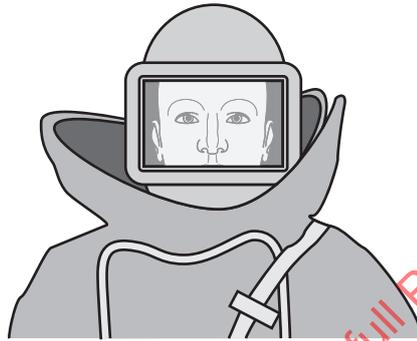


Figure 5 — Head/skull and body protection



Figure 6 — Respiratory and hearing protection



**Figure 7 — Body and leg protection**



**Figure 8 — Body and hand protection**



**Figure 9 — Body and fall protection**



Figure 10 — Fall and respiratory protection



Figure 11 — Leg and foot protection



Figure 12 — Under clothing and outer clothing



Figure 13 — Gloves and mittens



Figure 14 — Boots and over boots

#### 4.8.2.1 Electronic safety equipment

Item of PPE with electronic safety equipment, sensors and/or actuators should be reliable and not hinder the wearer. The PPE worn should not hinder the transmission of signals of the sensors. Any power supply (for example batteries) for the sensors and actuators should not hinder or harm the wearer.

**EXAMPLE** If location information is sent to the wearer by tactile signals, it is necessary that the sense of the skin will detect the tactile signals:

- Electronic devices and resistance to heat, or chemical
- Effect of fast temperatures change
- Thermal safety of electronics (temperature during operation against skin)
- Electrical safety (for example, electric shock IEC 60598-2-4)
- Resistance to water/humidity – IEC 60529 IP rating 44 to 47 is recommended (see classification based on the second digit). Possible, there are more areas of application in which a requirement, for example, to a higher IP protection class, an explosion-proof design or resistance to salty moisture is required.

- Batteries, in particular Lithium ion, secondary batteries placed on the market should comply with IEC 62133-2. Battery housings should meet IP protection class 44
- Sinusoidal vibrations
- Safety towards electromagnetic fields (for example, EN 50527 series)
- Explosive zones – A risk assessment is to be carried out according to CEN/TR 16832 to determine the level of protection needed due to the type of atmosphere (particulate or gas). IEC 60079 series for intrinsic safety
- Fail safe attributes of electronics
- Other considerations

In addition, for integrated smart textiles and non-textile devices which do not or do not solely interact with the user but with an external monitoring system (for example, a command centre), there are, among others, several ethical questions that might need to be assessed by the end user or the employer, which are outside the scope of this document, including but not limited to:

- any communication to stop worker from acting,
- any disobedience to such orders, any psychological effects of these,
- the effect if worker goes too far and is injured (who has the responsibility for the injury)
- how the insurance companies or the law will view any of this information in the event of any injury.

### 4.9 Applicability of test methods to ensembles

#### 4.9.1 General

The applicability of guidelines for PPE test methods should be assessed with any ensemble to ensure compatibility so that the wearers can don and doff within an appropriate time, perform their donning to doffing movements, maintain health and safety and/or use the PPE as intended. The list of applicable test method guidelines is given in [Table 3](#) and [Table 4](#).

#### 4.9.2 Specific combinations

If compatibility issues in an ensemble of items of PPE are identified from [Table 1](#), then testing of compatibility should be carried out.

[Table 3](#) identifies the clause numbers of the applicable test procedures.

These tables are a general guide, only, to compatibility, in assessing the issues in use conditions, attention should be given to the specific characteristics and needs of that location and a risk assessment carried out.

Table 3 — Test procedures for interfaces between items of PPE worn together as an ensemble

Test procedures in 6.1 through 6.17 apply to all ensembles.

Item of PPE	Head/skull physical impact protective devices	Head/face protective devices	Eye/face protective devices	Hearing protective devices	Respiratory protective devices	Torso and arms protective devices	Hand protective devices	Foot and leg protective devices	Protective clothing	Fall arrest devices	Personal flotation devices	Electronic safety equipment
Electronic safety equipment	6.16	6.14, 6.16	6.14, 6.16	6.16	6.14, 6.16	6.16	6.16	6.16	6.16	6.16	6.16	6.16
Personal flotation devices	6.2, 6.3, 6.4, 6.11, 6.12	6.2, 6.3, 6.4, 6.11, 6.12	#	#	6.2, 6.3, 6.4, 6.5, 6.11, 6.12	6.2, 6.3, 6.4, 6.6, 6.11, 6.12, 6.13, 6.15	6.9, 6.15	6.10	6.2, 6.3, 6.4, 6.6, 6.11, 6.12, 6.13	#	#	
Fall arrest devices	#	6.2, 6.3	#	#	#	6.5, 6.6, 6.7, 6.12, 6.13	6.15	6.8, 6.11	6.5, 6.6, 6.7, 6.12, 6.13			
Protective clothing	6.3, 6.4	6.4	#	#	6.4, 6.5, 6.6, 6.10, 6.11, 6.12, 6.13	6.3, 6.4, 6.5, 6.6, 6.11, 6.12, 6.13	6.3, 6.4, 6.5, 6.6, 6.7, 6.13, 6.15	6.5, 6.6, 6.7, 6.8	#			
Foot and leg protective devices						6.5, 6.7, 6.9, 6.10, 6.11, 6.12		6.7, 6.8, 6.9, 6.10, 6.13				
Hand protective devices						6.3, 6.4, 6.5, 6.6, 6.7, 6.13, 6.15	6.8, 6.9, 6.11					
Torso and arms protective devices	6.3, 6.4	6.4	#		6.4, 6.5, 6.6, 6.11, 6.12, 6.13	#						
Respiratory protective devices	6.3, 6.4, 6.13, 6.17	6.2, 6.3, 6.4, 6.14, 6.17	6.3, 6.4, 6.6, 6.12, 6.13, 6.17	6.2, 6.3								

Table 3 (continued)

Item of PPE	Head/skull physical impact protective devices	Head/face protective devices	Eye/face protective devices	Hearing protective devices	Respiratory protective devices	Torso and arms protective devices	Hand protective devices	Foot and leg protective devices	Protective clothing	Fall arrest devices	Personal flotation devices	Electronic safety equipment
Hearing protective devices	6.3, 6.4, 6.13	6.2, 6.4, 6.5	6.2, 6.12, 6.13									
Eye/face protective devices	6.3, 6.4, 6.13, 6.17	6.2, 6.3, 6.4, 6.13	6.12, 6.13, 6.17									
Head/face protective devices	6.2, 6.3											
Head/skull physical impact protective devices												

# Represents identified significant interfaces for which suggested test procedures are not provided or do not exist

STANDARDSON.COM: Click to view the full PDF of ISO/TS 20141:2022

## 4.10 Applicability of test methods for compatibility of PPE items

The compatibility of PPE should be tested if compatibility issues of items of PPE are identified from [Table 4](#).

[Table 4](#) identifies the clause numbers of the applicable test procedures.

**Table 4 — Compatibility of PPE items with the user and/or environment and applicable tests**

Item of PPE	Test clause applicable															
	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	6.10	6.11	6.12	6.13	6.14	6.15	6.16	6.17
Head/skull physical impact protective devices	x	x	x								x	x			x	x
Head/face protective devices	x	x	x								x	x	x		x	
Eye/face protective devices	x	x	x								x	x	x		x	x
Hearing protective devices	x	x	x								x	x			x	
Respiratory protective devices	x	x	x	x	x				x	x	x	x	Full face x		x	Full face x
Torso and arms protective devices	x			x	x	x		x	x	x	x	x		x	x	
Hand protective devices				x	x	x	x	x				x		x	x	
Foot and leg protective devices				x	x	x	x		x	x	x	x			x	
Protective clothing	x	x	x	x	x	x	x		x	x	x	x		x	x	
Fall arrest devices	x	x		x	x	x	x		x	x	x	x		x	x	
Personal flotation devices	x	x	x	x	x				x	x	x	x		x	x	
Electronic safety equipment													x		x	

## 5 Principles of compatibility testing

### 5.1 General

#### 5.1.1 Selection of the components of an ensemble

##### 5.1.1.1 Performance standards

Wherever possible, the components of the ensemble should meet the applicable performance standard for the types of PPE included and continue to do so when worn as part of the ensemble.

##### 5.1.1.2 Guidance documents

Wherever possible, the components of the ensemble should be selected and used according to the guidance for selection and use for the type of PPE included.

### 5.1.1.3 Manufacturer's instructions

The components of the ensemble should be selected and used according to the manufacturer's instructions for that model and size of PPE.

## 5.1.2 Selection of test persons

### 5.1.2.1 Characteristics of test persons

In selecting the test persons, the following should be considered:

- the intended user population;
- the critical tasks that the user will perform in or with the product design, and the type of clothing and equipment used during these tasks;
- the critical dimensions of the product under test;
- the worst-case combinations of critical dimensions and body characteristics, including critical measurements with additional equipment; and
- the safety margins, absolute (figures) or relative(percentile) to be added to the dimensions.

### 5.1.2.2 Number of test persons

The number of test persons to be used should be established by statistical evaluation considering inter- and intra- subject variability and magnitude of the effect of the combination of items of PPE on the user.

The number of test persons is dependent on the group of wearers of the tested PPE combination(s) and is to be representative for the total group of wearers considered the mix of gender. Each test person is to be experienced in the use of the combination(s) of PPE items, appropriately trained, and medically checked. The items of PPE evaluated are to be the appropriate size and correctly fitted for the wearer.

As a practical guideline it is recommended that at least six test persons should be representative for the user population. If it is not possible to use a representative sample from the user population then the sample of test persons used should match as closely as possible to the user population. To establish that the panel of test persons are representative of the PPE users in the workplace, the most important characteristics to consider are:

- age;
- height;
- body mass;
- gender;
- body fat content;
- an estimation of physical fitness;
- skill at the task being simulated.

The following are should be considered:

- For each critical characteristic, select at least six persons, representing the part of the user population anticipated to be limiting in that aspect. That is, if it is, for example, an arm's length that is to be tested, the test persons should, as far as possible, represent the 95th percentile for that characteristic. If a reach-distance is to be tested, the persons should, as far as possible, represent the 5<sup>th</sup> percentile.

- If the 95<sup>th</sup> and/or the 5<sup>th</sup> percentile for the critical characteristics are not known in the intended user population, then at least seven test persons representing the limiting (95<sup>th</sup> or 5<sup>th</sup>) percentile of stature are to be used. Of these seven test persons, at least two should be of slim, medium and corpulent body type, respectively. It is also recommended that at least one person representing the 95<sup>th</sup> or the 5<sup>th</sup> percentile of the breadth or depth measurement be included in the test group. A test person can be used for testing more than one critical characteristic.
- In a more complicated test situation, for example, where both arm length and reach-distance are of concern, the sample of test persons should be specifically selected for the test.
- It is recommended to use the 1<sup>st</sup> and the 99<sup>th</sup> percentile, instead of the 5<sup>th</sup> and the 95<sup>th</sup> wherever possible.

### 5.1.2.3 Training of test persons

All test persons are trained on how to use the PPE correctly prior to testing be carried out. The basis for this training is the instructions for use provided by the manufacturer/supplier.

The training includes but not be limited to

- information concerning limitations and capabilities of the PPE,
- what the PPE will protect from,
- what the PPE will not protect from, and
- what the effects are (if any) of long-term use,

how to

- don and doff, and, if appropriate, how to make the appropriate adjustments for the correct wear and use of the PPE.

The instructions and training provided will depend on the level of the complexity of the PPE provided.

### 5.1.2.4 Running of the tests

The test(s) is/are run, taking the following into account:

- documentation of the critical dimensions and corresponding body characteristics of the test persons;
- randomization of the order of wearing if more than one ensemble is to be tested;
- registration of the test persons' subjective opinions during and/or after using the product;
- registration of the test results without wearing the intended PPE combination;
- observations of the test persons' behaviour and ability to perform the task when using the product as intended; and
- Documentation of the test procedure and the test results.

### 5.1.2.5 Safety of test persons

Throughout the testing process the safety, health and wellbeing of the test persons should be of paramount importance. All test persons should be volunteers who have given informed consent to participate in the study. Test persons should be medically screened in accordance with the requirements of ISO 12894. Ethics committee scrutiny of all human subject tests is essential (Helsinki declaration).

In many situations, it is appropriate that persons with different acquaintance with the product in question are engaged for the test, provided they belong to the intended user population. When

analysing the test data, a distinction should be made between experienced and inexperienced (naïve) test persons, concerning the use of the product or the design under test. In some cases, it may be useful to have an even finer differentiation concerning familiarity with the test situation.

It is important that a test person is wearing all ensembles in a randomized order (see [Annex A](#)) when testing the compatibility for fit and interface of only a few specific items. These may not be directly adjacent to a specific item being considered in the test, however, this item of PPE may have an influence on the fit and interface with other items being tested.

**EXAMPLE** The compatibility between jacket and trousers, when tested according to a practical performance test like the testing sequence proposed in [Annex A](#), can be different in case the test person is wearing not only jacket and trousers but also a respiratory protective device. The amount of overlap between the jacket and trousers will be different when wearing a respiratory protective device or not.

### 5.1.3 Reports

Each report should include:

- a) a reference to this document, i.e. ISO/TS 20141:2022;
- b) the testing authority;
- c) the location(s) of the test(s);
- d) the date(s) of tests;
- e) the number of test persons and their characteristics (de-identified);
- f) the makes and models of the components of the ensemble and their compliance with the applicable performance standard;
- g) the size(s) of the components used.

## 5.2 Guidelines for setting acceptance criteria

### 5.2.1 General

The outcome of each of the tests set out in the document will need to be considered against acceptance criteria. These criteria are universally uniform but will depend on the demands of the specific application and operating environment. The establishment of appropriate criteria will require a risk analysis of the operating environment and activities. For detailed information, it is recommended that the reader consults appropriate guidance on the subject from other publications, for example, ISO 31000.

### 5.2.2 Principal factors to be considered

Consistent with ISO 31000, the acceptability of any observable effect of PPE and ensemble will depend, principally on

- a) the likelihood of an event, and
- b) the consequences of that event.

resulting in a decision on what are acceptable and unacceptable risks.

The more likely the event and the more dire the consequences, the less any adverse effect on performance of operations is acceptable.

## 6 Guidelines for practical performance tests

### 6.1 General

This is not an exhaustive list of all possible movements to cover all combinations of interfaces and PPE items. Users of this document should consider appropriate evaluation of movements to achieve appropriate evaluation results.

NOTE These guidelines for tests can also be used to carry out comparative testing of different ensembles with the same functions.

### 6.2 Donning and doffing items of PPE in an ensemble

#### 6.2.1 Procedure

- a) assess the optimal order to don the PPE and document;
- b) check that the order of doffing the PPE is the reverse of donning and document any deviation from this;
- c) assemble the list of items in the ensemble and manufacturer(s) instructions;
- d) create a set of instructions for the test person including the order and method of donning and doffing;
- e) assess the process and establish any acceptance criteria;
- f) instruct the test persons; and
- g) observe and the procedures.

#### 6.2.2 Observations

Recording any impairment for the wearers while donning or doffing and any undue time delays.

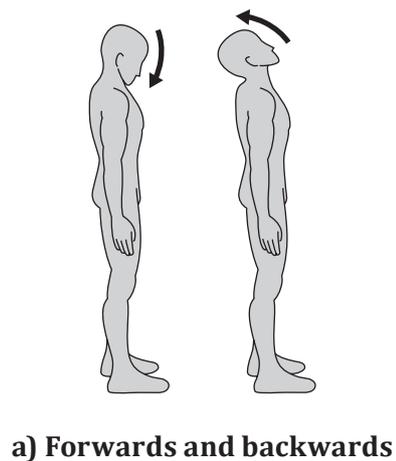
#### 6.2.3 Report

- a) reference to this guideline subclause, [6.2](#);
- b) record the set order of donning and doffing;
- c) record any restriction being able to don and/or doff and any significant effect on the time taken to don and/or doff the PPE items.

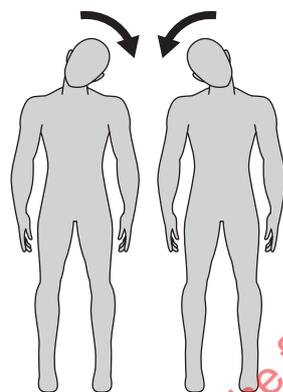
### 6.3 Head bending forward/backward and left/right

#### 6.3.1 Procedure

- a) Stand in an upright position and bend the head as far as possible forwards and then backwards.
- b) Stand in an upright position and bend the head as far as possible to the left and then the right shoulder.



a) Forwards and backwards



b) Showing extent of movement

Figure 15 — Example of head bending

### 6.3.2 Observations

Record any impairment for the wearers while being worn and any restriction or reduction to the protection level when used in an ensemble.

### 6.3.3 Report

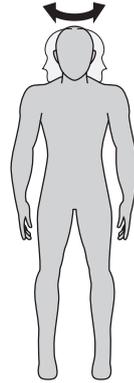
In addition to items required in [5.1.3](#),

- a) reference to this guideline subclause, [6.3](#), and
- b) record any impairment for the wearers while being worn and any restriction or reduction to the protection level when used in an ensemble.

## 6.4 Head shaking 'no' and nodding 'yes'

### 6.4.1 Procedure

- a) Stand in an upright position and shake the head as if indicating 'no'.
- b) Stand in an upright position and nod the head as if indicating 'yes'.



a) As if indicating 'no'



b) As if indicating 'yes'

Figure 16 — Example of shaking or nodding the head

#### 6.4.2 Observations

Record any impairment for the wearers while being worn and any restriction or reduction to the protection level when used in an ensemble.

#### 6.4.3 Report

In addition to items required in [5.1.3](#),

- a) reference to this guideline subclause, [6.4](#), and
- b) record any impairment for the wearers while being worn and any restriction or reduction to the protection level when used in an ensemble.

### 6.5 Hands reaching above the head

#### 6.5.1 Procedure

Stand, hands together (flat palm to flat palm) and reach overhead as high as possible.

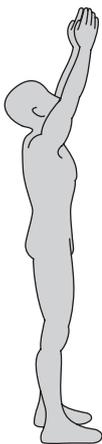


Figure 17 — Example of reaching overhead

### 6.5.2 Observations

Record any impairment for the wearers while being worn and any restriction or reduction to the protection level when used in an ensemble.

### 6.5.3 Report

In addition to items required in [5.1.3](#),

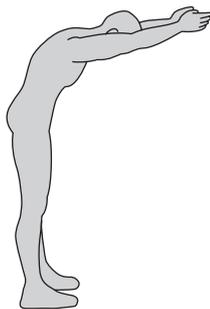
- a) reference to this test subclause, [6.5](#), and
- b) record any impairment for the wearers while being worn and any restriction or reduction to the protection level when used in an ensemble.

Hands reaching forwards, backwards, left and right.

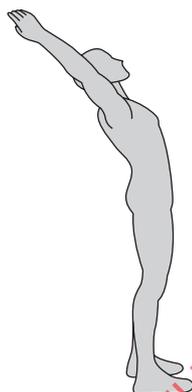
## 6.6 Torso flexing

### 6.6.1 Procedure

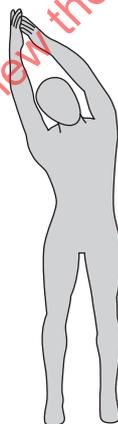
- a) Stand, hands together (flat palm to flat palm) and reach forward as far as possible, body bent at the waist.
- b) Stand, hands together (flat palm to flat palm), reaching overhead toward the back as far as possible, body bent backwards at the waist.
- c) Stand, hands together (flat palm to flat palm) and reach to the right as far as possible as far as possible, body bent at the waist and
- d) Stand, hands together (flat palm to flat palm) and reach to the left as far as possible as far as possible, body bent at the waist.



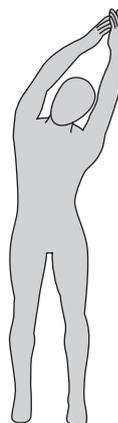
**a) Forward with body bent at the waist**



**b) Overhead toward the back**



**c) To the right with hands together**



**d) To the left with hands together**

STANDARDSISO.COM : Click to view the full PDF of ISO/TS 20141:2022

Figure 18 — Example of reaching

### 6.6.2 Observations

Record any impairment for the wearers while being worn and any restriction or reduction to the protection level when used in an ensemble.

### 6.6.3 Report

In addition to items required in [5.1.3](#),

- a) reference to this test subclause, [6.6](#), and
- b) record any impairment for the wearers while being worn and any restriction or reduction to the protection level when used in an ensemble.

## 6.7 Repeated bending movements of the arm

### 6.7.1 Procedure

- a) Place arm straight down by the side of the body, fists clenched.
- b) Raise the arm to bring the fist up to the level of the shoulder.
- c) Lower the arm.
- d) Repeat with the other arm.

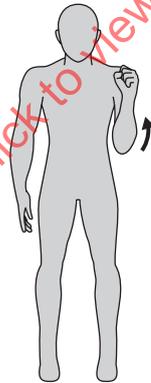


Figure 19 — Example of bending movements of the arm

### 6.7.2 Observations

Record any impairment for the wearers while being worn and any restriction or reduction to the protection level when used in an ensemble.

### 6.7.3 Report

In addition to items required in [5.1.3](#),

- a) reference to this test subclause, [6.7](#), and
- b) record any impairment for the wearers while being worn and any restriction or reduction to the protection level when used in an ensemble.

## 6.8 Lifting the upper legs

### 6.8.1 Procedure

- a) Stand on one leg and lift the other leg as high as possible.
- b) Repeat with the other leg.

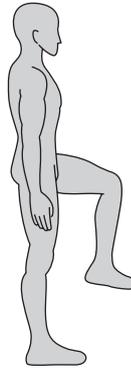


Figure 20 — Example of lifting upper legs

### 6.8.2 Observations

Record any impairment for the wearers while being worn and any restriction or reduction to the protection level when used in an ensemble.

### 6.8.3 Report

In addition to items required in [5.1.3](#),

- a) reference to this test subclause, [6.8](#), and
- b) record any impairment for the wearers while being worn and any restriction or reduction to the protection level when used in an ensemble.

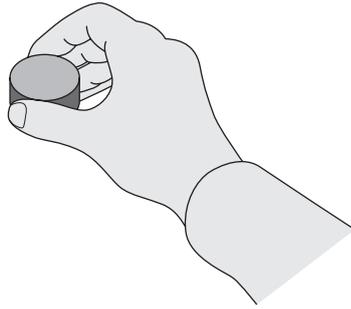
## 6.9 Grabbing and pinching

### 6.9.1 Procedure

NOTE See <https://www.lafayetteinstrument.com/> for the details of the tests Workability Rate of Manipulation and Purdue Pegboard Test.

- a) Workability rate of manipulation test (an adaptation of the Minnesota manual dexterity test).

Defined cylindrical blocks are picked up with one hand, turned over and replaced in a template with the other hand.

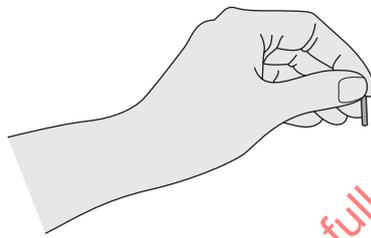


**a) Picking up blocks with one hand**

b) Purdue pegboard test.

Pick up and place defined pins into vertical holes in a board.

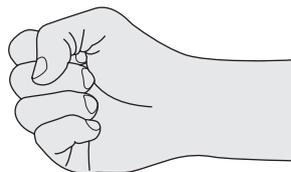
The test is carried out separately for each hand.



**b) Picking up pins**

c) Hand grip strength test.

Force production is scored with, for example, a hand dynamometer with all test persons with the left and right hand. Test persons are to be seated with back, pelvis, and knees as close to 90 degrees as possible, shoulder is adducted and neutrally rotated, elbow flexed at 90 degrees, forearm neutral, wrist held between 0-15 degrees of ulnar deviation. The arm is not supported by examiner or armrest and the dynamometer is presented vertically and in line with the forearm.



**c) Hand grip strength test squeezing a dynamometer**

**Figure 21 — Example of picking up and of hand grip strength test squeezing a dynamometer**

**6.9.2 Observations**

a) Workability rate of manipulation test.

Record time taken to pick up and replace all 60 blocks.

b) Purdue pegboard test.

Record the number of pins placed in 30 s for each hand.

- c) Hand grip strength test.

Record the maximum grip as the mean of three trials for the left and right hands.

### 6.9.3 Report

In addition to items required in [5.1.3](#),

- a) reference to this test subclause, [6.9](#);
- b) workability rate of manipulation test; report time taken to pick up and replace all 60 blocks;
- c) purdue pegboard test; report the number of pins placed in 30 s for each hand;
- d) hand grip strength test; report the maximum grip as the mean of three trials for the left and right hands.

## 6.10 Walking on a flat surface

### 6.10.1 Procedure

- a) Walk a minimum distance of 20 m.
- b) Run a minimum distance of 20 m.

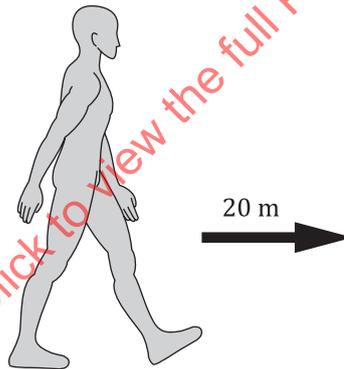


Figure 22 — Example of walking

### 6.10.2 Observations

Record any impairment for the wearers while being worn and any restriction or reduction to the protection level when used in an ensemble.

### 6.10.3 Report

In addition to items required in [5.1.3](#),

- a) reference to this test subclause, [6.10](#), and
- b) record any impairment for the wearers while being worn and any restriction or reduction to the protection level when used in an ensemble.

## 6.11 Walking up and down a ladder and stairs

### 6.11.1 Procedure

- a) Test persons must climb a ladder up least 20 m and down with protective clothing and equipment, including boots.
- b) Climb stairs to a height of at least 10 m.
- c) Turn around and come back down.

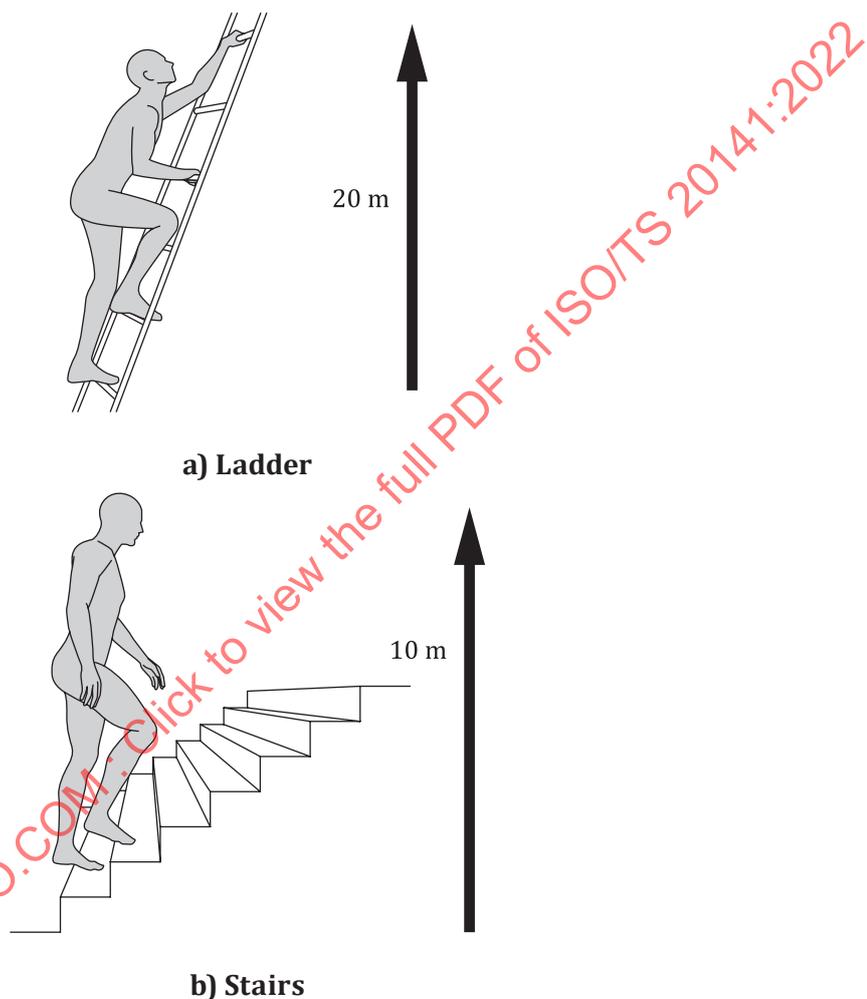


Figure 23 — Example of climbing

### 6.11.2 Observations

Record any impairment for the wearers and any restriction or reduction to the protection level when used in an ensemble.

### 6.11.3 Report

In addition to items required in [5.1.3](#),

- a) reference to this test subclause, [6.11](#), and
- b) record any impairment for the wearers while being worn and any restriction or reduction to the protection level when used in an ensemble.

## 6.12 Bending over

### 6.12.1 Procedure

Bend over and stand up five times.

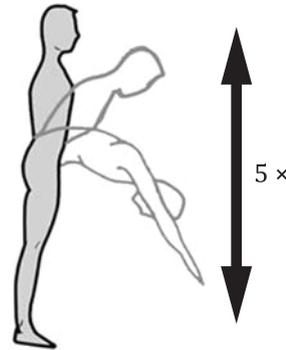


Figure 24 — Example of bending over at waist

### 6.12.2 Observations

Record any impairment for the wearers and any restriction or reduction to the protection level when used in an ensemble.

### 6.12.3 Report

In addition to items required in [5.1.3](#),

- a) reference to this test subclause, [6.12](#), and
- b) record any impairment for the wearers while being worn and any restriction or reduction to the protection level when used in an ensemble.

## 6.13 Crawling

### 6.13.1 Procedure

- a) Crawl for 10 m on hands and knees.
- b) Turn around and return.

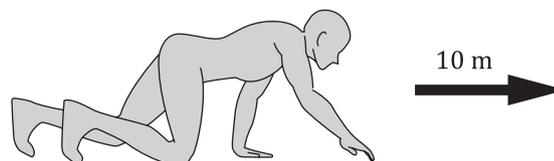


Figure 25 — Example of crawling

### 6.13.2 Observations

Record any impairment for the wearers and any restriction or reduction to the protection level when used in an ensemble.

### 6.13.3 Report

In addition to items required in [5.1.3](#),

- a) reference to this test clause, [6.13](#), and
- b) record any impairment for the wearers while being worn and any restriction or reduction to the protection level when used in an ensemble.

## 6.14 Reading instruments and instructions

### 6.14.1 Procedure

- a) Obtain examples of instructions for equipment and instruments used in the operating environment and identify those that pose the greatest problem.
- b) Read the instructions and instruments with the PPE and any necessary optical correction in place.



Figure 26 — Example of firefighter reading pressure gauge

### 6.14.2 Observations

Record any impairment for the wearers in reading or significant increase in time to read compared to unrestricted reading.

### 6.14.3 Report

In addition to items required in [5.1.3](#),

- a) reference to this test subclause, [6.14](#), and
- b) record any significant difficulty for the wearers in reading or significant increase in time to read.

## 6.15 Handling tools

### 6.15.1 Procedure

- a) Obtain examples of tools used in the operating environment and identify those that pose the greatest problems.
- b) Use the tools in a typical fashion with the PPE and any necessary optical correction in place.



**Figure 27 — Example of firefighter using hand tool**

### 6.15.2 Observations

Record any significant difficulty for the wearers using the tool.

### 6.15.3 Report

In addition to items required in [5.1.3](#),

- a) reference to this test subclause, [6.15](#), and
- b) record any significant difficulty for the wearers using the tools.

## 6.16 Operation of PPE with electronic safety equipment

### 6.16.1 Procedure

- a) Identify and list the electronic safety equipment in any PPE item of the ensemble.
- b) identify which of the suggested tests, [6.2](#) to [6.17](#), that are relevant to the prevailing conditions.
- c) Carry out the procedures identified in a) and monitor the output of sensors during the procedures.
- d) Observe any losses of electronic signal, irregularities in indicated output and/or interference with the tactile signal.

### 6.16.2 Observations

Record any losses of electronic signal, irregularities in indicated output and/or interference with the tactile signal.

### 6.16.3 Report

In addition to items required in [5.1.3](#),

- a) reference to this test subclause, [6.16](#), and
- b) report any significant difficulty for the wearers in using the equipment.

## 6.17 Multiple eye and face PPE and prescription spectacles

### 6.17.1 Procedure

- a) Establish which items are involved, which may comprise prescription spectacles or spectacle type eye protectors, over-specs, goggles, full-face respirators and eyeshields or faceshields.
- b) Starting from the item worn closest to the face, don the first item and check fit.
- c) Don the second item and check fit.
- d) Carry out the guidelines [6.2](#), [6.3](#) and [6.4](#).
- e) Carry out a standing jump on the spot five times.
- f) Repeat b) to e) until all the items are in place.

### 6.17.2 Observations

Record any significant impediment to correct wearing and use of each item, any physical insecurity or significant discomfort.

### 6.17.3 Report

In addition to items required in [5.1.3](#),

- a) reference to this test clause, [6.17](#), and
- b) record any significant impediment to correct wearing and use of each item, any physical insecurity or significant discomfort.

STANDARDSISO.COM : Click to view the full PDF of ISO/TS 20141:2022

## Annex A (informative)

### Experimental design and statistical testing

#### A.1 General

Basic information on experimental design and statistical testing is given in this Annex. If more advanced information and support is needed then the reader is referred to ISO 2602, ISO 2854, ISO 3301 and ISO 3494.

#### A.2 Use of test persons as controls (repeat testing)

To accommodate the effects of variability between individuals, tests involving test persons frequently make use of experimental designs in which the test persons each undertake the test with each of the different “treatments” or conditions, thereby serving as their own control group (intra-individual comparison).

In the present context, different PPE ensembles would form the various conditions. In this way, any effect on test outcome of differences between test persons is reduced, increasing the chances that any differences identified between conditions are due to genuine variations between those conditions rather than being attributable to the test persons taking part.

This convention is adopted in this document.

#### A.3 Balanced experimental design

In circumstances where there might be some form of “learning effect” associated with the performance of any test, experimental designs should be selected which balance out any such effects by the order in which the test conditions are carried out.

Again, this convention is adopted in this document with a balanced order of any person wearing different PPE ensembles. It should be noted that this does not remove any learning effect but balances the effect across the different conditions.

Where two or more ensembles are to be tested by comparative or benchmark testing a crossover design should be used, for example, test persons should be allocated ensembles so that each ensemble is worn first by half of the test persons and the test order is randomly selected (balanced experimental design).

In the event of there being three or more ensembles to be compared a study design can be adopted using a Latin square with individual test persons being allocated to a wearing order according to the rows of such squares.

#### A.4 Latin square

A Latin square is a puzzle where you try to figure out how many ways Latin letters can be arranged in a set number of rows and columns (a matrix); each symbol appears only once in each row and column. It is called a Latin square because it was developed based on Leonard Euler’s work, which used Latin symbols. However, any letters can be used.

[Table A.1](#) shows two such squares for six wearers of three ensembles. It will be noted that this requires each person to carry out the test three times, wearing each of the test ensembles once and that each

ensemble will be worn by two test persons on any one test occasion. Larger squares are given in many standard statistics texts.

**Table A.1 — Latin square design for three ensembles and six test persons**

Test person	Order of wearing of ensembles		
1	Ensemble A	Ensemble B	Ensemble C
2	Ensemble B	Ensemble C	Ensemble A
3	Ensemble C	Ensemble A	Ensemble B
4	Ensemble B	Ensemble A	Ensemble C
5	Ensemble A	Ensemble C	Ensemble B
6	Ensemble C	Ensemble B	Ensemble A

**A.4.1 Making the latin square**

The following algorithm, [Table A.2](#), can be used to make a balanced square for an even number of testing conditions:

**Table A.2 — Balanced square algorithm**

1	2	n	3	n-1	a	...
2	3	1	4	n	5	...
3	4	2	5	1	6	...
:	:	:	:	:	:	:
:	:	:	:	:	:	:
n-1	n	n-2	1	n-3	2	...
n	1	n-1	2	n-2	2	...

EXAMPLE Make a balanced square design for six participants A. B. C. D. E and F with six testing conditions.

Step 1: Make the first row using the algorithm: row 1 = 1, 2, n, 3, n - 1, n - 2.

**Table A.3 — Balanced square algorithm Step 1**

Participant	Order of testing conditions					
	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>	4 <sup>th</sup>	5 <sup>th</sup>	6 <sup>th</sup>
1	1	2	6	3	5	4
2						
3						
4						
5						
6						

Step 2: Fill in the first column sequentially.

**Table A.4 — Balanced square algorithm Step 2**

Participant	Order of testing conditions					
	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>	4 <sup>th</sup>	5 <sup>th</sup>	6 <sup>th</sup>
1	1	2	6	3	5	4
2	2					
3	3					
4	4					