

BRITISH STANDARD

Personal protective equipment for firefighters – Assessment of ergonomic performance and compatibility – Requirements and test methods

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This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 44, an inside back cover and a back cover.

Foreword

Publishing information

This British Standard is published by BSI and came into effect on 31 May 2007. It was prepared by Technical Committee PH/14, *Firefighters' Personal Protective Equipment*. A list of organizations represented on this committee can be obtained on request to its secretary.

Relationship with other publications

This standard reflects the guidance in BS EN 13921¹⁾ on applying ergonomic principles for personal protective equipment (PPE).

This standard complements the existing range of British Standards that exist for individual items of PPE by providing a method of testing the individual items as an ensemble.

Attention is drawn to the following statutory regulations.

- [1] The Personal Protective Equipment Regulations 2002.
- [2] The Personal Protective Equipment at Work Regulations 1992 (as amended).

Information about this document

It has been assumed in the preparation of this British Standard that the execution of its provisions will be entrusted to appropriately qualified and experienced people, for whose use it has been produced.

WARNING. This British Standard calls for the use of substances and/or procedures that can be injurious to health if adequate precautions are not taken. It refers only to technical suitability and does not absolve the user from legal obligations relating to health and safety at any stage.

Presentational conventions

The provisions of this standard are presented in roman (i.e. upright) type. Its requirements are expressed in sentences in which the principal auxiliary verb is “shall”. Apparatus items can also be in italic type, but will be of normal text size, unlike informative material, such as notes.

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

¹⁾ In preparation.

Introduction

The potentially severely adverse environments in which firefighters can be called upon to operate, present considerable challenges in protecting the firefighter. The personal protective equipment (PPE) provided by employers offers a high degree of technical performance thereby helping to minimize the risk of injuries.

Almost by definition, any item of PPE introduces a barrier between part or parts of the body and the external environment. Whilst this barrier is essential for protecting the body, it has long been recognized that this can have unwanted side-effects on the wearer in terms of imposing additional physical workload, hindering movement, impairing sensory perception or in some cases causing considerable discomfort. Such side-effects can reduce the efficiency of task performance and/or encourage the user not to wear the PPE correctly thereby impairing the level of protection afforded.

This problem has been recognized in legislation. The EC Directive on personal protective equipment [3] enacted in the UK by The Personal Protective Equipment Regulations 2002 [1] places duties on PPE manufacturers to take account of ergonomic requirements, whilst the associated EC Directive on the use by workers of personal protective equipment at the workplace [4] enacted in the UK by The Personal Protective Equipment at Work Regulations 1992 (as amended) [2] places similar duties on employers providing PPE for use.

To facilitate compliance with such legislation, European technical product standards for individual items of PPE are gradually introducing tests for ergonomic characteristics. However, such standards are for testing individual products and seldom include the assessment of interactions with other items of PPE except in isolated cases (e.g. helmet-mounted ear-muffs conforming to BS EN 352-3) where they are an essential element of their use.

This standard has therefore been prepared to enable firefighters' PPE ensembles to be evaluated and objectively assessed for ergonomic performance as a complete ensemble, rather than in their component parts. The general approach and the testing methodology included here have been developed under the DTI Consultancy Drafting Scheme, and incorporate practical experience gained during a major contemporary assessment of firefighters' PPE ensembles. The content of this standard has largely been developed against the background of the needs of PPE for structural firefighting ensembles but it might be applicable to PPE ensembles utilized in other circumstances, e.g. wildland firefighting. It is anticipated that it will be used by the Fire and Rescue Service and other firefighting organizations in evaluating their existing ensembles, proposed changes to individual items of PPE within these ensembles, or potential replacement ensembles, against a set of performance parameters derived from this standard.

Manufacturers or consortia can also use this standard to ensure or demonstrate the usability of combinations of their products.

In either case, the assistance of suitably qualified and competent thermal physiologists/ergonomists will be required to both develop the performance parameters, and to assess the results of these trials against those parameters.

1 Scope

This British Standard specifies requirements and test methods for the objective and subjective evaluation of the ergonomic and thermal impact of personal protective equipment (PPE) ensembles, including clothing and respiratory protective equipment (RPE), on firefighters.

This standard is not intended to be used in place of methods for assessing the performance of individual items of PPE specified in their product standards. It specifies the testing of individual items of PPE as an ensemble so that the compatibility of the individual items can be evaluated and any adverse interactions between the individual items can be identified.

It specifies requirements for testing by either assessing the performance of a PPE ensemble against a benchmark condition (i.e. benchmark testing) or assessing the performance of two or more PPE ensembles against each other (i.e. comparative testing).

The standard incorporates practical performance testing as well as laboratory-based testing.

The results of the testing in this standard can assist employers who use PPE to demonstrate compliance with the EC Directive on personal protective equipment at the workplace [4], enacted in the UK by The Personal Protective Equipment at Work Regulations 2002 [2].

This standard can be used by end users, Notified Bodies, manufacturers or others to compare the performance of different ensembles as part of a firefighters' PPE selection process, thereby assisting employers in demonstrating compliance with The Personal Protective Equipment at Work Regulations 1992 (as amended) [2].

The standard can be used to assess the performance of an ensemble that incorporates an item of PPE that has never before been incorporated into the ensemble.

2 Normative references

The following referenced documents are indispensable for the application 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.

BS 6391, *Specification for Non-percolating layflat delivery hoses and hose assemblies for fire fighting purposes*

BS EN 420, *Protective gloves – General requirements and test methods*

BS EN 1147:2001, *Portable ladders for fire service use*

BS EN ISO 12894, *Ergonomics of the thermal environment – Medical supervision of individuals exposed to extreme hot or cold environments*

BS EN ISO 9886, *Ergonomics – Evaluation of thermal strain by physiological measurements*

BS EN ISO 11904-1:2002, *Acoustics – Determination of sound immersion from sound sources placed close to the ear – Part 1: Technique using a microphone in a real ear (MIRE technique)*

BS EN 61260:1996, *Electroacoustics – Octave-band and fractional-octave-band filters*

BS EN 61672-1:2003, *Electroacoustics – Sound level meters – Part 1: Specifications*

3 Terms and definitions

For the purpose of this British Standard the following terms and definitions apply.

3.1 benchmark condition

test subject wearing non-restrictive, minimal, light clothing such as a light track suit and light, flexible footwear such as trainers

NOTE 1 Where the safety of the individual is at risk during ergonomic or thermal testing through the use of this benchmark condition, an alternative condition can be agreed with the client.

NOTE 2 Where sweat production/evaporation is being evaluated, track suits covering the body, arms and legs are preferable to shorts/t-shirts, as this avoids inaccuracies resulting from dripping sweat.

3.2 benchmark testing

assessing the performance of an ensemble against the benchmark condition

3.3 comparative testing

assessing the performance of two or more ensembles against each other

3.4 ensemble

those specific items of PPE and other items of clothing and accessories, e.g. radio, worn together for the purposes of benchmark and comparative testing

3.5 personal protective equipment (PPE)

device, appliance or clothing designed to be worn by an individual for protection against one or more health and/or safety hazards, including clothing which covers or replaces personal clothing

[BS 7963:2000, definition 3.8]

3.6 under clothing

any garments, either intentionally protective or otherwise, which are intended to be worn beneath outer protective clothing. These can be part of an ensemble under test, or worn with it (e.g. underwear, stationwear).

4 General

A balanced experimental design shall be used for both the benchmark and comparative testing of ensembles to ensure that the order of experimentation does not influence the test results.

NOTE Guidance on how to achieve a balanced experimental design is given in Annex A.

5 Test ensemble

5.1 General

All the items of a test ensemble shall be worn in accordance with the relevant instructions by the test subject during testing.

A complete description of a test ensemble shall be recorded in a test report conforming to Clause 9. If a range of outer garments only is being compared, any garments worn beneath these variants shall be kept constant throughout the testing. Similarly, close fitting or bulky garments can impact on mobility. To avoid any misinterpretation, any description of a test ensemble shall include all clothing layers from the skin outwards, footwear, hand wear and headwear (including helmets, hearing protection, communications systems and respiratory protection).

NOTE Although items of clothing being worn with the ensemble might not be classified as PPE they can have substantial influence on ensemble performance. For example, clothing worn beneath protective clothing can influence heat exchange and consequent thermal comfort or safety.

All testing shall either be conducted:

- a) in an absolute comparison against an “unencumbered” minimally restrictive benchmark condition, i.e. benchmark testing in accordance with 5.2; or
- b) to compare two or more PPE ensembles (with comparable protective functions), i.e. comparative testing in accordance with 5.3.

5.2 Benchmark testing

Where all the items of an ensemble are undergoing assessment by benchmark testing, all the items of the ensemble shall be new and each ensemble shall be subjected to relevant tests specified in Clause 8.

Where only a selection of the items of an ensemble are undergoing assessment by benchmark testing, those items being tested and all of those items which potentially impact upon the items being tested shall be new. Table 1 shows which items shall be worn as part of the test ensemble for a particular item undergoing assessment by benchmark testing, where such items form part of the ensemble.

NOTE Pass/fail criteria are impractical for many of the activities listed in Clause 8. Protection against the sort of heat/flame/mechanical hazards which firefighters are likely to encounter will inevitably involve some degree of ergonomic/physiological performance decrement relative to a minimally restrictive benchmark condition. It is essential that this decrement is carefully weighed against the degree of protection provided to establish an acceptable level of performance. In these cases, ensemble performance is rated, with a higher rating indicating less restriction.

Where only a selection of items of an ensemble are being tested, each ensemble shall be subjected to testing specified in Clause 8. However, if it can be reasonably assumed that the items undergoing benchmark testing have no influence on a particular test parameter specified in Clause 8 then it is not necessary to conduct the test for that parameter. Table 2 shows which tests from Clause 8 shall be conducted for a particular item undergoing assessment by benchmark testing.

Table 1 Items of PPE required to be worn for a particular item undergoing assessment by benchmark testing in accordance with Table 2, if they are part of an ensemble

Item of PPE being assessed	Items of PPE required to be worn during assessment									
	Helmet	Eye protection	Fire hood	RPE	Hearing protection	Clothing	Gloves	Footwear	Fall prevention	Buoyancy
Helmet	✓	✓	✓	✓	✓	✓	✗	✗	✗	✓
Eye protection	✓	✓	✓	✓	✓	✗	✓	✗	✗	✓
Fire hood	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗
Respiratory ^{A)}	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓
Hearing protection ^{B)}	✓	✓	✓	✓	✓	✗	✗	✗	✗	✓
Clothing ^{C)}	✓	✗	✓	✓	✗	✓	✓	✓	✓	✓
Gloves	✗	✓	✗	✓	✗	✓	✓	✗	✗	✓
Footwear	✗	✗	✗	✗	✗	✓	✗	✓	✗	✗
Fall prevention	✓	✓	✗	✓	✓	✓	✓	✗	✓	✗
Buoyancy	✓	✓	✓	✗	✓	✓	✓	✗	✗	✓

✗ indicates which items of an ensemble do not need to be worn for a particular item undergoing assessment by benchmark testing

✓ indicates which items of an ensemble shall be worn for a particular item undergoing assessment by benchmark testing.

A) Where RPE is a breathing apparatus, testing shall be carried out with the subject breathing from the apparatus.

B) This refers to ensemble items claiming to provide intentional hearing protection, e.g. ear-muffs, ear plugs.

C) Clothing includes any protective and non-protective garments (e.g. outer and under clothing) which form part of the ensemble.

5.3 Comparative testing

The items of an ensemble undergoing assessment by comparative testing need not be new, however, if this is the case it shall be documented in the test report conforming to Clause 9.

Where all the items of an ensemble are undergoing assessment by comparative testing, each ensemble shall be subjected to all the tests specified in Clause 8.

Where only a selection of items of an ensemble are being tested, each ensemble shall be subjected to testing specified in Clause 8, however, if it can be reasonably assumed that the items undergoing comparative testing have no influence on a particular test parameter specified in Clause 8 then it is not necessary to conduct the test for that parameter. Table 2 shows which tests from Clause 8 shall be conducted for a particular item undergoing assessment by comparative testing.

Table 2 **Parameters from Clause 8 required to be assessed for a particular item undergoing either benchmark testing or comparative testing**

Ensemble item being assessed	Parameters from Clause 8 required to be assessed			
	Restriction of movement 8.2	Manual dexterity 8.3	Sound attenuation 8.4	Thermal impact 8.5
Helmet	✓	✗	✓	✓
Eye protection	✓	✗	✓	✓
Fire hood	✓	✗	✓	✓
Respiratory	✓	✗	✓	✓
Hearing protection	✓	✗	✗	✓
Protective clothing	✓	✓	✓	✓
Under clothing	✓	✓	✓	✓
Gloves	✓	✓	✗	✓
Footwear	✓	✗	✗	✓
Fall prevention	✓	✓	✗	✓
Buoyancy	✓	✓	✗	✓

✓ indicates which parameters from Clause 8 shall be assessed for a particular item undergoing assessment either by benchmark testing or comparative testing.

✗ indicates which parameters from Clause 8 do not need to be assessed for a particular item undergoing assessment either by benchmark testing or comparative testing.

6 Test subjects

6.1 Safety of subjects

To ensure the safety of test subjects:

- a) the test subjects shall be medically examined and certified fit in accordance with BS EN ISO 12894;
- b) ethical clearance shall be obtained in accordance with the World Health Organization Declaration of Helsinki, *Ethical principles for Medical Research Involving Human Subjects* [5];
- c) the experimentation shall be performed in accordance with the provisions of the World Health Organization Declaration of Helsinki, *Ethical principles for Medical Research Involving Human Subjects* [5];
- d) there shall be physiological monitoring of test subjects;
- e) normal safety procedures shall be applied, including close supervision by trained, experienced staff, and voluntary withdrawal shall be permitted at any time.

6.2 Number of subjects

6.2.1 Benchmark testing

At least six test subjects shall be used to assess an ensemble against the benchmark condition, with each subject wearing each ensemble once in a balanced manner, such as described in Annex A.

6.2.2 Comparative testing

At least six test subjects shall be used to assess an ensemble against one or more others. The use of more than six test subjects shall be at the discretion of the client commissioning the tests.

NOTE Some of the reasons why it might be desirable to increase the number of test subjects above six are given in A.3.

The number of subjects shall be selected to ensure that each subject wears each ensemble once in a balanced (e.g. randomized Latin square) manner, such as described in Annex A.

6.3 Selection

Serving firefighters shall be used as test subjects. Individuals selected for the tests shall be familiar with the type of ensemble of equipment/clothing to be tested and shall not have any medical complaints which might adversely affect their ability to perform the test without risk of injury.

NOTE As a minimum, no firefighter, full or part-time, who would not otherwise be considered to be fit for operational duty should participate in tests.

Subjects shall be representative of the gender and range of stature of the population who will be expected to wear the ensemble. See also **A.4**.

NOTE To ensure a reasonable variation in height amongst the panel of subjects, for example using PeopleSize software²⁾ [6], the height of:

- a) one-sixth of the subjects should be drawn from the lowest quartile of the population, i.e. up to 162 cm;*
- b) two-thirds of the subjects should be drawn from the combined two middle quartiles of the population, i.e. (162 to 176) cm; and*
- c) one-sixth of the subjects should be drawn from the top quartile of the population, i.e. more than 176 cm.*

6.4 Subject withdrawal

Where subjects voluntarily withdraw or are withdrawn from the programme of exercises, results from any completed activities undertaken shall be included in any assessment of ensemble performance. Subject to there being sufficient remaining test subjects to ensure the required level of statistical significance, testing of ensembles shall continue. See also **B.5**.

7 Statistical testing

7.1 General

In order to determine whether the results of both benchmark and comparative testing conform to the performance requirements in Clause 8, differences between the test ensemble and the benchmark condition or between two or more ensembles undergoing comparative testing, shall be compared using the statistical tests in **7.2** and **7.3**.

7.2 Benchmark testing

For benchmark testing, the non-parametric sign test (Kanji, G.K., 1999 [7]) shall be used to determine significance at the 5% level.

7.3 Comparative testing

For comparative tests, the statistical comparison of results shall be performed to determine significance at the 5% level using either:

- a) the non-parametric sign test (Kanji, G.K., 1999 [7]); or
- b) where subject numbers permit, a more sensitive test such as paired t-tests or analysis of variation (Kanji, G.K., 1999 [7]) might be substituted.

The test used shall be stated in the test report conforming to Clause 9.

²⁾ PeopleSize software is a trade mark owned by Open Ergonomics Ltd., Loughborough, UK and is the trade name of a product supplied by Open Ergonomics Ltd. This information is given for the convenience of users of this standard and does not constitute an endorsement by BSI of the product named. Equivalent products may be used if they can be shown to lead to the same results.

8 Performance tests and requirements

8.1 General

The preparations for the testing specified in 8.2 to 8.6 shall conform to Annex B.

8.2 Restriction of movement

The restriction of movement imposed on the subjects by the ensemble shall be assessed in accordance with Annex C. The order of testing shall be as given in Table 3.

NOTE The series of activities included in this clause are considered to provide a representative sample of the movements and actions that are typically required of firefighters and their protective ensembles. Users of this standard should consider the ensembles under assessment and their intended applications, and conduct any additional testing which they deem necessary.

No visible separation of protective elements at the interfaces between items during any of the test movements shall occur. If any separation of protective elements is observed (e.g. exposed skin or under clothing) for an ensemble, that ensemble shall be deemed to have failed.

No visible loss of protective function shall be observed for any subject. If any loss of protective function is observed (e.g. dislodging of facemask or helmet during exercises) for an ensemble, that ensemble shall be deemed to have failed.

For benchmark testing, the relevant objective performance criteria in Table 3 shall be rated in comparison with the benchmark ensemble. If any subject is withdrawn from this part of the study because limiting criteria for deep body temperature or heart rate are reached, the ensemble shall be deemed to have failed.

Subjective assessments for individual activities shall be scored and ensemble mean scores reported. For the final subjective assessment, additionally report the proportion of the subjects who consider the ensemble to be less than acceptable.

For comparative tests, statistically significant objective or subjective differences in restriction of movement between ensembles shall be reported to the client and taken into account in the evaluation.

Table 3 Requirements for restriction of movement imposed by ensembles

Clause and Activity	Parameters reported for each ensemble	Requirement ^{A)}
All activities	Interface integrity	No observed separation of protective elements for any subject
All activities	Maintenance of protective function	No observed loss of protective function for any subject
All activities	Physiological measures	No subject withdrawn because limiting criteria reached
C.2.1 Don in cab simulation	Time to complete	Report ensemble mean time and standard deviation
C.2.2 Glove doff/don	Time to complete	None – see C.2.9
C.2.3 Walking	None	—
C.2.4 Ladder raise	Time to complete one raise/lower (mean of all subjects) Subjective assessment	Rate performance according to Table 4, relative to benchmark ensemble Report mean scores
C.2.5 Window sill obstacle	Time to complete (mean of all subjects) Subjective assessment	Rate performance according to Table 4, relative to benchmark ensemble Report mean scores
C.2.6 Hose rolling	Time to complete (mean of all subjects) Subjective assessment	Rate performance according to Table 4, relative to benchmark ensemble Report mean scores
C.2.7 Stretching	Subjective assessment only	Report mean scores
C.2.8 Crawl	Time to complete (mean of all subjects) Subjective assessment	Rate performance according to Table 4, relative to benchmark ensemble Report mean scores
C.2.9 Final glove doff/don	Time to complete (mean of all subjects) Subjective assessment	Rate performance according to Table 4, relative to that achieved in C.2.2 No separation of glove layers/linings. Report mean scores
C.2.10 Final subjective rating	Subjective assessment only	Report mean scores and proportion of subjects returning ratings of less than “acceptable”

^{A)} Pass/fail criteria are impractical for many of the activities listed here. Protection against the sort of heat/flame/mechanical hazards which firefighters are likely to encounter will inevitably involve some degree of performance decrement relative to a minimally restrictive benchmark condition. This has to be weighed against the degree of protection provided. In these cases, a higher rating will indicate less restriction.

Table 4 Rating of objective ensemble performance against benchmark condition

Relative performance requirement	Rating
Time to complete >200% of benchmark condition	1
Time to complete >150% of benchmark condition	2
Time to complete >110% of benchmark condition	3
Time to complete <110% of benchmark condition	4