# Assessment of the Protection Efficiency and Comfort of Personal Protective Equipment in Real Conditions of Use

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The lack of scientific and technical knowledge in certain complex fields, together with schedule constraints, have lead to adopting in EN standards insufficiently validated tests, relying sometimes on an empirical approach. Thus, even personal protective equipment (PPE) with positive results in tests required by the standards can nevertheless prove to be unsatisfactory when used at work.

Several research projects have already been carried out on equipment, fall arresting systems, protective clothing, and gloves by several health and safety institutes in Europe.

The results would suggest practical solutions to improve the representativity of several European Committee for Standardization (CEN) test methods and to focus more on informing and training workers on the manner of wearing PPE, in particular respiratory protective equipment or hearing protectors.

personal protective equipment, efficiency, ergonomics, standards
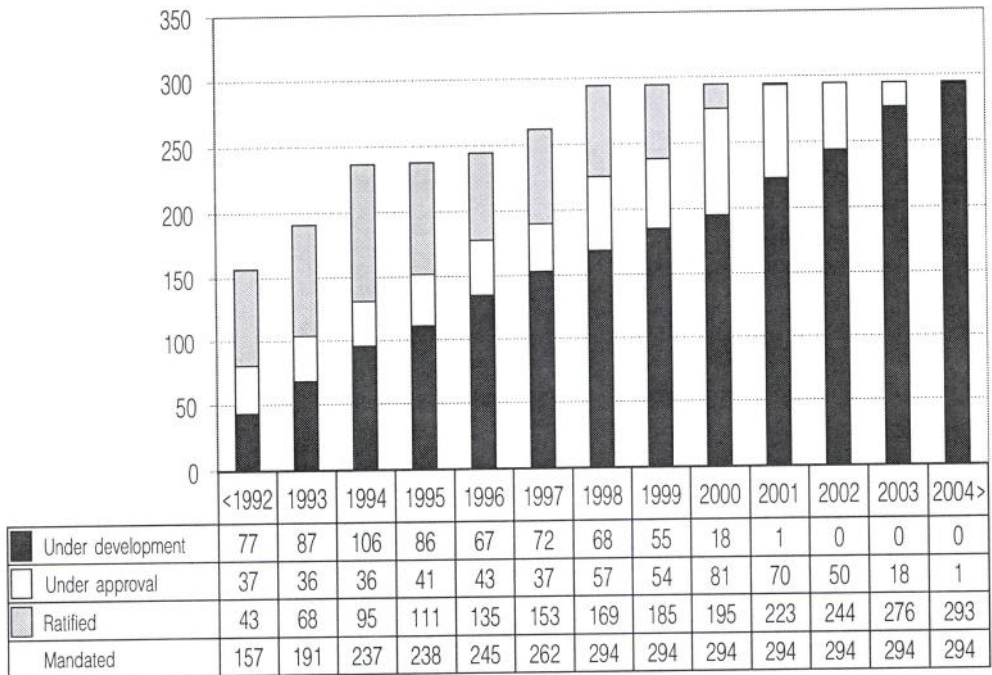
## 1. INTRODUCTION

Before going on to examine the benefits of studying the influence of working conditions on the comfort and efficiency of personal protective equipment (PPE) to improve both the content of European standards

and the design of PPE, we would like to present a brief overview of (a) the progress made on European standardisation relative to PPE, (b) the importance of the role of the European Committee for Standardization (CEN) harmonised standards, both from the legal and technical standpoints.

The European Directive 89/686/EEC (Council Directive 89/686/EEC) relative to the design of PPE came into force on July 1, 1992. The hundreds of experts of the seven technical committees and 70 PPE working groups, the majority created in 1989, were assigned to undertake an ambitious challenge: to prepare, in record time, a comprehensive range of some 300 very diversified standards. By the end of 1998, although the contract had not been entirely fulfilled, the work carried

| | <1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004> |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Under development | 77 | 87 | 106 | 86 | 67 | 72 | 68 | 55 | 18 | 1 | 0 | 0 | 0 |
| Under approval | 37 | 36 | 36 | 41 | 43 | 37 | 57 | 54 | 81 | 70 | 50 | 18 | 1 |
| Ratified | 43 | 68 | 95 | 111 | 135 | 153 | 169 | 185 | 195 | 223 | 244 | 276 | 293 |
| Mandated | 157 | 191 | 237 | 238 | 245 | 262 | 294 | 294 | 294 | 294 | 294 | 294 | 294 |

**Figure 1. Personal protective equipment (PPE) standardization statement as of August, 30, 1999.** *Notes.* Work items "Under development" include all active mandated work items not yet submitted to the European Committee for Standardization (CEN) enquiry*. Work items "Under approval" include all active mandated work items at a stage between the beginning of the CEN enquiry and the ratification, thus including work items at the formal voting stage*. "Ratified" work items include all mandated work items from the ratification to the publication included. The figures neither include corrigenda nor amendments.
*—excluded here are those work items under revision for which the original standard was already mandated.

out had been considerable. By the end of August 1999, more than 180 PPE standards had been duly adopted, and 54 others were being at the adoption stage (Figure 1). If a comparison were drawn with International Organization for Standardization (ISO) or CEN activity regarding PPE in the 1970s and 1980s, more than 20 years would have been required to achieve what had been done in 6 years.

On a legal level, they have an almost regulatory status, and act as a "peace-keeper" in verifying the respect of the essential safety requirements (ESR) of the directive. National and European authorities are indeed obliged to recognise products meeting these standards as being in conformity with the essential requirements covered by the said standards. On a technical level, although limited to voluntary application, these standards have become a reference.

They are vital, not only for manufacturers and notified bodies to assess conformity with the directive, but also for control bodies such as labour inspectorates to monitor products placed on the European market.

It was indeed illusory to think that a valid assessment of the conformity of PPE could be made on the word of an expert, with direct reference to the essential safety requirements, without recourse to detailed technical reference documentation. This would inevitably have led to differences in judgement between laboratories and inspectors, resulting in sources of contention and new barriers to exchanges. The specifications and test methods laid down in CEN standards, the result of a consensus between experts, are indeed meant to avoid such problems.

## 2. PROBLEM FORMULATION

The quality of PPE currently found on the European market is undoubtedly linked to the involvement of both manufacturers and test laboratories, but also, and more particularly, to the quality of the standards that have been drawn up. Four of the main qualities that can, in my view, be expected of a harmonised European standard are that

1. the standards, as far as possible, must contain the technical specifications to allow the ESR applicable to the product in question to be respected;
2. the technical specifications retained must reflect current state of the art, in other words, correspond to the highest level of safety and ergonomics that can be reasonably expected of PPE;

3. the test methods employed must be capable of being reproduced and repeated, in other words, defined clearly so as to eliminate any factors likely to affect the quality of the results;
4. the test methods and the specifications must be representative of the risks that the PPE is intended to protect the user against, and take account, if possible, of all foreseeable conditions of use. Put another way, the laboratory results must correlate perfectly with the effective efficiency and comfort of PPE assessed in real conditions of use.

All those directly involved in standardisation, of course, have gradually taken on board these quality objectives that are vital for the credibility of the standards and of the new approach. However, the ambitious and possibly over ambitious challenge assigned to the PPE Technical Committees in 1989 has, on occasion, required experts to overlook quality slightly in order to meet target dates.

A lack of scientific and technical knowledge in certain particularly complex domains has led CEN Technical Committees either to cover certain ESR only partially or not at all. Moreover, they have, on occasion, adopted insufficiently-validated test methods developed on the basis of a very empirical approach. In numerous cases, these involved methods employed nationally by only one or two laboratories with no knowledge of their real reproducibility or representativeness. How indeed can good quality standards be guaranteed?

In practice, there is a comprehensive range of technical, administrative, and organisational solutions, certain of which have already been applied and have proved their efficiency, with others still waiting to be developed like the launching of systematic interlaboratory test. The intention of this presentation is not to deal with all these solutions, but to communicate, in the light of our experience, the benefits that can be expected from research undertaken jointly in the laboratory and in the field within firms.

As previously mentioned, the current standards have dealt with the "urgent matters" by encompassing existing national and international specifications, but the most complex and difficult problems still have to be resolved. It is indeed these outstanding problems that require the back up of research. They concern not only the standardisation of innovative products employing state of the art technology, but also more conventional yet equally delicate subjects like assessing the ergonomics, comfort, durability and the ageing properties of PPE.

# 3. RESEARCH ON THE REAL EFFICIENCY AND COMFORT OF PPE

The procedures used to assess efficiency and comfort of PPE in the laboratory remain, in some cases, rather theoretical. Consequently, PPE having successfully undergone all the standardised tests can turn out to be somewhat less than satisfactory in use. They can, in particular, be deemed uncomfortable and even cumbersome by workers. Furthermore, their efficiency measured in real conditions of use can prove lower than that expected in theory.

These differences in appreciation can come to light when the real qualities of the PPE are difficult to assess objectively in the laboratory, as they are closely linked to the morphological and psychophysiological characteristics of the future users and to the nature of the very diversified tasks required of them.

This applies to all PPE, particularly when objectively appraising their ergonomic characteristics including comfort, ease of fitting, and even the biological, thermal, sensorial, and biomechanical constraints linked to their wear. This is also the case for certain aspects covering their efficiency, such as the air tightness of masks or breathing protectors and the acoustic attenuation of hearing protectors.

A great many research projects (Bancroft, Clayton, & Hughes, in press; Bolsover, 1996; Bruhl, Corbiere, Labarde, Gölte, & Röckel-Schütze, 1996; Garrod, 1998; Gronqvist, 1998; Hery, Villa, Hubert, & Martin, 1991; Hery et al., 1994, 1997a, 1997b; Hoikkala, 1985; Hospach, Grams, & Kloss, 1996; Howie, Johnstone, Weston, Aitken, & Groat, 1996; Jung, 1991, 1995; Klen & Väyrynen, 1985; Kloss, Lawrenz, & Maltern, 1994; Makinen, Tammela, & Andersen, 1984; Meyer et al., 1997; Pekkarinen & Starck, 1984; Pfeiffer, 1992; Poirot, Grzebyk, Hery, Possoz, & Subra, in press; Riala & Riipinen, 1998; Salsi & Barlier, 1991; Tuomi, Pasanen, & Ahonen, 1985; Vaughan, 1995; Villa, Hubert, Lima, Kauffer, & Hery, 1994–1995; Werkmeister-Stephan, 1985) have already been undertaken both in Europe and throughout the world, particularly by occupational health and safety research institutes including Health and Safety Laboratory (HSL, the UK), Finnish Institute of Occupational Health (FIOH, Finland), French National Research and Safety Institute (INRS, France), Berufsgenossenschaftliches Institut für Arbeitssicherheit (BIA, Germany), Central Institute for Labour Protection (CIOP, Poland),

and Instituto Nacional de Seguridad e Higiene en el Trabajo (INSHT, Spain).

They consist, primarily, in conducting assessments of the situation in firms to appreciate the real level of acceptability of the PPE made available to the users, and also in measuring the real efficiency of certain types of PPE being worn by the operators while carrying out their task.

To illustrate the benefits of such initiatives, we would like to give three examples of recently undertaken research projects, by INRS and FIOH on respiratory protective equipments and by BIA on hearing protectors.

The aim of the INRS study (Hery et al., 1991; Meyer et al., 1997) was to assess the effects of work conditions on the acceptability and efficiency of respiratory protective devices (RPDs). The subjective evaluation of comfort, protection, respiratory and visual constraint, and the acceptable duration of wear of six RPDs against dust was achieved by 30 workers during their actual work in four different plants. Metabolic rate was evaluated for each worker. Thermal parameters of the working environment and RPDs' objective protection factors were measured during each of the 180 test periods.

The results (Table 1) show in particular that

- subjective assessments were well related to certain objective measures such as visual impairment or to subjective assessment during laboratory tests like breathing discomfort or general comfort,
- the leakage measured at workplaces is higher from a factor of 2 to 52 than the corresponding laboratory values.

TABLE 1.  Technical Characteristics of Tested Devices (French National Research and Safety Institute [INRS], France; Meyer et al., 1997)

| Mask | Type of Half Mask | Weight (g) | Leak L (%) | Leak F (%) | Notes |
|------|-------------------|------------|------------|------------|-------|
| 1 | PF | 180.0 | 0.15 | 7.8 | two filtering |
| 2 | PF | 220.0 | 4.70 | 8.6 | cartridges |
| 3 | PF | 220.0 | 2.50 | 11.8 | filtering face piece, |
| 4 | FF | 32.5 | 1.20 | 9.0 | thick material |
| 5 | PF | 21.8 | 0.25 | 7.5 | filtering face piece, |
| 6 | FF | 8.5 | 2.00 | 10.9 | thin material |

*Notes.* PF—with filtering cartridge, FF—with filtering face piece, Leak F—geometric mean in the field, Leak L—arithmetic mean in a laboratory.

This means that the EN leakage test can be used to classify an RPD's protective capacities but is of little interest in predicting the effective protection factor of an RPD at the workplace.

To explain these discrepancies in the results, three hypotheses can be proposed:

1. the influence of the characteristics of the pollutant (NaCl) used for the CEN test (concentrations, particle size) and its ability to be absorbed by the respiratory tract in comparison with those at workplaces;
2. the influence of the duration of the test. The exposure duration in the laboratory standardized leakage test is only 15 and 60 min in the INRS study, which is closer to reality and corresponds to the limit of the acceptable duration of wear. This longer exposure duration may alter the comfort of the workers and modify their behaviour in maintaining the mask in place;
3. the influence of the thermal parameters of the working environment that can have a direct effect on the moisture level inside the mask and on the increase of leakage.

In a second study (Riala & Riipinen, 1998) done in FIOH, the real efficiency of RPDs used in asbestos abatement work was studied. It was also stated that asbestos abatement workers may be exposed to asbestos, despite the wearing of high-performance respirators. The respirator protection factors tested in the laboratory may differ from those in real work situations.

The workers' real exposure was studied with a method where the inhalable air inside the respirator was sampled via an injection needle on a sampling filter. The performance of full face mask respirators with P3 filters were studied at 21 work sites (Table 2).

The sample filters were analyzed by phase contrast microscopy and scanning electron microscopy. Only 8 of the tested 21 respirators (38%) fully protected the workers against fibbers (< 0.01 f/cc). In the other 13 respirators, the fiber levels varied from 0.01 to 4.6 f/cc, the mean concentration being 0.46 f/cc and the median 0.12 f/cc. The 8-hr TWA exposures were usually low, < 0.01–0.15 f/cc, but in four cases (0.15, 0.2, 0.49, and 2.0 f/cc) the 8-hr concentration exceeded the OSHA PEL for asbestos, 0.1 f/cc. The respiratory protection factors varied from 5 to 18,000. Fiber leakage through the face seal may occur in difficult working postures, or through poorly fitted filter systems, for example, in multisupplier systems.

**TABLE 2.   Asbestos Concentrations and Respirator Protection Factors (FIOH, Finland; Riala & Riipinen, 1998)**

| Work Object Description | Asbestos Concentration Inside Respirator (f/cc) | Asbestos Concentration 8-hr Exposure (f/cc) | Asbestos Concentration at the Lapel | | | Respirator Protection Factor | Mask Type | Power Unit Type | Filter Type and Hours Used |
|---|---|---|---|---|---|---|---|---|---|
| | | | Mean (f/cc) | Number of Samples | Range (f/cc) | | | | |
| 1. Boiler room pipe insulation | 0.17 | 0.20 | 2.35 | 1 | | 14 | Brand A | Brand E | Brand P3 |
| 2. Pipe insulation | 0.24 | 0.09 | 1.17 | 1 | | 5 | Brand A | Brand E | Brand P3 |
| 3. Pipe insulation | 0.10 | 0.05 | 2.20 | 1 | | 22 | Brand A | Brand A | Brand P3 |
| 4. Boiler room pipe insulation | 0.70 | 0.49 | 3.50 | 1 | | 5 | Not registered | Brand D | Brand P3 |
| 5. Asbestos cement ceiling tiles | <0.01 | <0.01 | 0.50 | 1 | | >50 | Brand A | Brand E | Brand P3 |
| 6. Boiler room pipe insulation | <0.01 (SEM) | <0.01 | 180 (SEM) | 1 | | >18,000 | Brand A | Brand E | Brand F P3, new |
| 7. Crocidolite on ventilation duct | 4.60<br>0.30 (SEM) | 2.03 | >100<br>209 (SEM) | 1<br>1 | | >21.7<br>697 | Brand B | Brand E | Brand G P3, new |
| 8. Crocidolite on ventilation duct | <0.01<br><0.01 (SEM) | 0.004 | >100<br>>100 (SEM) | 2<br>2 | >100<br>>100 | >10,000<br>>10,000 | Brand A | Brand E | Brand F P3, new |
| 9. Pipe insulation | 0.14<br><0.01 (SEM) | 0.03 | 69.9<br>11.8 (SEM) | 3<br>2 | 41–100<br>2.3–23.2 | >499<br>>1,180 | Brand B | Brand E | Brand E P3, used for 3 days |
| 10. Boiler room pipe insulation | <0.01<br><0.02 (SEM) | <0.01 | 24.8<br>9.5 (SEM) | 3<br>3 | 15.9–32.7<br>5.8–14.9 | >2,400<br>>475 | Brand C | Not registered | Brand P3, new |
| 11. Vinyl floor tiles | <0.01<br><0.01 (SEM) | <0.01 | 0.04<br>0.05 (SEM) | 1<br>1 | | >4<br>>5 | Brand C | Brand E | Brand F P3, used for 2 weeks |
| 12. Pipe insulation | *<br><0.01 (SEM) | 0.01 | 16.20<br>5.6 (SEM) | 3<br>2 | 0.68–31.0<br>5.1–6.3 | >560 | Brand A1 | Brand E | Brand G P3, new |

TABLE 2. (continuation) Asbestos Concentrations and Respirator Protection Factors (FIOH, Finland; Riala & Riipinen, 1998)

| Work Object Description | Asbestos Concentration Inside Respirator (f/cc) | Asbestos Concentration 8-hr Exposure (f/cc) | Asbestos Concentration at the Lapel Mean (f/cc) | Number of Samples | Range (f/cc) | Respirator Protection Factor | Mask Type | Power Unit Type | Filter Type and Hours Used |
|---|---|---|---|---|---|---|---|---|---|
| 13. Boiler room pipe insulation | 0.03 <0.01 (SEM) | 0.01 | 17.8 3.9 (SEM) | 3 3 | 14.7–22.3 3.3–4.4 | 592 >388 | Brand A | Brand E | Brand H P3, new |
| 14. Boiler room pipe insulation | 0.46 0.06 (SEM) | 0.09 | 53.0 8.0 (SEM) | 3 3 | 40.0–63.0 2.3–18.6 | 116 133 | Brand B | Brand E | Brand F P3, used for a few hours |
| 15. Crocidolite on ventilation duct | 0.09 <0.01 (SEM) | 0.08 | 22.0 23.3 (SEM) | 1 | | 244 2,300 | Brand A | Brand A 120 L/min | Brand A P3, new |
| 16. Pipe insulation in a power plant | 0.04 | 0.03 | 15.3 | 1 | | 383 | Brand A | No power unit | Brand G P3, new |
| 17. Ceramic tiles | 0.03 <0.01 (SEM) | 0.07 | 13.7 1.8 (SEM) | 2 2 | 12.3–15.1 0.7–1.6 | 457 >178 | Brand A | Brand E | Brand E P3, new |
| 18. Pipe insulation in a factory | 0.39 | 0.15 | 15.7 | 2 2 | 11.7–17.8 3.4–4.3 | 40 | Brand A | Brand E | Brand E P3, used for a few hours |
| 19. Boiler room pipe insulation | <0.03 (SEM) | 0.01 | 10.9 (SEM) | 3 | 6.0–15.6 | >363 | Brand A1 | Brand E | Brand A P3 |
| 20. Pipe insulation in a factory | 0.01 0.04 (SEM) | 0.04 | 1.6 1.7 (SEM) | 2 2 | 0.66–2.6 0.70–2.6 | 160 42 | Brand B | Brand A | Brand G P3, new |
| 21. Pipe insulation | <0.01 <0.01 (SEM) | <0.01 | 8.4 5.5 (SEM) | 3 3 | 1.3–20.6 1.3–7.3 | 4,213 >546 | Brand A | Brand E | Brand E P3, new |

Notes. *—sample omitted due to wetness.

The reason for the low protection level lies mainly in the wrong selection and use of the devices. Sometimes also poor maintenance causes the non-functioning of the device.

In CEN Technical Report No. 529 (European Committee for Standardization, 1993) on the selection and use of RPDs nominal protection factors are given. These factors are based on the requirements given in the relevant product standards. These protection levels cannot be achieved by all the users and, therefore, in some countries like in Germany and the UK assigned protection factors are given. These protection factors are based on workplace studies on real efficiency. For example, power assisted particle filtering devices incorporating a full face mask according to Standard No. EN 12942:1998 (CEN, 1998) with a TMP3 filter must have a protection factor greater than 2,000. This is measured by using test persons who are doing simulated work. All certified CE-marked products have fulfilled this requirement. Based on experience, the German recommendation is that the assigned protection factor is 5,000 and in the UK it is only 20. This leads to the requirement that more efficient and in many cases heavier or more uncomfortable devices shall be selected. Keeping in mind that the most important factor is anyway the time of use of a RPD during exposure to harmful contaminants, most comfortable devices shall be selected in order to assure the device is used all the time.

**TABLE 3. Difference Between Attenuation of Hearing Protectors Measured in a Laboratory and in Enterprises (BIA, Germany; Pfeiffer, 1992)**

| Hearing Protectors | $\Delta d$ in dB According to Frequencies (Hz) | | | | | $\overline{\Delta d}$ (dB) |
|---|---|---|---|---|---|---|
| | 500 | 1000 | 2000 | 4000 | 8000 | |
| Bilsom POP | −7.5 | −3.4 | −3.1 | −8.0 | −7.4 | −5.9 |
| Bilsom SOFT | −7.5 | −1.1 | −8.1 | −11.7 | −15.2 | −8.7 |
| Cabot EAR | −21.0 | −14.4 | −6.5 | −9.4 | −15.2 | −13.3 |
| Mean value Stöpsel (ear plugs) | −12.0 | −6.3 | −5.9 | −9.7 | −12.6 | −9.3 |
| Bilsom blau 2450 | −5.6 | −2.7 | −6.8 | −4.3 | −4.7 | −4.8 |
| Optac Optigard 4000 | −2.5 | +6.1 | −4.1 | −1.5 | −9.4 | −2.3 |
| Optac Optigard 4000 S | +0.5 | −4.3 | −7.7 | −11.5 | −5.5 | −5.7 |
| Peltor H9A | −11.9 | −6.5 | −4.0 | −0.2 | −3.6 | −5.2 |
| Mean value KGS (ear muffs) | −4.9 | −1.9 | −5.7 | −4.4 | −5.8 | −4.5 |

*Notes.* $\overline{\Delta d}$—arithmetical mean value according to frequency (Hz).

The third study (Pfeiffer, 1992) on noise attenuation characteristics of hearing protectors was carried out by BIA in Germany in a series of enterprises of different industrial sectors. The results (Table 3) show that the effective attenuation values for earplugs were distinctly below what could be expected according to the type test in a laboratory.

Mean differences come up to 13.3 dB for foam plugs and 5.9 to 8.7 dB for glass wool. It would be possible to considerably decrease these differences if workers were instructed on how to correctly use the ear plugs and how to survey their own wearing behaviour. With a mean value of 4.5 dB, differences for ear muffs are distinctly smaller. Control measurements of already worn and new ear muffs prove decreased protective efficiency to be mainly a consequence of ageing and wear. This could be avoided by guaranteeing regular maintenance (substitution of cushions and liners) and limiting the usable life.

## 4. CONCLUSIONS

The results of these studies given as examples are fully in agreement with research of other laboratories. These studies are indispensable to appreciate the level of the representativity of the existing CEN tests methods regarding the risks to prevent and to the various situations and conditions of use. They are also useful to identify additional factors related in particular to comfort that should be objectively assessed in a laboratory. The results of these studies all suggest improving some CEN test methods and focusing more on the proper selection of the devices, and on the information and training of workers on the manner of wearing PPE.

As suggested in the conclusions of the 4th seminar on *Personal Protective Equipment in Europe* held in Kittila, Finland, on December 2–5, 1997, it could be useful

1. to make a synthesis of the studies already carried out by health and safety institutes, manufacturers, trade unions, and so forth, on the real protection, usability, and comfort of PPE in use in Europe, including of course all interested Central and East European countries;
2. to identify the remaining needs and priorities in terms of complementary studies and actions to improve the content of the existing EN standards and the aforementioned characteristics of the PPE;

3. to ask national and European authorities (CEC/DG III[1], CEC/DGV[2], ESF[3], TUTB[4], CEN, etc.) to launch a programme of concerted studies and actions to be carried out in particular by independent and competent research institutes;

4. to establish a network to collate and maintain information and to disseminate it in an appropriate form for a continuous improvement of PPE and EN standards.

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[1] Commission of the European Communities/Directorate General Internal Market and Industrial Affairs

[2] Commission of the European Communities/Directorate General Employement, Industrial Relations and Social Affairs

[3] European Safety Federation (PPE manufacturers)

[4] Trade Union Technical Bureau for Health and Safety

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