Test of Fire Fighter Garments

Protection against fire-smoke polyaromatic hydrocarbons after 24 smoke diving events

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1. Background

Firefighters show an elevated risk of developing certain forms of cancer due to exposure to hazardous substances in the fire smoke. In this context, polyaromatic hydrocarbons (PAH) are of special concern. Penetration of PAHs through the protective garments leads to exposure by skin deposition.

Multiple tests of adsorptive protective clothing developed by CPP Garments AB and Blücher GmbH, Germany, have been carried out between 2019 and 2021 at the fire-fighting exercise facility at Guttasjön, to the south of Borås, Sweden. These tests were made on new, previously unused garments, and on garments that had been used up to twenty-four smoke diving events.

The new unused protective clothing, comprising a conventional standard outer garment and an adsorptive undergarment, showed a protection factor of about 3300 on average. When the same combination of standard outer garment and adsorptive undergarment had been used during twelve smoke diving events (a total of 300 minutes) the protection factor was reduced to 660. This means that the amount of polyaromatic hydrocarbons found under the garments (on the skin-side) was 1/660 (0,15%) of the amount found in the highly concentrated smoke on the outside of the clothing.

The present report presents the result of further testing of the same combination of standard outer garment and adsorptive undergarment, after 24 smoke diving events comprising a total of 600 minutes. The tests were carried out on 24 August 2021, at the same fire-fighting exercise facility as used for the previously reported tests (Guttasjön).

The work has been carried out by:

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- Sarka Langer, Adj. Prof. IVL Swedish Environmental Research Institute, Gothenburg (www.ivl.se).
- Bo Strandberg, Docent, Division of Occupational and Environmental Medicine, Lund University (https://www.lunduniversity.lu.se/lucat/group/v1000552)

2. Objective

The purpose of the test is to determine the degree of protection offered by the tested garments against exposure to polyaromatic hydrocarbons in fire smoke – after use during a total of 24 smoke dives, with conventional washing and drying cycles of both standard outer garments and the adsorptive undergarment between the smoke diving events.

3. Tested materials

The tested garment combinations are:

I. Standard undergarment and standard outer garment. The typical/normal protective clothing worn by Swedish fire-fighters during smoke diving. The standard undergarment has an outer layer of merino wool and an inner layer of viscose from bamboo. The garments were used, but newly washed, according to the standard method used by the fire-department.

II. Novel adsorptive undergarment and standard outer garment. This represents clothing with enhanced protection by the use of the novel undergarment. The adsorptive undergarment had been used for 24 smoke diving exercises each lasting 25 minutes.

Also the outer garment was previously used. Both the outer garments and the undergarments were newly washed according to the standard method used by the fire department.

4. Test method

The test method was identical to the method used in the previous tests conducted and reported by the same team, see reports by CIT Energy Management from 31 March 2021 and 25 May 2021.

PAH sampling procedure

- PAHs were sampled using a passive sampling method comprising polyurethane foam discs (PUF-discs), with a diameter of 14 cm.
- The PUF-discs were attached directly onto the skin of the test subjects (firefighters). Thus, sampling was made on the chest, arm, thigh and neck.
- One PUF-disc was applied on the outside of the outer clothing – directly exposed to the fire smoke.
- The PUF-discs were attached immediately before a smoke-diving exercise.
- The PUF-discs were removed after completion of the smoke-diving exercise.
- The PUF-discs were packed in aluminum foil and transported promptly to the laboratory for chemical analysis.

Smoke diving exercise

The fire was generated by burning pure wood and the temperature at ceiling height was maintained between 170 and 230°C. Three temperature loggers (Tiny Tag) were placed in the outer garment pockets of each fire-fighter; at ankle, waist and chest height. The temperatures during smoke diving ranged between 40°C and 60°C, with the highest temperatures measured by the logger placed high (chest) and the lowest temperatures measured at the low position.

Four fire-fighters were carrying out the smoke diving exercise simultaneously in the test facility. Two of the fire-fighters were dressed in garment combination type I, while the other two were dressed in garment combination type II, according to the description above.

The exercise began with 25 minutes smoke diving. Then the fire-fighters rested during a 25 minute break, leaving clothes and PUF-samplers on. Finally, a second 25-minute smoke diving event took place. The PUF-samplers were removed immediately after the last smoke diving event.

Method for chemical analysis of PAH

At the laboratory for chemical analysis, PAHs were extracted from the PUF-samplers with an Accelerated Solvent Extractor (ASE 350) equipment. The sample was then purified from interferences using a column containing silica gel and finally analyzed on a gas chromatograph with mass spectrometer (GC/MS) equipment.

Results are expressed as the sum of the 35 PAH species listed in Appendix 1. Also the individual compounds were quantified, including the 16 priority PAHs classified by The US Environmental Protection Agency (https://doi.org/10.1016/j.chemosphere.2017.09.106). The quantification is expressed as ng/sampler.

Expression of results

In the present report, the results are expressed as the amount of PAH found on the skin-side as a percentage of the amount found on the outside of the clothing (smoke-side). This result represents the fraction of PAHs that penetrate the garment layers. In one set of diagrams this is denoted "Skin-side to smoke PAH-ratio". In another set of diagrams the performance of the protective clothing is denoted "Protection factor", which simply is the inverse of the skin-side to smoke PAH-ratio.

If, for example, the amount of PAH found on the skin-side is 1% of the amount found on the outside of the clothing (in the concentrated smoke), the skin-side to smoke PAH-ratio is 1%, and the protection factor is 100.

5. Results

Figure 1 shows the result of the 25 + 25 minute smoke-diving exercise with four fire-fighters – two with garment combination type I (standard) and two with garment combination type II (adsorptive). The skin-side to smoke PAH-ratio ranged between 10% and 26% (median = 15%) for the smoke divers who were dressed in the standard protective garments. This means that 10-26% of the PAHs in the smoke penetrated through the clothing. The corresponding penetration for the garment combination comprising the adsorptive undergarment was 0.3% and 2,9% (median 0,8%). The logarithmic scale in Figure 1 clearly shows that the penetration through the adsorptive garment typically was less than one tenth of the penetration through the standard garments. Based on the median values the relation is twentyfold. Figure 2 shows the same result, but expressed as protection factor.

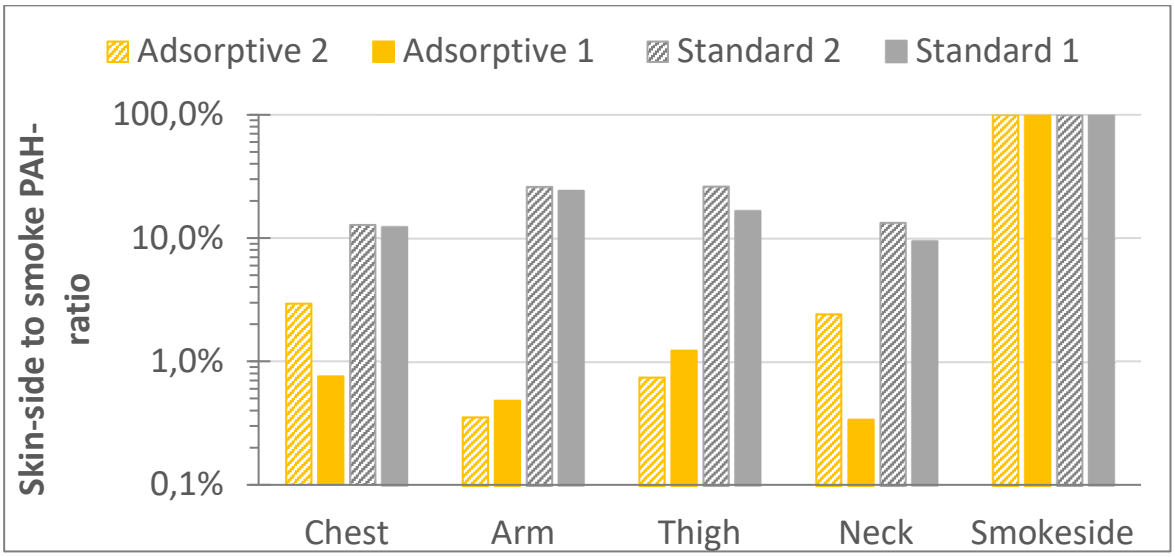

Figure 1. Result from the smoke diving exercise carried out in August 2021. The exercise comprised two 25 minute smoke diving events divided by a 25 minute break. The results have been normalized to the amount of PAH found on the outside (smoke side) of the garments. The garments were all used. The adsorptive undergarment had been used during twenty-four 25 minute smoke dives.

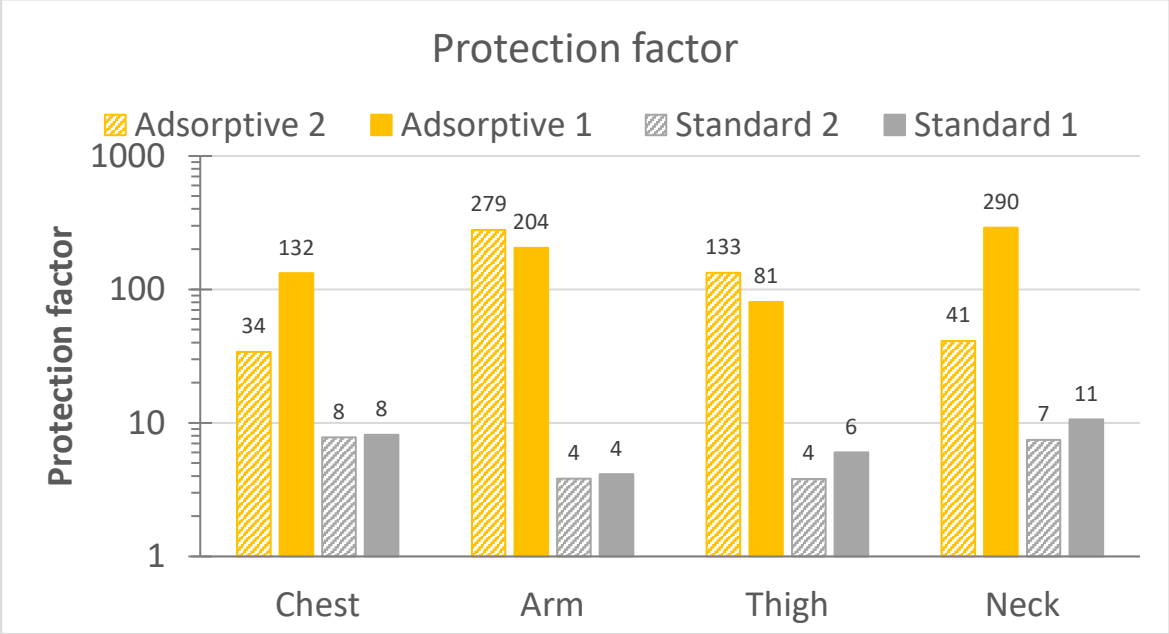

Figure 2. The same results as presented in Figure 1 but expressed as "Protection factor". The smoke diving exercise was carried out in August 2021. The exercise comprised two 25 minute smoke diving events divided by a 25 minute break. The garments were all used. The adsorptive undergarment had been used during 24 smoke dives, 25 minutes each (total 600 minutes).

The box-plots in Figure 3 summarizes the test result. The box to the left shows that the median value for the standard garment is 15%. In the box to the right - representing the adsorptive clothing - the median value is 0.76%. As mentioned above these numbers mean that, based on the median values, the adsorptive garment has a twenty-fold lower penetration of PAHs.

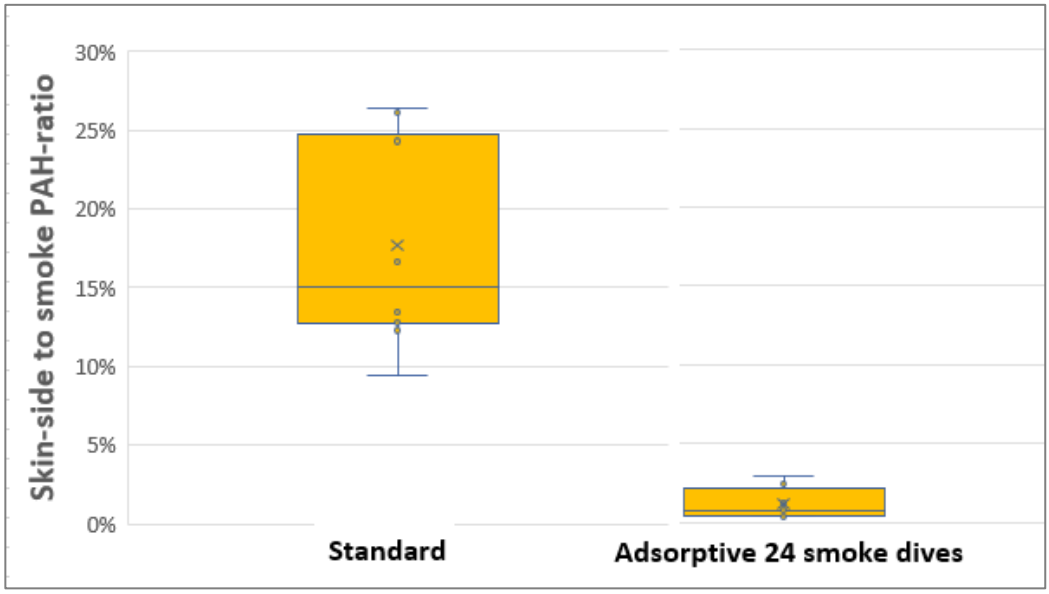

Figure 3. Summary of the test result. The box represents 50% of the observations, i.e. 25% of the observations are under the box and 25% are over (above the box). The cross represents the mean value and the horizontal line within the box is the median value.

To summarize, the median values of the skin-side to smoke PAH-ratio was 15% for the standard garment 15%, and 0.76% for the adsorptive clothing. These values correspond to a protection factor of seven (7) for the standard garment and one hundred thirty-two (132) for the adsorptive.

6. Conclusions

The tests show that

- The tested adsorptive undergarment reduced the PAH penetration through the clothing system substantially.
- After 24 smoke diving events, comprising a total of 600 minutes exposure to wood smoke, the protection factor was found to be about 132 for the garment comprising adsorptive underwear, compared to about 7 for the standard garment.
- The penetration of PAHs is roughly twenty times lower through the used adsorptive garment combination, compared to the standard garment combination.

Appendix 1. Identified and quantified PAHs

naphthalene
2-methylnaphthalene
1-methylnaphthalene
biphenyl
2,3-dimethylnaphthalene
acenaphthylene
acenaphthene
2,3,5-trimethylnaphthalene
fluorene
1-methylfluorene
phenanthrene
anthracene
2-methylphenanthrene
3-methylphenanthrene
1-methylphenanthrene
1-methylanthracene
2-phenylnaphthalene
fluoranthene
pyrene
1-methylfluoranthene
retene
1-methylpyrene
benzo(a)anthracene
chrysene
2-methylchrysene
5-methylchrysene
benzo(b)fluoranthene
benzo(k)fluoranthene
benzo(e)pyrene
benzo(a)pyrene
perylene
indeno(1,2,3-c,d)pyrene
dibenzo(a,h)anthracene
benzo(g,h,i)perylene
coronene

The 16 priority PAHs classified by The US Environmental Protection Agency are indicated in *italic* font. (https://doi.org/10.1016/j.chemosphere.2017.09.106).