Toxicology Letters 192 (2010) 61–65

Contents lists available at ScienceDirect

Toxicology Letters

journal homepage: www.elsevier.com/locate/toxlet

Fire fighting trainers' exposure to carcinogenic agents in smoke diving simulators

Juha Laitinen[a,*], Mauri Mäkelä[b], Jouni Mikkola[c], Ismo Huttu[d]

[a] Finnish Institute of Occupational Health, PO Box 93, FI-70701 Kuopio, Finland
[b] Finnish Institute of Occupational Health, Oulu, Finland
[c] Finnish Institute of Occupational Health, Helsinki, Finland
[d] Emergency Services College, Kuopio, Finland

ARTICLE INFO

Article history:
Available online 1 July 2009

Keywords:
Fire fighter
Smoke diving
Dermal exposure
Smoke diving simulators
Benzene
Muconic acid
1-Naphthol
Polycyclic aromatic hydrocarbons
1-Pyrenol

ABSTRACT

It is well known that fire fighters are potentially exposed to various carcinogenic agents at a fire scene. An almost unheeded issue, however, is fire fighters' exposure to carcinogenic agents in smoke diving simulators. Biomonitoring (urinary muconic acid, 1-naphthol and 1-pyrenol), dermal (polycyclic aromatic hydrocarbons) and occupational hygiene measurements (cyanides, hydrogen cyanide, polycyclic aromatic hydrocarbons, volatile organic compounds and formaldehyde) were used to determine how the burning material, the type of simulator and protective clothing used affect fire fighting trainers' exposure.

The highest excretion of 1-pyrenol (sampled 6 h after end of exposure, in average 4.3–9.2 nmol/L) and emissions of benzene (1.0–2.5 mg/m^3) and hydrogen cyanide (0.2–0.9 mg/m^3) were measured during the burning of conifer plywood and chipboard, and the lowest when pure pine and spruce wood (1.5 nmol/L, 0.6 mg/m^3, and 0.05 mg/m^3) was burned. However the safest burning material seemed to be propane (1.0 nmol/L, 0.2 mg/m^3, and not measured).

The type of simulator used affected trainers' exposure very clearly. The highest dermal whole body exposures to polycyclic aromatic hydrocarbons were measured in the fire house simulator (in average 1200 ng/cm^2). Clearly lower exposure levels were measured in container training sessions (760 ng/cm^2), where the average dermal exposure level was 35% lower than in the fire house. The exposure levels (30 ng/cm^2) in the gas simulator in turn, were only 4% of the levels in container training sessions. The amount of polycyclic aromatic hydrocarbons decreased by 80% on trainers' hands when they used under gloves (in average 8.7 ng/cm^2) compared to those (48.4 ng/cm^2) who did not. There was not difference in protection efficiency against polycyclic aromatic hydrocarbons between tested fire suits (Brage and Bristol).

1. Introduction

In new fire extinction techniques for burning buildings, smoke divers' preliminary work is crucial. They are the first rescue forces to go inside and try and find possible victims and the initial point of the fire, and their efforts make it possible to direct fire extinction procedures to the right targets. Although this technique has greatly minimized water damage in buildings, it has also increased fire fighters' risk of exposure to carcinogenic agents.

Smoke divers should be safe from chemicals in their protective fire suits, fire gloves and compressed air line breathing protectors. Unfortunately, in many epidemiological studies, the risk of cancer among fire fighters has been found to be much higher than that of the normal population. An elevated metarelative risk of multiple myeloma, and, in addition, a probable association with non-Hodgkin lymphoma and with prostate and testicular cancer have been found (LeMasters et al., 2006). It is well known that fire fighters may be exposed to various mixtures of particulates, gases, mists and fumes (Brandt-Rauf et al., 1988; Kirchner and Savolainen, 1998; Savolainen and Kirchner, 1998; Edelman et al., 2003) in fires, but almost unrecognized is the fact that fire fighters' also face exposure to carcinogenic agents in smoke diving simulators. This raises the question: how significant a role do these training sessions play in fire fighters' lifetime exposure to carcinogens?

In Finland, active fire fighters are required to annually update their smoke diving licence. This procedure is in place to ensure fire fighters' work ability in real accidents. Part of their training under conditions resembling real situations involves smoke diving simulators. Smoke diving trainers at the Emergency Services College are responsible for fire fighting students training in these simulators, which mean as many as 120 smoke diving tasks per year

* Corresponding author. Tel.: +358 40 5023714; fax: +358 30 4747474.
E-mail address: Juha.Laitinen@ttl.fi (J. Laitinen).

0378-4274/$ – see front matter © 2009 Published by Elsevier Ireland Ltd.
doi:10.1016/j.toxlet.2009.06.864

for each trainer. Trainers, rather than fire fighters, were chosen for the study, because they have more information on how to lower exposure through this training method, on emissions of burning materials, and on the best protective clothing. In addition they are the most heavily exposed group of fire fighters.

This study thus showed how fire fighting trainers can be exposed to carcinogenic agents, and how it is possible to decrease this exposure in normal training situations by choosing different burning material, type of simulator and protective clothing. We also give new recommendations on how biomonitoring should be used in fire fighters' routine exposure follow-ups.

2. Materials and methods

2.1. Occupational applications

2.1.1. Fire house and gas simulators

The first aim of the fire house and gas simulator tests was to evaluate how burning material affects trainers' exposure. Four different burning materials were tested. The first three tests were performed in a fire house simulator in Kuopio and the fourth one in a gas simulator in Paris. The fire house simulator was a block of flats (three floors) built mainly from concrete, but the partition walls were made of burning material. The fire house simulator has been developed as a training location where fire fighters can be trained in victim rescuing and extinction techniques inside buildings.

In the first test, the partition walls of the fire house simulator were made from chipboard. The burning of chipboard released a great deal of heat, which alone made diving conditions in the simulator extremely difficult. To make the conditions even harder, trainers decreased the visibility distance in the simulator as much as possible by burning polystyrene foam, which emits black smoke inside the simulator. As a firing liquid kerosene was used, which together with chipboard and polystyrene foam made working conditions very dangerous to the fire fighters' health.

In the second fire house simulator test, the material of the partition walls was replaced by board made from conifer plywood. This board material contained less glue than chipboard. In addition, kerosene was replaced by sinol, which contains 80% ethanol. Polystyrene foam was not burned in this case. The usefulness of undergloves worn under fire gloves was tested in fire house simulator tests. Half of the smoke divers used undergloves and half did not when chipboard and conifer plywood were burned.

In the third fire house simulator test, the partition walls were made of pure spruce wood, and sinol was used as the firing liquid.

Four smoke diving trainers participated in each fire house simulator test. They performed three smoke dive tasks, one of which lasted an average of 30 min. They used fire fighter suits manufactured by Bristol (Gore-Tex Smart, Ergotec) and Brage (Europ 2000, Nomex III), and wore respirators by Dräger (Pss 90, Panorama Nova P Supra) in all simulator tests. All trainers used undergloves.

In the gas simulator test (one floor), the burning material was propane and the artificial smoke was made of mineral oil by a smoke generator. Two smoke diving trainers participated in this test; both dived three times each, and each smoke dive task lasted for an average of 30 min. Trainers used Bristol fire fighter suits and Dräger respirators. Both trainers used undergloves. All participants in all tests were non-smokers.

2.1.2. Container simulator

The second aim of the testing procedure in the container simulator (one floor) was to evaluate the protection effectiveness of different fire fighter suits. The container simulators are designed for training, which teaches fire fighters to identify explosive fire gas, and how to control it with a water shower.

Four smoke diving trainers participated in the tests, each smoke diving three times, the average duration of one dive being 30 min. Trainers used Dräger respirators. The difference of protection effectiveness of the fire fighter suits was tested by dermal exposure measurements taken from the trainers' skin surface under the protective fire suit, from the chest and back areas. In the first session, two of the four trainers wore Bristol fire fighter suits, and two wore Brage fire fighter suits. The second training session was similar, but the trainers changed their fire fighter suits. The burning material was conifer plywood board and the firing liquid used was sinol. All participants were non-smokers.

2.2. Methods

Biomonitoring, occupational hygiene, and dermal exposure measurements were used to determine trainers' exposure to chemicals. To be able to measure trainers' total exposure, their urinary 1-pyrenol (Jongeneelen et al., 1987), 1-naphthol (Keimig and Morgan, 1986) and muconic acid (Ducos et al., 1990) excretion were measured before exposure, immediately after exposure, 6 h after the end of exposure, and again the following morning.

Dermal exposure was measured by a dermal exposure sampler, which was located on the surface of the skin. They were taken from trainers' chest and back areas, which were under protective suits. The trainers washed their hands with sunflower oil before lunch and immediately after the work day: the oil was rubbed into their hands, which then were wiped with cellulose ester towels. Then the towels were analysed, and 15 different polycyclic aromatic hydrocarbons were measured (Mäkelä and Pyy, 1995).

The air concentrations of polycyclic aromatic hydrocarbons, hydrogen cyanide, cyanides, formaldehyde, and volatile organic compounds were measured in the air of the simulator during training. All air samples were stationary samples from a fixed place of the corridor in simulators, where smoke divers waited their turn for the next smoke diving session. Samples were taken during smoke diving actions, when doors from the corridor were open directly to the simulators.

3. Results and discussion

3.1. The effect of burning materials on fire fighting trainers' exposure

The burning of polystyrene foam affected hydrogen cyanide concentrations in the simulator (Fig. 1). Hydrogen cyanide emissions decreased by almost 80% when the burning of polystyrene foam was stopped. When conifer plywood was replaced with pure spruce and pine wood, hydrogen cyanide emission decreased even more, by almost 95%. There might be a potential risk of exposure to hydrogen cyanide in smoke diving simulators, or at least the risk is present in real fire overhauls (Bolstad-Johnson et al., 2000). Hydrogen cyanide has very drastic effects on respiratory chain, thus all fire fighters must be made aware of these effects.

The total emissions of the volatile organic compounds showed the same trend as hydrogen cyanide concentration. The most significant volatile organic compounds in the air were benzene, aliphatic hydrocarbons, and phenol compounds. We focused on the concentration of carcinogenic benzene, of which the burning of conifer plywood emitted the highest concentrations (Fig. 2). The concentration of benzene during the burning of chipboard was on average 40% of that measured during the burning of conifer plywood. The concentration of benzene emissions from the burning of pure spruce and pine wood, on the other hand, was 20% of that emitted from the burning of conifer plywood. However, according to our results, the safest burning material seems to be propane: its emission of benzene was on average only 10% of that form the burning of conifer plywood.

Because benzene concentrations in the air of simulators were high, trainers' urinary muconic acid excretion was followed up (Fig. 3). The excretion of muconic acid showed that the burning of conifer plywood caused greater exposure to benzene for the trainers than the burning of pure spruce and pine wood or propane.

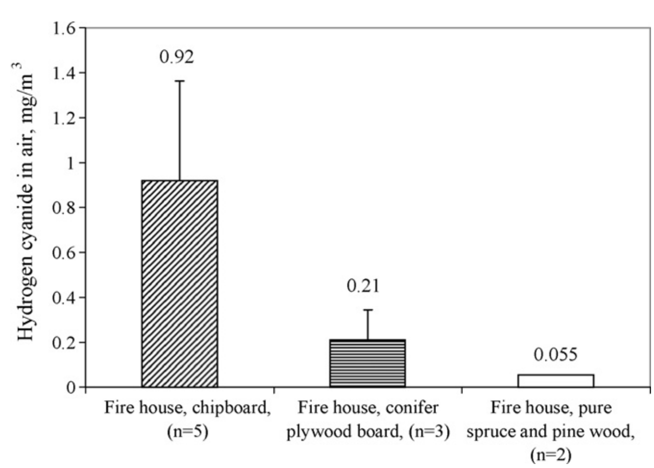

Fig. 1. The effect of burning materials on hydrogen cyanide air concentration (mean ± S.D. or mean) in simulators.

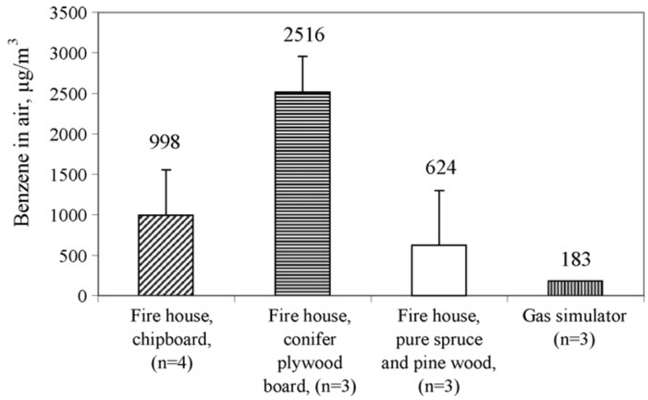

Fig. 2. The effect of burning materials on benzene air concentrations (mean ± S.D. or mean) in simulators.

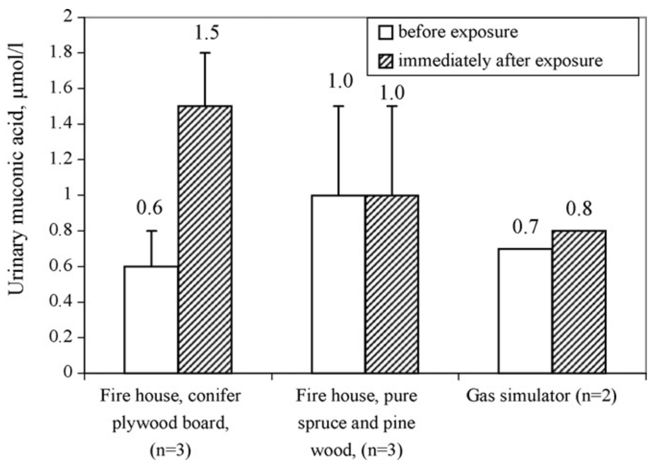

Fig. 3. Fire fighting trainers' urinary excretions of muconic acid (mean ± S.D. or mean) before exposure and immediately after exposure, when they used different burning materials.

Fire fighters' increased muconic acid excretion proved that trainers might still be exposed to benzene, despite a high level of protection. Bolstad-Johnson et al. have also reported benzene concentrations, which exceeded occupational limit value in fire fighters' breathing zones during fire overhaul (Bolstad-Johnson et al., 2000).

Exposure to polycyclic aromatic hydrocarbons was measured by following fire fighters' urinary 1-pyrenol excretions in time (Fig. 4).

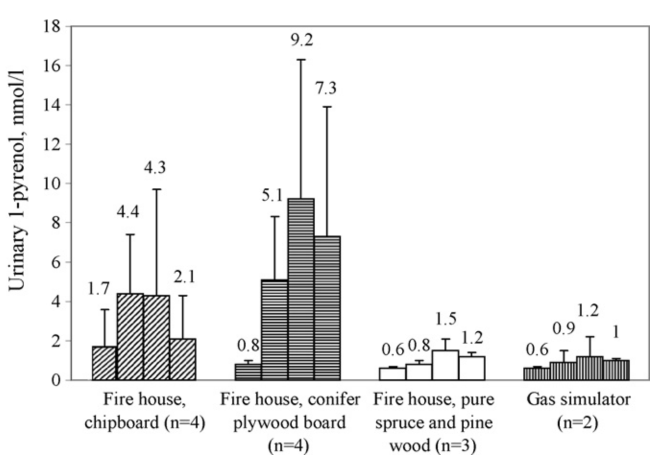

Fig. 4. Fire fighting trainers' urinary excretion of 1-pyrenol (mean ± S.D. or mean) before exposure, immediately after exposure, 6 h after the end of the exposure and next morning, when they used different burning materials.

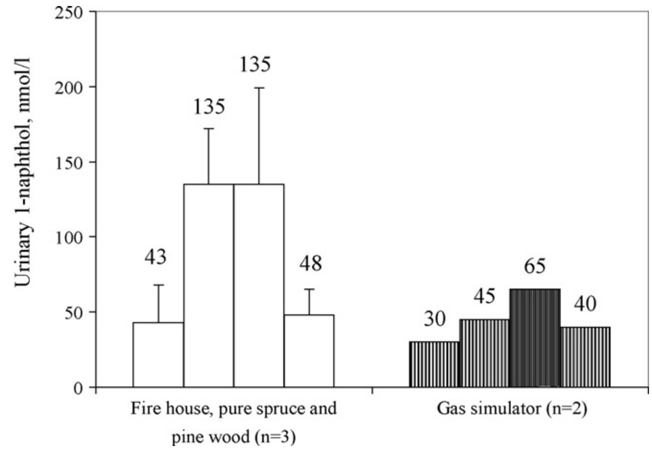

Fig. 5. Fire fighting trainers' urinary excretion of 1-naphthol (mean ± S.D. or mean) before exposure, immediately after exposure, 6 h after the end of the exposure and next morning (mean only), when they used pure spruce and pine wood and gas as burning materials.

The highest exposure levels were measured when conifer plywood was burned, the second highest being recorded when chipboard was burned. The ratio between pyrene and benzo(a)pyrene concentrations in the air samples was on average 1.9 in the fire house and 9 in the gas simulator. Using Bouchard and Viau's proposed biological action limit value for 1-pyrenol and the equations introduced by Jongeneelen, we recommend a biological action limit value of 16 nmol/L for 1-pyrenol in fire fighting trainers' exposure evaluations (Bouchard and Viau, 1999; Jongeneelen, 2004).

Trainers' 1-pyrenol excretions after exposure were below the concentrations measured in non-exposed population, when spruce and pine wood or propane was burned. However, the difference between these burning materials could be detected by following the fire fighters' urinary excretion of 1-naphthol (Fig. 5). The trainers' excretions of 1-naphthol after trainings in the gas simulator were only 50% the excretions when pure spruce and pine were burned.

The emissions of formaldehyde were the highest in the gas simulator (Fig. 6). The reason for this was probably the artificial smoke, which was produced by mineral oil in the smoke generator. Pure spruce and pine wood seemed to be the best material according to these results. Formaldehyde has also been found to be a problem in wild land fires, where the highest measured formaldehyde concentrations have been over the occupational exposure limit value of 0.37 mg/m^3 (Materna et al., 1992).

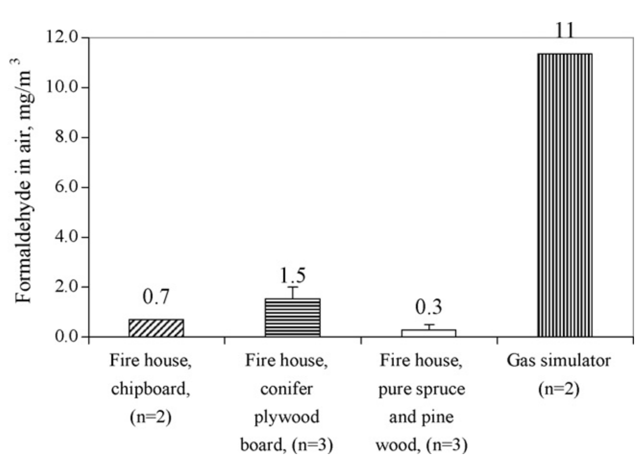

Fig. 6. The effect of burning materials on formaldehyde air concentration (mean ± S.D. or mean) in simulators.

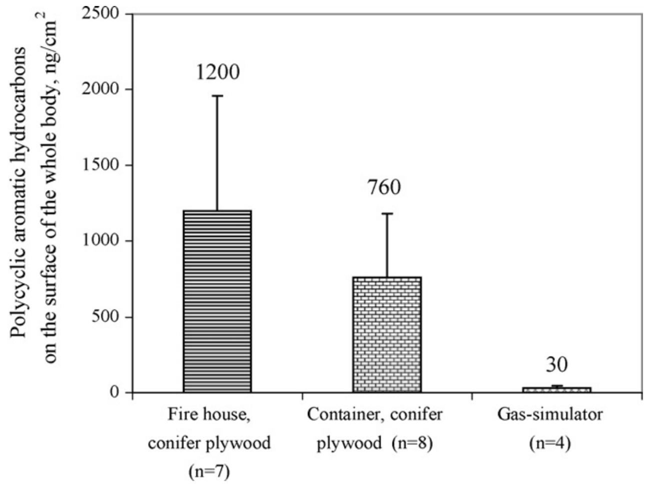

Fig. 7. The effect of the type of simulator on fire fighting trainers' dermal exposure to polycyclic aromatic hydrocarbons (mean ± S.D.).

3.2. The effect of protective clothing on fire fighting trainers' exposure

The use of undergloves had a significant effect on fire fighters' exposure through the hands to polycyclic aromatic hydrocarbons in the fire house simulator training. The amount of polycyclic aromatic hydrocarbons on trainers hands decreased by 80% if they used undergloves ($8.7 \pm 3.9\,ng/cm^2$, $n = 8$) compared to those ($48.4 \pm 8.7\,ng/cm^2$, $n = 12$) who did not.

There was no difference in protection effectiveness against polycyclic aromatics between tested fire suits. In the comparison study, exposure time was also taken into account. The whole body dermal exposure to polycyclic aromatic hydrocarbons was $13.5 \pm 8.9\,ng/cm^2\,min^{-1}$ ($n = 8$) using Bristol fire suit and $14.4 \pm 10.8\,ng/cm^2\,min^{-1}$ using Brage fire suit ($n = 8$).

3.3. The effect of the type of simulator on fire fighting trainers' exposure

The type of simulator used affected trainers' exposure very clearly. As dermal exposure seemed to be the main route of exposure to polycyclic aromatic hydrocarbons, dermal exposure measurements were used to determine the effect of the type of simulator on fire fighting trainers' exposure. Exposure to polycyclic aromatic hydrocarbons was highest in the fire house simulator training sessions (Fig. 7). The level of dermal exposure in the container simulator was only 65% the dermal exposure in the fire house simulator. The amount of polycyclic aromatic hydrocarbons after training in the gas simulator was only 4% the amount observed after the container simulator tests. In addition, in air samples, the concentration ratio between pyrene and benzo(a)pyrene was on average 1.9 in the fire house simulator. In the gas simulator, the corresponding ratio was 9. This also proves that artificial smoke is not as dangerous as real smoke.

4. Conclusion

The highest excretion of 1-pyrenol and muconic acid and emission of benzene and hydrogen cyanide were measured during the burning of conifer plywood and chipboard, and the lowest when pure pine and spruce wood was burned. However, the safest burning material seemed to be propane. As a result of these findings, we suggest glueless wood or gas as the safest burning material, and sinol as the safest firing liquid. Moreover, it is absolutely imperative that polystyrene foam no longer be burned.

The use of undergloves decreased the amount of polycyclic aromatic hydrocarbons on trainers' hands by almost 80%. However, no difference was found in the protection effectiveness between different manufacturers' fire fighting suits.

The highest dermal exposures to polycyclic aromatic hydrocarbons were measured in the fire house simulator. Clearly lower exposure levels were measured in container training sessions, where the average whole body dermal exposure level was 35% lower than in the fire house. The exposure levels in the gas simulator in turn, were only 4% the levels in container training sessions.

The risk of exposure to carcinogenic agents is highest in a simulator which has more than one floor, and where training is simultaneously being carried out on different floors. In order to decrease exposure, we suggest a one-floor simulator only for normal training. If it is necessary to use a block of flats, we suggest to organize the training in such a way that trainers burn only one floor at a time.

Inhalation exposure can be decreased by choosing smokeless places for feedback sessions and having breaks between smoke diving sessions. Fire fighter suits have to be removed during breaks in recovery room to prevent fire gases entering the trainers' breathing zones between smoke diving sessions.

Dermal exposure can be decreased by using undergloves during the smoke diving session, and especially during the maintenance of smoke diving equipment. It is also possible to decrease whole body dermal exposure by choosing the right burning materials and removing polycyclic aromatic hydrocarbons form the surface of the skin by washing it immediately after exposure.

Trainers' health should be followed up more closely at work, because of the risk of cancer. For routine exposure follow-ups we recommend biomonitoring urinary 1-pyrenol, 1-naphthol and muconic acid. We also suggest that 16 nmol/L for 1-pyrenol is a suitable biological action limit value for taking actions for risk reduction in the fire house and container simulator training sessions.

According to the observations of this study, trainers' exposure to carcinogenic agents can be diminished by re-arranging smoke diving procedures, conditions and regulations.

Conflict of interest statement

None.

Acknowledgements

The authors wish to thank the Finnish Work Environment Fund for financial aid. We also thank Alice Lehtinen for the language revision.

References

Bouchard, M., Viau, C., 1999. Urinary 1-hydroxypyrene as a biomarker of exposure to polycyclic aromatic hydrocarbons: biological monitoring strategies and methodology for determining biological exposure indices for various work environments. Biomarkers 4 (3), 159–187.

Bolstad-Johnson, D.M., Burgess, J.L., Grutchfield, C.D., Storment, S., Gerkin, R., Wilson, J.R., 2000. Characterization of firefighters exposures during fire overhaul. Am. Ind. Hyg. Assoc. J. 61 (5), 636–641.

Brandt-Rauf, P.W., Fallon Jr., L.F., Tarantini, T., 1988. Health hazards of fire fighters: exposure assessment. Br. J. Ind. Med. 45, 606–612.

Ducos, P., Gaudin, R., Robert, A., Francin, J.M., Maire, C., 1990. Improvement in HPLC analysis of urinary trans, trans-muconic acid, a promising substitute for phenol in the assessment of benzene exposure. Int. Arch. Occup. Environ. Health 62, 529–534.

Edelman, P., Osterloh, J., Pirkle, J., 2003. Biomonitoring of chemical exposure among New York City firefighters responding to the World Trade Center fire and collapse. Environ. Health Perspect. 111, 1906–1911.

Jongeneelen, F.J., Anzion, R.B.M., Henderson, P.Th., 1987. Determination of hydroxylated metabolites of polycyclic aromatic hydrocarbons in urine. J. Chromatogr. 413, 227–232.

Jongeneelen, F., 2004. Guidelines for biological monitoring of workers in aluminium production facilities for urinary 1-hydroxypyrene (1-pyrenol). J. Environ. Monit. 6, 61–65.
Keimig, S.D., Morgan, D.P., 1986. Urinary 1-naphthol as a biological indicator of naphthalene exposure. Appl. Ind. Hyg. 1, 61–65.
Kirchner, N., Savolainen, H., 1998. Triage of Fire Smoke Intoxicated Victims in a Disaster Situation. Internet J. Rescue Disaster Med. 1 (2).
LeMasters, G.K., Genaidy, A.M., Succop, P., Deddens, J., Sobeih, T., Barriera-Viruet, H., Dunning, K., Lockey, J., 2006. Cancer risk among firefighters: a review and meta-analysis of 32 studies. J. Occup. Environ. Med. 48 (11), 1189–1202.
Materna, B.L., Jones, J.R., Sutton, P.M., Rothman, N., Harrison, R.J., 1992. Occupational exposures in California wildland fire fighting. Am. Ind. Hyg. Assoc. J. 53 (1), 69–76.
Mäkelä, M., Pyy, L.J., 1995. Effect of temperature on retention time reproducibility and on the use of programmable fluorescence detection of fifteen polycyclic aromatic hydrocarbons. J. Chromatogr. A 699, 49–57.
Savolainen, H., Kirchner, N., 1998. Toxicological mechanism of fire smoke. Internet J. Rescue Disaster Med. 1 (1).