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Phosphorus, Inorganic & Nitrogen Flame Retardants Association

Pinfa Newsletter special edition n°70

fire smoke toxicity

Fire Toxicity 2016 UCLan Preston, UK, 22-23 March 2016

COFISH Aalborg University, Copenhagen, 15th April 2016

*This special issue of pinfa Newsletter summarises **two international conferences addressing the toxicity of smoke and soot from fires**. pinfa recognises the importance of this question, given the concerns about the increased rate of cancer suffered by firefighters (see pinfa Newsletter n°66). The conference presentations and discussions confirm that uncontrolled fires burn mainly in oxygen-deprived conditions with incomplete combustion. Thus all fires will generate potentially toxic partial combustion products. The need is recognised to work to improve protection of firefighters from exposure to smoke and soot (e.g. through procedures, personal protective equipment, equipment washing). It is also clear that knowledge needs to be completed concerning emissions from different materials depending on the type of fire, in particular to support improvement of legislation to reduce smoke emissions and toxicity.*

There is an agreed need for more research and testing and for continuation of the dialogue engaged at these conferences, in order to better understand smoke emissions and toxicity.

*This Newsletter **summarises the speakers' presentations and participant discussions** at these two conferences, transcribed as accurately as possible, and are not validated by or positions of pinfa. They are intended as a contribution to dialogue and information.*

*Recognising the importance of improving information about how PIN flame retardants can impact smoke toxicity, pinfa is launching work to bring together and assess available literature and study data, and define needs for further information. **All input of data or information is welcome**.*

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Fire Toxicity 2016 UCLAN Preston, UK, 22-23 March 2016

Organised with support of the EU FLARETEX COST Action MP 1105, and the University of Central Lancashire

Conference summary below prepared by Anna Stec and Richard Hull.

http://www.uclan.ac.uk/news/international-conference-fire-toxicity.php

The organisers opened the conference by underlining that the inhalation of toxic smoke is the biggest killer and the largest cause of injury in fires, but is a neglected area of fire science and fire safety engineering. This conference highlighted the health concerns in a multidisciplinary way: on the first day scientists described the evolution and measurement of toxic products from fires, while medical practitioners described dealing with the short and long-term care of fire victims; the second day was devoted to the issues of fire fighter safety and the abnormally high rates of cancers amongst them; the third day focused on the regulatory framework that currently fails to protect fire victims from smoke inhalation, and how this problem may be addressed.

Quantification and Assessment of Acute Toxicants

Richard Hull, University of Central Lancashire (UCLan), introduced the chemical and physical aspects of smoke toxicity. He discussed the importance of material composition in defining released combustion gases in case of fire and their potential toxicity. The fire conditions are also important: if the fire is under-ventilated, which is almost inevitably the case for uncontrolled fires, then the yields of toxic products, such as CO and HCN are typically a factor of 10 to 50 greater than with a small, well ventilated fire.

David Purser CBE (awarded for services to fire safety in 2015) went on to explain the physiological basis of fire toxicity, focusing on the sequence of effects during fires, the toxicology of CO and HCN, how carbon dioxide (CO_2) enhances uptake of these gases by stimulating respiration. He considered in detail the incapacitating effects of HCN at sub-lethal concentrations.

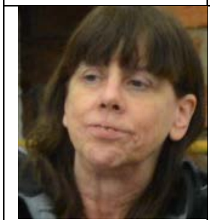
Mark Sabbe, University of Leuven and a practicing emergency physician at the university hospitals, was responsible for setting up the European Guidelines for the Therapy of Smoke Inhalation Victims. Prof. Sabbe described the assessment and treatment of fire victims, emphasizing the need to understand quickly what the victim had inhaled, and hence the diagnostic value of knowing what fuels had contributed to the fire. He outlined the benefits of hydrogen cyanide antidotes, and observed that HCN was a significant toxicant in most fire smoke victims.

Ken Dunn, a consultant burns injury surgeon in Manchester, UK, and the medical director of the international burn injury database (IBIDB) described the treatment needed to keep fire victims alive, aid their recovery in the longer term, and deal with the frequent complications resulting from damage to the lungs by fire effluents, combined with the secondary effects of skin burns. He had found that around a third of fire smoke deaths were missing from the UK datasets because the fire had gone out before the victim was discovered, so that the Fire Services, who collect this information, had not been involved. He also explained that the UK was unusual in not sending physicians to the fire scene, resulting in 4 to 6 hours' delay before specialist medical care was provided.

Anna Stec, University of Central Lancashire (UCLan), outlined the methods and challenges of quantifying the toxicity of fire effluents: both the acute toxicants and irritants responsible for preventing escape from a fire and the cocktail of other carcinogens and toxicants present in fire effluents, including polycyclic aromatic hydrocarbons (PAHs), isocyanates, dioxins etc. In general, specialised methods were needed to quantify individual species at the toxicologically significant levels that were present in fire effluents.

Toxicity from large scale fires

Richard Walker, West Midlands Fire Service, burned eight identical sofas in different ventilation conditions in a three bedroomed house, and compared the tenability at various locations. This data provides valuable input to better define fire and rescue service procedures in emergency rescue, and provides data on emission and dispersion of toxicants during a residential fire.

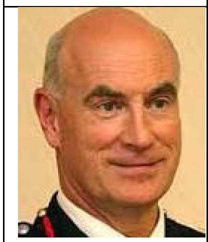


Beth Weckman University of Waterloo in Canada, compared sofas which were purpose built, using materials compliant with the UK and former Californian standards to those from jurisdictions without such stringent furniture fire safety standards. The tests were conducted under typical domestic ventilation conditions, rather than the artificially high ventilation of a fire test rig. The fire retarded sofas showed a slower rate of fire growth, but higher carbon monoxide concentrations than those non-fire retarded sofas.

David Crowder, UK Building Research Establishment (BRE), described his role as the fire investigator responsible for reporting the failures in specification or compliance with UK building codes which have led to fire deaths. He described the investigation of a number of high profile incidents, and their re-creation in facilities where the toxicity of effluents had been quantified, and used to explain the fatalities.

Francine Amon, SP Fire Research, Sweden, showed how fire effluent dispersal, into air, water and land, had adverse effects on the built and natural environment. Firefighting strategies had a significant influence on the effluent dispersal route.

Firefighter's perspective: understanding fires and risks



Peter Holland CBE, Chief Fire and Rescue Advisor to the UK Government, outlined the changing role of the fire and rescue services from firefighting towards risk management and fire prevention, and highlighted further areas for improvement, including making better use of the UK's Fire Statistics by improving transparency and accessibility. He lamented the time it took for the lessons from fire disasters to become available and particularly the lack of firefighters' awareness about the dangers of sandwich panels in fires.

Tommy Kjaer, firefighter and founder of the Danish Fire Fighters' Cancer Organisation, explained that fires had become faster growing and more toxic. Coinciding with the day of the Brussels bombings he described scenes where most people were rushing to escape, but firefighters were rushing in to help the victims, disregarding their own safety. He identified heart problems, brain damage (often misdiagnosed), post-traumatic stress disorder and cancers as the major occupational injuries of firefighters, highlighting carcinogens in fire smoke as the major cause of death, resulting from absorption through lungs, skin and contaminated uniforms and equipment. He stressed the need for scientists and fire fighters' cancer organisations to continue working together for the common good, for fire fighters, citizens, environment and society. "We are all important pieces of the puzzle to see the bigger picture".

Donald Lucas, Lawrence Berkeley National Laboratory in California, outlined his work on the formation of toxic products during fires, and especially the inhalation of combustion derived particulates, causing 10 million deaths per year worldwide (including diesel fumes, wood burning industry and agriculture). He showed that the smaller the particle, the larger the adverse health effects, but that after emission, agglomeration reduced the toxicity. However, the time and distance scales over which this occurred were largely unknown.

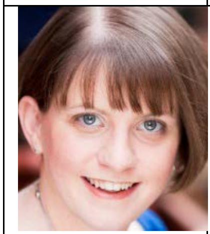
Jeff Burgess, qualified physician, and specialist in occupational health of firefighters at the University of Arizona, presented the different stages of firefighting operations, highlighting those such as overhaul (ensuring the fire was completely extinguished) where breathing apparatus was not normally worn. He compared the effects of different personal protective masks (air purifying respirator (APR) cartridges were much less effective than chemical, biological and radiological and nuclear (CBRN) masks). He noted that studies looking for toxic and carcinogenic substances using epigenetic and micro-RNA markers, provide clear evidence of links between exposure and the various occupational diseases of firefighters: a peak in carcinogenic PAH metabolites was found in urine two hours after firefighter exposure.

Doug Daniels, US National Institute for Occupational Safety and Health (NIOSH), has investigated the overall excess cancer incidence in firefighters, including oesophagal, intestinal, lung and kidney cancers. He identified the exposure to PAHs, formaldehyde, benzene, asbestos, diesel exhausts and shift work as increasing cancer risk, and suggested that dermal exposure, rather than inhalation, may be the main route. He went on to explain the difficulties of proving links to increased susceptibility of firefighters, who were healthier than the general population. For example, only mesothelioma and oral cavity cancer showed as proven firefighter occupational diseases in pooled studies, based on large numbers of smaller studies, compared with the larger number of occupational cancers in the International Agency for Research on Cancer (IARC) findings.

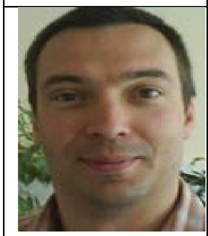
Susan Shaw, State University of New York-Albany and Marine and Environmental Research Institute, described studies on cancer and firefighters, opening with the statement that cancer is the leading cause of line-of-duty deaths amongst fire fighters, accounting for approximately 60% of all deaths. The proportion of cancer deaths had been growing steadily from the 1970s to the present, in tandem with the increase in synthetics and plastics in homes and buildings. Studies were needed to assess the broad range of chemicals that may accumulate in firefighters, many of which have not been analysed. Structure fires today are a 'toxic soup" containing numerous carcinogens. Her study of California firefighters showed higher levels of PBDE fire retardants, brominated dioxins/furans and perfluorooctanoaic acid (PFOA) in firefighters' blood than the general population. These levels were similar to those in workers recycling furniture foam and e-waste, who were subject to constant occupational exposure. Moreover, toxics' absorption through skin increases by a factor of four with every 5 °C rise in temperature.

David Wales, Kent Fire and Rescue Service UK, has studied human behaviour in accidental dwelling fires, collecting detailed information from over 700 of Kent's fire victims. This shows a uniform age distribution of injuries, but higher rates of death for the over-forties and the highest for the over-eighties. Currently, available data describes the volume of smoke, but potentially this could be extended to cover descriptions of its irritancy.

Regulatory assessment of fire toxicity



Beth Dean, Exova Warringtonfire, UK, described development and validation of toxicity test methods for European railways EN 45545-2. Fire safety on trains is obtained through the combination of many considerations together, including material fire toxicity assessment. Two European projects (FIRESTARR 1997 to 2001 and TRANSFEU 2009 to 2012) aided the development of test methods which quantify 8 gases relevant to acute toxicity which could hinder escape from a fire. She described how a modified smoke chamber test coupled to Fourier transform infrared spectroscopy (FTIR) had been validated through numerous test fires in real railway carriages. She observed that it would be inappropriate for other industries to use this test method without reviewing its applicability and conducting appropriate validation exercises.



Eric Guillaume, Effectis France, described the development of FTIR spectroscopy for the analysis of fire gases, particularly EN 45545, and explained the detailed calibration and validation requirements necessary to produce a valid analytical data for the main gases normally considered in acute toxicity assessment. He proposed a systemic approach at building level, using fire safety engineering, to assess the fire toxicity of both contents and construction products, using appropriate design fire scenarios for fire safety assessment.

David Purser, CBE, and visiting professor at UCLan, compared the different methods for assessment of fire effluent toxicity and related the results of each to large-scale fire behaviour. He concluded that the steady state tube furnace (ISO TS 19700) was capable of replicating both well-ventilated and under-ventilated flaming, together with the more expensive fire propagation apparatus (ISO 12136), while the modified smoke chamber and controlled atmosphere cone calorimeter appeared to only replicate well-ventilated combustion, and the conditions in the NF X 70-100 were poorly defined, but possibly intermediate between well-and under-ventilated flaming. He then described how the visual obscuration and irritancy of fire smoke increased people's escape times, highlighting the need to use incapacitation (when the victim can no longer effect their own escape), and not death, as the endpoint in fire safety prediction, and the value of applying toxicity data to fire engineering calculations.

Smoke toxicity in fire safety regulation

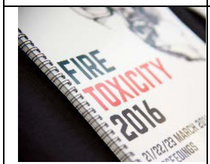
Gwenole Cozigou, European Commission DG GROW (Internal Market, Industry, Entrepreneurship and SME's) is responsible for the Construction Products Regulations. He asked whether additional regulatory measures were needed to address smoke toxicity, since it is seen as the biggest cause of death and injury in fires. He suggested, in particular, to consider the large changes in methods and materials of construction, and the lack of a common approach by Member States when adopting new building regulations. He also observed that fire safety in buildings was not solely determined by construction materials, but also by contents, and other fire safety engineering aspects. In certain cases, for example, better alarm systems may be an effective way to achieve fire safety. The question of smoke toxicity on the health and safety of firefighters and other workers is being examined in the framework of European regulations concerning the exposure of workers to carcinogens and mutagens, including considering the possibility and the costs and benefits of regulating fire toxicity under the Construction Products Regulations.

Björn Sundström, SP Fire Research, Sweden, described the development of the European Construction Products Directive and later Regulations (CPR), including measures for ensuring safety in the case of fire. He noted the fire toxicity regulations in air, rail and sea transport, and contrasted it to the complete absence of regulations on fire toxicity in either European buildings (under the CPR), or in buses and coaches.

Stuart Winter, Arup fire safety engineering consultancy, outlined the UK's regulatory framework, which sets out the broad requirements for fire safety, without specific reference to fire toxicity. He described the challenges in obtaining fire toxicity data suitable for use in fire safety engineering, stating that the lack of robust test data on fire toxicity was a major obstacle to ensuring a life safety of building occupants in a fire. He considered that if the Construction Products Regulations were to adopt a measure of fire toxicity for building products, this would be a major step forward. He cited the use of timber framed construction, and structures where smoke and toxic gases could penetrate barriers within a building, as potential examples of fire hazards in buildings.

Ciara Holland, UK Building Research Establishment (BRE) fire investigation, described the UK building codes and their relationship to fire safety. Using an example investigation, she explained that non-compliance was frequent in fire incidents, and breaches in fire stopping allowed toxic fire effluents to penetrate through the building, potentially exposing large numbers of occupants to the effluent from a fairly small fire. Of greater concern is that such failures to follow construction codes appear to be widespread, but only become evident after a fire.

Fire Toxicity 2016 conference conclusions



In the closing discussion, **Richard Hull** highlighted the value of having all the fire safety professionals working together, from material's scientists, fire scientists and toxicologists, to emergency medical teams for the protection of the public, to the medical specialists who had identified the causes of cancer clusters and other occupational diseases in firefighters. It is clear that this group of experts should not work in isolation. As well as being a heroic rescue service, fire fighters also face greater health risks than the civilian population from repeated smoke exposure. The discussion continued by focusing on the need for robust data on the fire toxicity of materials, and the best way to make that information available. It was concluded that if the Construction Products Regulation were to require generation of smoke toxicity data, this would be very valuable for engineering calculations designed to ensure life safety. In the absence of toxicity labelling in the Construction Products Regulations, cooperation between competitor organisations, such as fire test laboratories and fire safety engineering consultancies, would be difficult to secure, in order to ensure the availability of toxicity data and hence improve life safety in the event of fires.

COFISH – Conference on Fire Safety and Health Copenhagen, 15 April 2016

Danish Building Research Institute (SBi) and Aalborg University Copenhagen www.cofish16.aau.dk

COFISH16 CONFERENCE ON FIRE SAFETY & HEALTH 15 APRIL 2016

Lars Schiøtt Sørensen, Danish Building Research Institute (SBi), Aalborg University is the initiator of the conference. Lars opened the conference, thanking the cooperation team at SBi, **Marie Frederiksen, Birgitte Christiansen, Niels Samsø Nielsen** and **Simon Lei Fredslund.** This is the first conference organised in Scandinavia to bring together fire fighter health specialists, toxicologists and building fire safety experts with the aim of assessing the implications for human health of fire safety measures.

Smoke and toxic gas emissions in fires

Richard Hull, University of Central Lancashire (UCLan), pointed to recent major fires which illustrate the considerable fire load, smoke emissions and structural dangers related to the combustibility of modern building materials (see photos).

Ancarano sandwich panel factory fire 29th March 2016

Wiesenhof chicken factory fire 28th March 2016

Prof. Hull explained that toxic gases are the main cause of occupant deaths in fires in the UK, and that over the last 30 years the number of fire deaths and injuries from burns has considerably decreased, whilst the number of deaths and injuries from toxic gases has only started to decrease more recently. Most fire tests do not give relevant data about fire toxicity, because they are carried out in well-ventilated conditions, whereas real fires are nearly always under-ventilated: small fires because they are in enclosed spaces, and large fires because air cannot access the burning material fast enough. This leads to incomplete combustion favouring production of carbon monoxide (CO), hydrogen cyanide (HCN), smoke, soot and long-term toxic chemicals and carcinogens, such as poly aromatic hydrocarbons (PAHs). The SSTF (steady state tube furnace, ISO TS 19700) enables toxic gas emissions to be quantified in both well-ventilated and under-ventilated conditions.

Lars Schiøtt Sørensen, SBi, also underlined that fires today burn faster and more intensively than 30-40 years ago, and also that smoke is today more toxic. This is due to materials present in today's buildings, both flammable building materials (such as polymers replacing wood for structures, flammable insulation materials) and building content (furniture, decorations, wiring and cables, electronics and other goods). Toxicity of smoke emissions from building materials are today regulated in different countries, but in general not in Europe. For firefighters, this poses issues of both immediate danger, in fire situations, and long term health risks.

Rolff Ripke Leisted, Technical University Denmark, presented 1/5th room-scale testing of construction-condition installations of sandwich panels. The insulation panels tested had 100 mm of insulation material (polyisocyanurate foam or mineral wool) between steel coverings.

Looking for fire safety solutions which do not increase smoke toxicity

Thorbjorn Laursen, FireEater www.fire-eater.com presented his personal experience from selling halon 1301 fire extinguishing chemicals in the past, to now developing and installing the Inergen fire extinguishing system today, which uses non halogen containing inert gases. He presented Inergen systems now installed and validated in marine and offshore, where safety requirements are very stringent, in heritage buildings, cold storage installations, and in tyre storage. Halon extinguishers produced both HBr and HF toxic and corrosive gases in contact with fire, posing risks for both firefighters and occupants. They have been replaced with solutions (HFC and Fuorinated Ketone) decomposing into HF, TFA, MFA, PFIB, COF_2, F-propionic, in contact with fire, heated surfaces, moisture or sunlight, and which can pose dangers to occupants in case of accidental leakages and during fire extinguishing actions. (see "Eight die in Thai bank after chemical fire extinguisher leak", Guardian 14/3/2016. This accident involved particulate aerosol, another chemical fire extinguishing solution). The halogen-based extinguishers, can lead to incomplete combustion and considerably increase toxic carbon monoxide emissions. The Inergen system, because it generates turbulence, has shown on the contrary to reduce carbon monoxide emissions in the fire extinguishing process.

Chris Thornton, pinfa, explained that the PIN flame retardant producers and users in pinfa share a vision of an "ideal" flame retardant, which ensures material fire safety, has minimal environmental impact and is safe for health, and does not contribute to or release additional smoke, toxic or corrosive gases in case of fire. pinfa is active in projects working towards this objective, in Europe, in the USA, and through companies' internal sustainability programmes. pinfa recognises that epidemiological evidence shows higher rates of cancer in firefighters, and that smoke is a known carcinogen. Improving procedures for firefighter use of and cleaning of PPE (personal protective equipment) is essential, but industry, science and regulators must also work to reduce the toxic emissions to which firefighters are exposed. Flame retardants contribute to reducing dangers for firefighters by avoiding fires and delaying flashover, and less material burned means less smoke and less soot. The mode of action of flame retardants is also important: gas phase FRs (halogen FRs, and in some cases P-FRs) cause incomplete combustion as discussed by other speakers above; PIN FRs however act mainly by dilution (emitting water vapour or inert gases), cooling (endothermic reactions) and by generating a char layer or intumescent protective layer on material surface. PIN FRs are key to "Low Smoke Zero Halogen" fire safety solutions, by combining mineral PIN FRs, mineral smoke suppressants and PIN char forming FRs.

Firefighters, smoke exposure and cancer risks

Jesper Bo Nielsen, University of Southern Denmark, explained the mechanisms by which toxins from smoke and soot can be taken into the body through skin, and the precautions which can be taken to reduce uptake. Skin uptake is very variable on different parts of the body, between different individuals and for different chemicals, so highly complex to assess risks. However, uptake is significantly increased by heat (40% higher uptake of some chemicals with a 5°C skin surface temperature increase) and by humidity (can occur within protective clothing). A number of studies have shown that PPE (personal protective equipment) can reduce skin exposure considerably, and has improved greatly over recent years. However, cleaning of both equipment (hoses, vehicles) and clothing is essential, as are contacts with clothing as it is removed, but in many cases procedures are today not in place.

Pleil et al (2014) J. Breath Res. 8 037107; Fent et al (2014) Ann Occup Hyg 58; 830-845; Fernando et al (2016) Environ Sci Tehnol 50: 1536-1543; Kirk and Logan (2015) J Occup Environ Hyg 12: 227-234

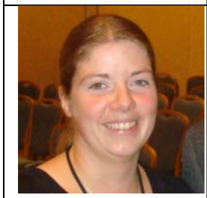
Tommy Kjaer, Denmark Firefighters Cancer Organisation, underlined the dangers faced by firefighters every day to protect the public and save fire victims. He emphasised that today's fires are faster growing, and emit more toxic fumes, because of increasing use of polymers in buildings (insulation, structures such as windows and doors, interior decoration). He considers that the number of particles emitted can increase by up to twelve times when synthetic materials are involved in fires. A fire used to take 15 minutes to reach flashover 30 years ago, but today only three minutes. Foam insulation panels can burn behind covering materials, emitting black smoke because of lack of air, and difficult to extinguish. Firefighters face not only the immediate dangers of fires, but also long term risks including heart disease, brain damage (related to carbon monoxide exposure), psychological risks and cancer. Carcinogens to which firefighters are exposed in smoke and soot include: benzene, formaldehyde, PAHs (polycyclic aromatic hydrocarbons), dioxins. Firefighters are also exposed to asbestos, arsenic, cobalt, chromium and lead. Carbon monoxide (CO) gives symptoms similar to a stroke, and is often wrongly diagnosed. Equipment cleaning procedures need to be improved to reduce firefighter exposure, including cleaning all gear and equipment which returns to fire stations, and clean / non-clean areas in stations. Particles of < 1 µm are not visible to the eye but are dangerous for the long term health, so it is necessary to wear proper respiratory protection in all phases in fire interventions. IARC classifies smoke as a group 1 carcinogen, but firefighting only as a class 2B occupation. The Firefighters Cancer Organisation states that fire fighters are not treated fairly by the workers compensation boards and wants to see cancer recognised as an occupational disease for firefighters and reclassified to IARC class 2A.

Kajsa Petersen, Danish Cancer Society Research Centre, presented the EIPBRAND project for a register based cohort study of cancer comparing nearly 17 000 firefighters in Denmark to reference groups in military and the police. The study will also look at smoke samples from the Smoke Diver sampling 1930 – 1980.

Health and environmental questions about brominated flame retardants

Katrin Vorkamp, Aarhus University, summarised findings on environmental and human exposure to brominated flame retardants. Some PBB, PBDE and HBCD brominated flame retardants are now banned as POPs (Persistent Organic Pollutants) under the Stockholm Convention. Deca-BDE is under consideration under this Convention, and is restricted in electrical and electronic equipment (EEE) in the EU and is no longer produced in the USA. Dr. Vorkamp stated that, due to their persistence, these compounds are still found in the environment and in human blood and tissue. She indicated that further research and information is needed about newer brominated flame retardants now being used.

"Novel brominated flame retardants and dechlorane plus in Greenland air and biota", Vorkamp et al., Environmental Pollution 196, 284-291, 2015 http://dx.doi.org/10.1016/j.envpol.2014.10.007



Marie Frederiksen, Danish Building Research Institute, presented the NoFlame research project. This aims to investigate environmental levels and possible human uptake of replacement brominated flame retardants. Work so far indicates that brominated flame retardants are present only in a small proportion of tested building materials (<7%), but tend to be present in recycled plastics

Anne Thoustrup Saber, Denmark National Research Centre for the Working Environment, presented the BIOBRAND project. This will measure particle exposure inside fire masks and on skin for around 80 trainees and fire fighters in real fire actions, and also biomarkers of cancer and CVD (cardio vascular disease) and other metabolic factors.

Discussion and conclusions

In discussions, participants' comments included the following proposals:

- Studies on firefighter exposure to fire carcinogens and statistics of firefighter cancer and clarification of the professional cancer risk of firefighters
- Research to assess carcinogens and long-term toxins in smoke and soot emitted by accidental fires involving different materials under different conditions
- Full scale fire tests to improve understanding of implications for fire safety and for smoke emissions and toxicity of materials and contents as present and as used in modern buildings.
- Definition of appropriate smoke emission and smoke toxicity requirements for buildings regulations, e.g. in the EU Construction Products Regulation