Report on “Fire Toxicity 2016”

A unique event took place in Preston last week. Although the inhalation of toxic smoke is the biggest killer and the largest cause of injury in fires, it is very much the neglected area of fire science and fire safety engineering. However, this conference was special for another reason, it highlighted the health concerns in a unique, 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 fails to protect fire victims from smoke inhalation, and how this problem may be addressed.

Generation, analysis and effects of fire toxicants and medical treatment of victims

Professor Richard Hull from the University of Central Lancashire (UCLan) provided an introduction to the chemical and physical aspects of smoke toxicity, showing the importance of material composition (such as whether the polymer contained nitrogen and thus produced hydrogen cyanide on burning, or used halogenated flame retardants which increased the yield of carbon monoxide (CO) and hydrogen cyanide (HCN), as well releasing acid gases), and the fire condition (if flaming was under-ventilated the yields of toxic products, such as CO and HCN are typically a factor of 10 to 50 greater). **Professor 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, and the incapacitating effects of HCN at very low concentrations.

Dr Mark Sabbe, Professor of Emergency Medicine at the 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 and 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. **Mr 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 the fire and rescue services, who collect the 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.

Dr Anna Stec, Associate Professor in Fire Toxicity at UCLan, outlined the methods and challenges of quantifying the toxicity of fire effluents. Starting with the acute toxicants and irritants responsible for preventing escape from a fire, she then described methods for analysing the cocktail of other carcinogens and toxicants present in fire effluents, including polycyclic aromatic hydrocarbons (PAHs), isocyanates, dioxins etc. This was followed by two presentations quantifying the toxicity in experimental studies of large scale fires. First, from **Richard Walker** of West Midlands Fire Service, who burned eight identical sofas in different ventilation conditions in a three bedroomed house, and compared the tenability at various locations. The second, from **Professor Beth Weckman** of the University of Waterloo in Canada, who 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, and showed a slower rate of fire growth, but higher toxic gas concentrations for the fire retarded sofas than those reported for well-ventilated fires. **Dr David Crowder** leads the fire investigation team at the UK's Building Research Establishment (BRE), 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 recreation in facilities where the toxicity of effluents could be quantified.



Firefighters and cancer

Mr Peter Holland CBE, the Chief Fire and Rescue Advisor to HM Government, and a tireless promoter of better liaison between government agencies, academia, research organisations and the insurance industry, 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. In particular, he lamented the lack of awareness firefighters had about the dangers of sandwich panels in fires, and the time it took for the lessons from fire disasters to become available.

Mr Tommy Kjaer, a practicing firefighter and founder of the Danish Fire Fighters' Cancer Organisation, explained that fires had become faster growing and more toxic. On the day of the Brussels bombings he described the scene 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 an important piece of the puzzle to show the bigger picture".

Dr Donald Lucas, an expert on environmental energy technologies from the 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. 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.

Professor Jeff Burgess is a qualified physician, whose research at the University of Arizona has specialized in occupational health of firefighters. His presentations started with the stages of firefighting operations, highlighting those such as overhaul (ensuring the fire was completely extinguished) where breathing apparatus was not normally worn; 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); and described studies looking for toxic and carcinogenic substances using epigenetic and micro-RNA markers, providing the clearest 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.

Dr Robert (Doug) Daniels is an epidemiologist working at the National Institute for Occupational Safety and Health (NIOSH) in the U.S., where he has investigated the overall excess cancer incidence, including oesophagal, intestinal, lung and kidney cancers in firefighters. 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, showing only mesothelioma and oral cavity cancer as proven firefighter occupational diseases in pooled studies, compared with the larger number in the International Agency for Research on Cancer (IARC) findings.

Professor Susan Shaw, State University of New York-Albany and Director, 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, similar to the levels in furniture foam and e-waste recyclers, who were subject to constant occupational exposure. Moreover, toxics' absorption through skin increases by a factor of four for every 5 °C rise in temperature.

Mr David Wales, Research Manager for Kent Fire and Rescue Service, where he has studied human behaviour in accidental dwelling fires, collecting detailed information from over 700 of Kent's fire victims, which 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. Of course, victims of fire effluent toxicity are not confined to the human population, and **Dr Francine Amon**, a scientist at SP Fire Research, showed how fire effluent dispersal, into air, water and land, had adverse effects on the built and natural environment, while firefighting strategies had a significant influence on the effluent dispersal route.




Regulatory Assessment of Fire Toxicity

The final day was focussed on the regulation and control of fire toxicity. **Dr Björn Sundström**, Director of Fire Research at SP, Sweden, and a key player in the development of the European Construction

Products Regulations, described the 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, or coach transport. As a successful example of fire toxicity regulation, **Beth Dean**, Technical Lead, Exova Warringtonfire, described the development and validation of the toxicity test methods for European railways, EN 45545-2. Fire safety on board trains is obtained through the combination of many considerations which work 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 to consider 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.

Dr Eric Guillaume, Technical Director of Effectis France, described the development of FTIR spectroscopy for the analysis of fire gases, 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. As part of BRE's fire investigation team, **Ciara Holland** 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.

Professor **David Purser** 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.

Mr Gwenole Cozigou, Director, DG Growth (DG Internal Market, Industry, Entrepreneurship and SME's) at the European Commission, explained that since June 2015 he was responsible for the Construction Products Regulations, and 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. In this context, one must in particular 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 its construction materials, but also by its 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. He announced that DG Growth is launching a study, to consider the need as well as the costs and benefits of regulating fire toxicity under the Construction Products Regulations, expected to start in June 2016, to run for nine months."

Mr Stuart Winter is a senior fire engineer for Arup, the world's leading fire safety engineering consultancy. He outlined the UK's regulatory framework, which sets out the broad requirements for fire safety, without specific reference to fire toxicity. He went on to describe 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, and if the Construction Products Regulations were to adopt a measure of fire toxicity for building products, that 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.

In the closing discussion, Professor 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 were also the "canaries in the coal mine" for the building-occupying public. 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 having toxicity data required by the Construction Products Regulation would ensure data was available for engineering calculations. In the absence of toxicity labelling within the Construction Products Regulations, cooperation between competitor organisations, such as fire test laboratories and between fire safety engineering consultancies, would be the best way to secure publicly available data and hence ensure the life safety in the event of a fire.



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Anna A Stec and T Richard Hull

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