Institution: University of Central Lancashire (UCLan)

Unit of Assessment: 13 Electrical and Electronic Engineering, Metallurgy and Materials

Title of case study: Robust assessment of fire toxicity leading to safer products and less loss of life and injury from fires

1. Summary of the impact (indicative maximum 100 words)

The Steady State Tube Furnace (ISO/FDIS 19700) allows fire toxicity to be quantified in real fire conditions. This has led to the introduction of “acidity classification” for cables in the European Construction Products Directive/Regulation (2008/2013) (as a surrogate for fire toxicity) to promote the use of safer, low smoke, zero halogen (LSZH) alternatives to PVC cables. Additionally, architects and building specifiers can use our data to avoid the most toxic foam insulation materials in low energy buildings. The biggest impact of our work, the global reduction in loss of life in fire is probably the most difficult to quantify, as too many other factors influence the fire statistics.

2. Underpinning research (indicative maximum 500 words)

From 1955-1980 the number of deaths and injuries from fire increased steadily. While deaths and injuries from burns (80% of total in 1955) showed a modest increase, deaths and particularly injuries from inhaling toxic smoke increased rapidly, and continued to rise until 2000 (over 50% of total in 2011). Eventually, the rise was attributed to the increased use of synthetic polymers, especially polyurethane foam furnishings. Although much work was undertaken from 1980-1995, the difficulty of replicating this toxicity on a bench-scale meant that investigation of fire toxicity could only be achieved using large scale fire tests (prohibitively expensive). Instead, efforts in fire safety focussed on reductions in ignitability and heat release, rather than the toxicity of effluent. Moreover, as coroners require evidence that fire was not used to cover-up murder, and that the victims of fire were breathing at the time of the fire, they quantify carbon monoxide inhalation as blood carboxyhaemoglobin concentration. Unfortunately, this data has been used to support the erroneous conclusion that carbon monoxide (which forms carboxyhaemoglobin) is the *only* significant toxicant present in fire effluents[1].

As a fire grows, it becomes ventilation controlled and the yields of toxic products (especially carbon monoxide and hydrogen cyanide) increase by factors of between 10 and 50. Most bench-scale fire apparatuses cannot replicate these under-ventilated fires as too much radiant heat from the flame is lost to the surroundings and the test fire is extinguished when the oxygen concentration falls. The steady state tube furnace was designed specifically to replicate each stage of fire growth in order to quantify fire effluent toxicity under all conditions, including the most toxic under-ventilated conditions, by surrounding the flames in a high temperature, high radiant flux environment.

From the initial concept, by UCLan’s visiting Prof Purser, (then based at the UK’s Fire Research Station, now BRE Fire and Security), the development of the steady state tube furnace (SSTF) was led by Prof **Hull**, based at UCLan from September 2007. In October 2007, Dr **Stec** was appointed to a Lectureship, then Readership at UCLan, to lead the development of the fire toxicity research. In addition to the SSTF development, she quantified the fire toxicity of many important materials; recognised the importance of particulates in toxicity; identified the need to obtain more large-scale validation data to correlate against behaviour observed in the steady state tube furnace; and set-up the Large Instrumented Fire Enclosure (LIFE) facility to achieve this, at Lancashire Fire and Rescue Service’s Washington Hall Training Centre. This led to further funding from EPSRC (£125k) to understand the problems of fire toxicity in real fires.

The first breakthrough came when the group rationalised the toxic product yields from burning polymers as a function of stoichiometric equivalence ratio. They then developed the realistic bench scale measurement of fire toxicity, from bespoke research equipment to international standard. They have over 60 publications on the subject. In May 2010[2] their book, “Fire Toxicity” was recognised as the “best currently available understanding and application of fire toxicity”[3] by the editor of the Journal of Fire Sciences.

[1] Nelson, G.L. Carbon monoxide and fire toxicity, (1998) Fire Technology, 34 (1), pp. 39-58.
[2] A.A. Stec, T.R.Hull, Fire Toxicity, CRC Press/Woodhead Publishing, Cambridge, UK 2010
[3] G.Hartzell, Book Review, FIRE TOXICITY, Journal of Fire Sciences, Vol. 29, pp. 489-490, 2010

This research has:

- Developed, and characterised a method for replicating large scale fire behaviour on a bench scale.
- Established relationships between fire effluent toxicity, material composition, temperature and ventilation conditions for a wide variety of materials.
- Investigated the effect of fire retardants and nanofillers on fire effluent toxicity.
- Developed a methodology for separation and analysis of soot particles from fire effluents.
- Established a unique (LIFE) facility at Lancashire Fire and Rescue Service's Washington Hall Training Centre, for investigation of large scale fire behaviour.
- Demonstrated the validity of the approach by monitoring effluent toxicity from the real fires in domestic houses (prior to scheduled demolition).

3. References to the research (indicative maximum of six references)

*Best indication of quality of research

*A.A.Stec, T.R.Hull, J.A. Purser, D.A. Purser, *Comparison of Toxic Product Yields from Bench-Scale to ISO Room,* Fire Safety Journal 44, 62– 70, 2009. (Shows validity of the test method from bench to large scale).

*A A Stec, T R Hull and K Lebek, *Characterisation of the steady state tube furnace (ISO TS 19700) for fire toxicity assessment,* Polymer Degradation and Stability, 93, 2058–2065 (2008). (Describes a number of experimental studies to understand and characterise the SSTF apparatus).

Anna A Stec and T Richard Hull, *Assessment of the fire toxicity of building insulation materials,* Energy and Buildings 43, 498–506, (2011). (Uses the SSTF apparatus to measure fire toxicity of insulation materials).

*A.A.Stec, T.R.Hull, K.Lebek, J.A.Purser, D. A. Purser, *The Effect of Temperature and Ventilation Condition on the Toxic Product Yields from Burning Polymers,* Fire and Materials 32, 49-60, (2008). (Rationalises fire toxicity as a function of temperature and ventilation condition for a range of common materials).

T.R. Hull, K. Lebek, and J.E. Robinson, *Acidity, toxicity and European cable regulation*, Transactions of the International Wire and Cable Symposium (Trans IWCS), 1, 111-117, (2008). (Shows the relationship between acidity and fire toxicity for 10 typical cable formulations; used to support the acidity classification in the EU Construction Product Regulations).

J. A. Purser, D. A. Purser, A. A. Stec, C. Moffatt, T. R. Hull, J. Z. Su, M. Bijloos, and P. Blomqvist *Repeatability and reproducibility of the ISO/TS 19700 steady state tube furnace* Fire Safety Journal 55, 22–34, (2013). (Reports an investigation of interlaboratory reproducibility of the SSTF, needed for acceptance by standardisation bodies).

Funding

Feb '05 – Dec '08	EU Framework 6: PredfireNano project – Prediction of the fire behaviour (flammability and fire toxicity) of polymer nanocomposites (€300k)
Oct '06 – Sept '09	PhD studentship "Comparison of Toxicity data from Bench and Large Scale tests" from the European Association of Producers of Flame Retarded Olefinic Cable Compounds (FROCC) (£61k) (T R Hull)
Oct '07 – Sept '09	Borealis: "Development of Tube Furnace Toxicity Standard" (£14k) (A A Stec)
Jan '11 - Dec 13	Rockwool International: research into the fire toxicity of building materials (T R Hull and A A Stec) (£90k).
Jan '12 - Dec '13	EPSRC: Investigation of Fire Toxicity and Scale-Up of Fire Behaviour £125k (A A Stec)
Dec '12 – Nov '15	EU Framework 7: Deroca – Assessing the fire safety (flammability, fire toxicity and particulate releases) of replacements for brominated flame retardants (€ 535k).

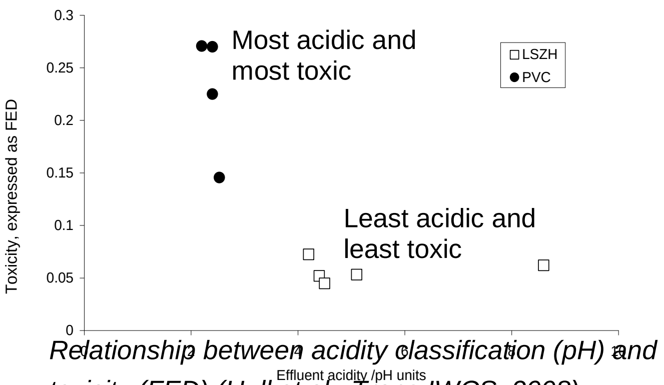
4. Details of the impact (indicative maximum 750 words)

Overall, our work has demonstrated that fire toxicity can be replicated on a bench scale, using the steady state tube furnace apparatus (SSTF). This method was adopted by ISO as a technical specification in 2007 (ISO TS 19700); Prof **Hull** has been ISO Project Leader since 2004. This is a publicly available document and, now the interlaboratory reproducibility has been demonstrated, is currently (2013) published as ISO/FDIS 19700 (final draft international standard) due to be published as ISO 19700 in 2014. This provides the first robust framework for the realistic bench-scale quantification of fire effluent toxicity as a function of fire condition. As the major killer, and major source of injury in fires, this provides the vital tool for improving fire safety. Some industries (for example the glass and mineral wool insulation, and electric cable industries) have recognised the importance of fire toxicity, supported our research, and are using it to market products of greater fire safety. Recently, we have used the SSTF to show that phosphorus based fire retardants are much safer than the brominated materials they replace[4], of great interest to their manufacturer, Clariant, and the environmental groups concerned about brominated flame retardants.

The adoption of performance based design by fire regulators, as an adaptable strategy to free designers from the inappropriateness of specific regulations that have no significant fire safety benefit, includes a requirement to estimate the available safe escape time. This is the time between detection of a fire and the safe evacuation of occupants. The toxic product concentration along the escape route must be low enough not to hinder or prevent escape. This requires prediction using robust data on toxic product yields as a function of fire condition, and so far the SSTF has proved the only apparatus capable of providing such data. In addition, the SSTF provides regulators with a tool to quantify hazards, and if necessary to restrict the use of the most dangerous materials in the highest risk applications (e.g. mass transport, high rise buildings, electrical and electronic components etc.)

Closer regulation of fire toxicity has saved lives, and forced industry to replace dangerous products with safer materials; the progressive switch-over from PVC to “zero-halogen” cables across Europe is the clearest example. Meanwhile, for many years, the older products will remain installed and sometimes in use, making it very difficult to quantify the benefit in terms of reduced fire deaths and injuries. Thus, while there is a clear societal benefit to reducing the toxicity of fires, the short term cost has to be offset against the longer term benefits of better designed materials and products (from which there is generally greater profit) as well as improved fire safety. Industries already manufacturing fire safe products, such as the zero-halogen cable and mineral and glass wool insulation industries have been the immediate beneficiaries in terms of increased sales.

One of the most tangible current outcomes has been the introduction of the acidity classification in the European Construction Products Regulation (305/2011/EU - CPR) – requiring all cables in Euroclasses B, C and D to be classified according to the hazardous properties of gases developed in the event of fire, which “compromise the ability of the persons exposed to them to take effective action to accomplish escape”, allowing users to discriminate between high toxicity (PVC) and low smoke/zero halogen (LSZH), low fire toxicity cables. This is illustrated below, showing the acidity of the effluent as measured by the EN 50267-2-3 regulatory test (a lower pH value means greater acidity; cables with pH<4.3 do not meet the low hazard “acidity classification”), against the toxicity (quantified using ISO 19700 expressed as Fractional Effective Dose – the



Relationship between acidity classification (pH) and toxicity (FED) (Hull et al., Trans IWCS, 2008)

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[4] S Molyneux, A A Stec, T R Hull, *The effect of gas phase flame retardants on fire effluent toxicity* Polymer Degradation and Stability (in Press) 2013 [doi: 10.1016/j.polymdegradstab.2013.09.013](https://doi.org/10.1016/j.polymdegradstab.2013.09.013)

higher the value, the greater the toxicity). This clearly shows the relationship between the acidity classification and the toxicity, was presented in the IWCS paper, and was used to persuade the regulators of the need to introduce such as classification in the Construction Products Regulation (2011), which came into force across Europe in 2013. This has driven the switchover from PVC to LSZH cables in the non-domestic sector over the last 5 years. Our industrial contacts have helped to ensure that ISO 19700 is a usable tool, that our supporting publications are relevant to current industrial practice, and have participated in our “Hazards from Fire” short course. We have been proactive on national and international standardisation bodies. Dr **Stec** represents the Society for Chemical Industry on the British Standards *Hazard to Life from Fire* Technical Committee (FSH/16), and is designated the UK’s principal expert on Fire Chemistry, playing a key role in ISO *Fire Threat to People and the Environment* sub-committee (TC 92 SC3), while Prof **Hull** represents the Royal Society of Chemistry on the same committee and is the Principal expert on Fire Models, and leads the UK delegation to TC92 SC3 , the premier international body on fire toxicity, where he is project leader for the ISO 19700 steady state tube furnace.

Key dates:

2010	“Fire Toxicity” published by Woodhead publishing, raising the profile of fire toxicity amongst the fire safety community
2011	ISO “Official” Interlaboratory Reproducibility Exercise completed
2011	Acidity regulation requirement introduced across Europe (305/2011/EU – CPD now CPR)
2012	Detailed publication of correlations of various bench scale methods with large scale.
2013	Ballot approves circulation of ISO/FDIS 19700, prior to adoption as a full international standard.

5. Sources to corroborate the impact (indicative maximum of 10 references)

CONTACT 1: [Material redacted]

CONTACT 2: [Material redacted]

CONTACT 3: [Material redacted]

CONTACT 4: [Material redacted]