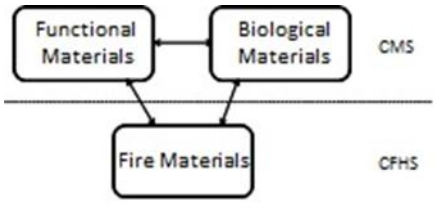
Institution: University of Central Lancashire

Unit of Assessment: 13

a. Overview



The development of materials research within the School of Forensic and Investigative Sciences has been a strategic university initiative and represents a £7.5 M investment in laboratories, equipment and high priority research projects. The research is delivered through two related research centres, the Centre for Materials Science (CMS) and the Centre for Fire and Hazard Science (CFHS). Both research centres were returned in RAE 2008; CMS to UoA 19 (Physics) and CFHS to UoA 30 (Architecture and Built Environment). There are three main research themes (Functional Materials, Biological Materials and Fire Materials) with a high degree of cross fertilisation.

The key achievements during the current REF Period, of staff within this UoA include:

- Grant capture in excess of **£3.6M** including an EPSRC Fellowship, First Grant Scheme and Responsive Mode funding and EU FP7 Programme Grants
- Over **160** papers in peer reviewed journals
- **33** Published book chapters
- **150** conference presentations, **39** as invited, keynote or plenary lectures
- **6** patent applications
- Development of **35** industrial partnerships including Samsung, Borealis and Westinghouse

b. Research strategy

UCLan is a research active university. Our research strategy aims to boost the quality, scope and capacity of our research activities. UCLan was the first modern university to enter the QS World University Rankings and has been awarded four QS stars rating it as highly international, demonstrating excellence in both research and teaching.

The key objectives for research within this UoA, over the current assessment period, have been to:

- Significantly enhance the research standing of the University in the area of materials science
- Focus our research on specific world-leading areas and cross-cutting interdisciplinary themes (Functional Materials, Biological Materials and Fire Materials)
- Strengthen our research community (academics, research students, postgraduates and undergraduates)
- Develop our research infrastructure
- Maximise our external income

Centre for Materials Science (CMS)

In RAE 2008 CMS activity was focussed around three themes: Catalysis and Cleaner Processes (including microwave and nanotechnology); Sensors and Devices; and Nuclear Science and Technology). During the REF period CMS has continued with research in these areas as well as expanding and developing their research base. This has required a restructuring of CMS and refocus into the areas of **Functional Materials** and **Biological Materials**.

CMS has been successful in recruiting researchers with strong track records and high future potential; currently CMS has 10 academic staff. As such, the composition of staff submitted here is significantly different with only one member of staff, **Bond** (Head of Centre), remaining from RAE 2008. Of the staff that were returned in 2008, two have accepted chairs elsewhere, three are being returned in other UoAs and three have retired. As indicated in the following, investment in staffing, equipment and facilities have resulted in the creation of an realigned research infrastructure.

Functional Materials – Research in nanomaterials includes projects on magnetic bio-separations and food bio-sensors; (patented, and currently being commercialised (**Sen**)); hierarchically ordered porous superparamagnetic nanocomposites containing antimicrobial silver nanoparticles for the removal of toxic chemicals and biochemicals from industry and municipal sewage (**Sen**); targeted

drug delivery (**Sen**); heterogeneous catalysis (**Sen, Bond**); the use of nanoparticles and nanostructured surfaces to develop surface enhanced Raman biosensors (**Baker**); formation / stability of nanopores within lipid bilayers and lipid nanobilayers for healthcare applications (**Kulkarni**); fire retardant coatings based on biomass-derived carbogenic nanoparticles (**Kelarakis**). This is an area of growth for CMS which is expected to deliver significant results and impact. Sen is developing commercial ventures in nanotechnology through UCLan Biomedical Technology (Shenzen) Ltd; his work in collaboration with Fudan Unviersity has developed multifunctional nanocomposites for the separation of pollutants from industrial and municipal sewage water.

Prof Bond's projects in the area of nuclear materials, waste remediation, organometallics and catalysis include the removal of toxic gases from air streams funded by CBRN S&T**;** upgrading of biogas**;** EPSRC / NDA projects on irradiated graphite and the separation and disposal of radionuclides.

Biological Materials – Projects include the synthesis of highly conjugated and/or heterocyclic materials for use in biosensors and smart devices for wound care; photoantimicrobial chemotherapy (PACT)**;** development of the next generation of detection technologies using spectrometric (ICP-MS, LC-MS/MS and GC-MS/MS) and spectroscopic (Raman and FTIR) methodologies for surgical, diagnostic and pathological healthcare tools, for detecting chemical weapons within biological systems and biological weapons in the environment (**Baker**); and computational drug design and development for anti-cancer agents and targeting new treatments for Diabetes (**Hayes**). Developments in this highly interdisciplinary area are new and have already benefitted from patents being filed.

Centre for Fire and Hazard Science (CFHS)
The aim of CFHS remains the improvement of fire safety through the application of sound science to better understand fire behaviour. Research is focussed on maintaining and developing our world leading expertise in a few areas (fire retardancy and fire toxicity) and using this expertise to support growth in other areas (predictive modelling of fire behaviour, issues affecting fire safety arising from sustainable buildings and manufacturing processes, and the development of an engineered approach to risk management and fire safety).

Fire Materials – Our pioneering role in fire toxicity has been described in Fire Toxicity, Woodhead Publishing, Cambridge, UK, 725 pages, published 2010 (**Hull, Stec**); two draft international standards (ISO 19700 and 19702) and resulted in the award of EPSRC and EU FP7 (**Stec**) grants together worth ~ **£625k** with additional industrial funding from Rockwool, Borealis and Clariant. In fire retardancy, we have received external funding from EU FP6, EPSRC, Victrex and Elkem (**Hull**). The use of finite-element computational models, such as the 1-D pyrolysis and flammability model ThermaKin, and computational fluid dynamics models such as Fire Dynamics Simulator for gas phase processes provide important support for the Fire service. We have pioneered the use of pyrolysis modelling of fire-retarded polymers, with the support of the model's developer, Prof Stoliarov at the University of Maryland. Our work in sustainability and fire safety has led to many publications, including two invited chapters in Elsevier's prestigious Handbook of Green Flame Retardancy (in press). In addition, through his expertise in fire retardancy, **Hull** has been the only European member of the Project Advisory Committee of the US EPA's Great Lakes PBDE Reduction Project. Substantial support through UCLan Biomedical Technology (Shenzen) Ltd has enabled a project with the State Key Laboratory for Fire Science, at the University of Science and Technology of China and developed important understanding on the toxicity of nanoparticles in fire (**Stec)** to inform international standards and fire service practices to protect the public and personnel and develop new fire retardant materials (**Hull**).

Strategic Plan for Materials Research 2014 – 2020:
Academic staff in this UoA have been provided with protected time (50% of their time dedicated to research), thus enabling more rapid research development. This strategy is linked to our teaching development strategy, whereby the growth of taught courses underpinned by our research base will provide a firm foundation for the future. So far this has resulted in a concentration of research

excellence in the thematic areas as evidenced by the research outputs. During the period 2014 - 2020 we anticipate recruitment of at least another three full time members of academic staff. In addition to the increase in research active staff, a teaching fellow has been recruited to provide support to allow research active staff to focus on research via structured career support, developing excellent research scientists for the future success of both centres. The research strategy for this period has been very successful. The Strategic Research Plan 2014 – 2020 will reviewed every two years (with a detailed mid-term review in 2017) and is a slight adaptation of that for the current assessment period:

- Develop and enhance our international research standing
    - Through presenting at and organising international conferences such as one of the SPEC series and the British Zeolite Association meeting
    - Further developing the academic interaction and research within UCLan Biomedical Technology (Shenzen) Limited in China
- Enhance the sustainability and quality of our research through competitive funding
    - Continue to target research council funding whilst diversifying the income stream via other funders such as charities, TSB and further develop industrial consultancy
- Develop our research and networks to ensure they maximise their impact
    - Continue and increase our involvement in international Networks (e.g. Prof Bond is a member of a consortia of 12 UK Universities involved in a collaborative EPSRC bid (PACIFIC – Providing a Nuclear Fuel Cycle in the UK for Implementing Carbon Reduction) and Dr Baker is Co-I on a successful EPSRC Network Grant Bid for a network in Clinical Infrared and Raman Spectroscopy (CLIRSPEC, awarded October 2013))
- Expand and strengthen our research community and support future growth
    - Exploit Preston's City Deal to develop Lancashire Enterprise Zones by increasing our interaction with an support to local SMEs
    - Use every opportunity o commercialise research and spin out companies
- Strengthen the research capacity and diversify the research base within the thematic areas
    - Develop a Centre of Excellence in Chemical Imaging through ERDF funding targeting support for regional SMEs
- Provide structured career support and space for the research community
    - Provide career space for high potential researchers through "buy-out" of teaching
- Attract and retain the very best research staff and students and develop the research infrastructure

c. People,

i. Staffing strategy and staff development

Changes in research activity and institution, coupled to a clear strategy to develop young researchers mean that of the staff submitted in 2008, only 2 remain in the current submission (**Bond** and **Hull**), with the reminder in the early stages of their independent research careers. Staff have been supported through significantly reduced teaching loads and University funded sabbaticals (**Sen, Stec**). In addition the University has provided funding for 9 PhD studentships (6 full-time, 3 part-time) 4 MSc (research) studentships, and 13 years of PDRAs. The research strategy has been very successful in attracting new staff to the university with strong research track records and future potential. These include **Baker**, **Hayes**, **Kelarakis** and **Kulkarni**. These appointments provide an upward trajectory for the research centres as evidenced by their research outputs. We are committed to staff development and have found that our "home grown" talent in some areas often have the best expertise available. Two research assistants have benefited from this development and are now starting to lead their own research projects.

Research students

PGR Recruitment Strategy: Our recruitment strategy exists to attract the highest calibre of postgraduate students. We have been very successful securing external (EPSRC CASE awards, industrial sponsorship and charities such as Brain Tumour North West) and internal research funding for PhD students through various schemes PhD schemes, together with self-funded students.

Training and Support: UCLan has a comprehensive training programme for research staff and students, recently awarded the Vitae Excellence in Research Training award and associated kitemark. All new full-time and part-time students attend a comprehensive induction day, eight of which are run each year close to the point of student intake (quarterly). This introduces them to the key personnel and processes related to their research degree, and is supported by literature including Student Handbooks, Vitae research relevant publications, and a host of information on the facilities available for their support. Additionally, all full time students attend a compulsory two week validated Graduate Research Skills programme, at the outset of their study. This is a validated programme, and contains around £1700 worth of centrally funded training. It contains vital information on skills including Communication and Presentation; Reflective Practice; Project Management; Academic Writing; RefMan/RefWorks and NVivo; Team-working; and Coaching.

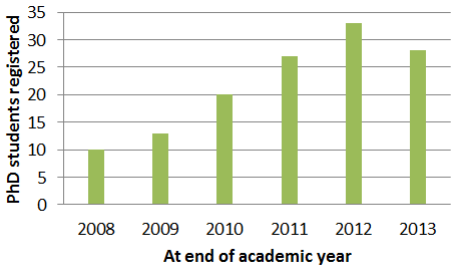
Part-time students can elect to attend parts of this course, but if they are unable, the University has invested close to £80k through the purchase of the on-line Research Masters Programme from Epigeum. Epigeum's on-line resources for researchers are ranked as being amongst the highest quality available. The suite of programmes enable progressive learning from research student to senior research academic via a combination of face-to-face, e-learning and web-based training.

In addition to all of the above, the University runs a stand-alone programme of training, again, free to all part-time and full-time students, as well as staff. It covers a huge variety of topics that are required in order to comply with the training requirements of the RCUK, HEFCE and QAA.

Environment: UCLan has a thriving research student society – PROGRESS – that organises monthly events, talks, social outings, annual banquets, targeted grant schemes – and all students are encouraged to become part of this. The department organises monthly researcher evenings to develop a research community through events such as Pub Science talks on scientific subject's of topical interest.

Each year the Research and Innovation Office hosts the, now very popular, Research Student Conference over a three-day period. It showcases the work of individual research students by oral and poster presentations with awards for outstanding work. Academics within the UoA have been very successful in obtaining funding for undergraduate research Internships and this enables us to highlight research across our degree programmes; for the last two years running, research interns from the UoA have been awarded the best intern poster prize in competition across the whole university as well as external poster prizes (e.g. Andrew Tyler won the poster prize at the Peakdale Medicinal Chemistry conference). Our postgraduate students are also successful at external conferences, an example of this is James Hands (a 1st year PhD student of Baker) being awarded the best clinical poster prize at the British Neuro-oncology Society 2013 meeting in competition with other PhD students, Postdoctoral researchers and MD researchers.

PhD Completions There have been 10 PhD completions over the period 2008-2013. The rapid growth in the materials area, coupled with the changes in personnel, means that the number of PhD completions has been steadily increasing. There are currently **30** postgraduate research students, all in years of study; this marks a significant increase in research student numbers and provides evidence of growth in research during the assessment period. The graph (below) shows this growth in enrolled PhD student numbers. The reduction in students shown in 2013 is a result of 6 completions in 2011-12. The Strategic Research Plan 2014 – 2020 outlines how to continue this upward trend and as many of the newer members of the staff have been appointed since January 2012 their contribution to PhD completions will be felt in the next assessment period. For example **Baker** (appointed in Jan 2012) has already built a group that consists of 1 PDRA, 7 PhD and 5 MSc by Research students.



c. Income, infrastructure and facilities

Infrastructure and Facilities

Research in this UoA is supported by dedicated specialist state-of-the-art laboratory facilities located in the university's new **£11.5 M** J.B. Firth Building. Opened in 2011, for the delivery of teaching and research in the chemical and fire sciences, half of the building is dedicated to research laboratories in fire materials, biological materials and functional materials, a 140 m^2 analytical instrumentation suite and offices for our postgraduate students.

Materials research is supported by excellent instrument laboratories and specialised technical staff. Investment in state-of-the-art equipment over the assessment period has been in excess of £900k which has been used to strengthen / modernise our equipment portfolio. The materials analysis laboratories has benefited from new XRD, XRF, 300 MHz NMR, Raman microscope, infrared microscope, TEM with elemental analysis, CDS pyrolyser and a high pressure catalyst testing facility. The laboratory also includes 400 MHz solid state NMR, ICPMS, AAS, GCMS (3), LCMS (2), ion chromatography, SEM EDAX, d-ATR FTIR, etc.

Continued investment in the fire laboratory has established one of the best equipped facilities of its type in the world. It combines industry standard test procedures with research instruments for investigation of individual aspects of burning behaviour. Equipment includes thermoanalytical tools for the investigation of polymer decomposition, including thermogravimetric analysis, coupled with evolved gas analysis, py-GCMS, differential scanning calorimetry and microscale combustion calorimetry. For physical property determination the laboratory has a parallel plate rheometer with environmental chamber and thermal conductivity measurement instrumentation. Our standard fire test capability includes two cone calorimeters (ISO 5660), lateral ignitability and flame tests (ISO 5658), radiant ignitability tests (ISO 5657), limiting oxygen index (LOI), Bunsen burner tests (UL 94 V, HB etc.,), small flame ignitability tests (ISO 11925), non-combustibility tests (ISO EN 1182), and motor vehicle flammability tests (MVSS 302). In addition the laboratory includes the prototype ISO 19700 Steady State Tube Furnace, developed by the group since 1996, the French static tube furnace toxicity test (NF X 70-100) and the Smoke Density Chamber (ISO 5659-2) with FTIR gas phase analysis. External facilities, for large scale fire test facilities exist at Lancashire Fire and Rescue Service's Washington Hall Training Centre which includes a dedicated building for studying the action of sprinklers on fires, and the Large Instrumented Fire Enclosure (LIFE) facility, allowing controlled ventilation toxicity studies to be carried out on large scale fires. Mobile fire monitoring facilities, permitting instrumentation of third party fires, such as those in novel low energy homes or buildings due for demolition in conjunction with regional Fire and Rescue Services, the University of Edinburgh, and BRE Fire and Security Ltd. Instrumentation have also been built for sampling and effluent analysis.

To facilitate the successful identification and development of bidding for external research income, the UoA is supported by the university's central Funding, Development & Support (FDS) unit.
In the initial stages of grant development, FDS is available to help shape proposals and identify and negotiate with appropriate collaborators and end users. FDS also helps to identify any activity which requires further support, e.g. IP development. If activity is deemed to be of benefit to the general public or would have specific beneficiaries, support is available from FDS to identify sources of funding for the promotion and implementation of research findings. FDS undertakes the full costing of research bid proposals while the Business Partner Unit (BPU) in Finance are responsible for the financial management and audit of projects once a grant has been awarded. FDS also supports academic teams to negotiate and draft contracts and ensure projects are completed on time and to budget and that the contracted outputs are delivered. New research programmes with external partners are guided by the Innovation and Enterprise (I&E) Unit including writing contracts / letters of agreement and revenue sharing agreements, the identification of IP, Licensing and IP ownership.

Income

One of the strategic aims during this assessment period was to enhance the sustainability and quality of our research through competitive funding. CMS staff have been successful been awarded **£3.6M** in research income over the REF period.

The audited spend on research grants during this REF period by staff returned to this UoA is **£1.3M**, approximately half of which is from funding councils and other governmental bodies. The remainder results from direct industrial, European funding agencies / industry or funding charities. This represents grant capture of almost **£48k** per person per year, only 4 staff being in place for the full REF assessment period. This figure does not reflect the successes prior to joining the institution which include **£283k** for a PI on an EPSRC LSI Postdoctoral Fellowship (**Baker**) and **€1.2M** for an EU project in which **Hayes** was a Co-I and named researcher. Nor does it reflect the recent successes which include **£168k** from the Defence Science and Technology Laboratory (**Baker**), Synchrotron beam time and EPSRC funded time on the National Mass Spectrometry Service (£**220k**). Over the assessment period, staff within the UoA have been awarded 5 EPSRC Industrial Case PhD Studentships (**£424k**). **Stec** was awarded **£125k** from EPSRC to support her study of large scale fire behaviour and toxic product generation in 2011, and **€533k** for an EU FP7 project on carbon nanotubes as fire-safe replacements for brominated flame retardants in 2012. **Bond** as part of a Collaborative project with the Universities of Bristol and Huddersfield was awarded **£170k** by EPSRC / NDA to study the post disposal behaviour of ^{14}C in irradiated graphite. Staff have also received significant industrial funding (**£350k**) from multinationals including Johnson Matthey, Jaguar Cars, Borealis and Elkem. In addition, **£70k** was received from the EU FP6 Predfire Nano project, **£30k** from three Envirolink projects, and **£90k** from the TSB to support the Lonza Knowledge Transfer Partnership.

In addition to staffing and PhD studentships the university has also invested in specific projects for the UoA. UCLan Biomedical Technologies (Shenzhen) Ltd invested over £1M in developing collaborative research programmes with Chinese institutions in the area of nanotechnology and bioengineering. **Sen** secured **£126k** to develop novel water purification technologies based on antimicrobial nanoparticles in collaboration with Fudan University, while **Stec** received **£325k** to develop the study of fire toxicity and nanoparticulate fire retardant additives.

Fire materials has benefited from significant internal investment. In particular, the university set up a number of strategic "2010 Centres" including CFHS, which received an additional £400k to develop fire research over the period 2006-2010. This provided financial support to develop the computational aspects of fire safety engineering – hardware and staffing. The fund also made a small contribution to the establishment of the LIFE facility at Washington Hall, and the modelling of polymer decomposition and fire retardant behaviour. Overall the CFHS has benefited from £1.3M investment by the University over the REF assessment period.

In addition this UoA has benefited from a recurrent "QR" grant from the university which constituents an investment of over **£400k** over the assessment period. This has been used to provide PhD and postdoctoral support for specific projects in this UoA and to facilitate dissemination of the research through conferences.

d. Collaboration or contribution to the discipline or research base

Research Collaborations

Collaborations in the biological and functional materials areas with formal outcomes resulting in publications grant applications and or joint projects include: Universities of **Durham**, **Kent** and **Manchester,** UK; **State University of New York,** and **Mayo Clinic**, USA; **Deakin** University, Australia; University of **Caen**, France; **SINTEF** Norway; **Fudan** University, China**;**, MN-55905, USA**; Pasteur Institute of Iran**; **Indian Association for the Cultivation of Science**.

Collaborations in the fire materials areas with formal outcomes resulting in publications, grant applications and or joint projects include: **Imperial College,** Universities of **Edinburgh**, **Leeds**, and **Bolton**, UK and University of **Maryland** and the **Federal Aviation Administration (FAA)**, US; **National Research Council**, Canada; Universities of **New South Wales**, **Queensland**, and **Newcastle**, Australia; University of **Canterbury**, New Zealand; **Ecole Nationale Superiore de Chemie de Lille**, **Ecole de Mines d'Ales**, and **LNE**, France; **BAM**, Germany; Universities of **Stockholm** and **Lund** and **SP** – the National Testing Laboratory, Sweden; **Politechnico Torino**, Italy; **University of Science and Technology of China** (USTC) and **Sichuan University**, China.

Staff are at different stages in their careers. Highlights over the REF period are summarised below.

Bond: Attracted over £236k of Funding council and government support and a further £111k of industrial support for his research. Visiting Professor at CNRS Laboratory for Catalysis and Spectroscopy, University of Caen, France and is a member of the Management Committee of AMPERE (Association for Microwave Power in Europe for Research and Education). Regular reviewer for a number of international journals. He has made International Conference Presentations (2) and been part of International Scientific Committees (2). He played a key role in the organisation and delivery of International summer schools in Avignon, France 2011 and Long Beach, USA 2012 both of which attracted an audience of over 40 scientists and engineers from both industry and academia with representation from Europe and the rest of the world. This led to him being invited by the Romanian Academy of Sciences to deliver a similar event in Bucharest 2012.

Baker: Awarded an EPSRC Life Science Interface Fellowship under the auspices of which has held visiting researcher / academic positions at a number of prestigious institutions including: Robert Koch Institute, Berlin, Harvard Medical School, Boston and Monash University, Melbourne, and has led interdisciplinary teams consisting of clinicians and pathologists from the Christies Hospital NHS Trust and the Paterson Institute of Cancer Research. His British Journal of Cancer paper was highlighted in Trends in Biotechnology as a Research Focus; his Journal of Biophotonics paper was a most accessed article and featured on Urotoday.com. He was recently awarded the front cover of the RSC journal Analytical Methods and Analytical and Bioanalytical Chemistry and is Secretary for the RSC Industrial Physical Chemistry Group (IPCG) Committee

Hull: Developed tools and investigated mechanisms of fire retardant behaviour; pioneered steady state tube furnace (ISO/DIS 19700) for bench-scale measurement of fire toxicity; developed and maintained links between the fire retardancy and fire-safety engineering communities. UK Principal Expert on Physical Fire Models for ISO TC92 SC3, Fire Threat to People and the Environment. Member (and acting Chair) BSI Hazard to Life from Fire technical committee (FSH/16). Editor: Fire retardant polymers: new strategies and mechanisms Royal Society of Chemistry (2009); Guest Editor of Polymer Degradation and Stability (2008). Editorial Board of Springer *Fire Science Reviews;* Editorial Board of *Fire Science and Technology.*

Kulkarni: Recently completed postdoctoral work at University of Cambridge, Bayreuth and Graz. Has two papers in the top ten most read Phys Chem Chem Phys (PCCP) papers, has been successful in securing beam time on the synchrotron source Elettra, Italy. Was a guest editor for themed issue of PCCP, he is a referee for numerous international journals and has given invited lectures at many international conferences.

Kelarakis: Recently completed a postdoctoral fellowship at Cornell University, has a successful track record of securing EU funding “Complex Architectures in Di-block Copolymer Systems” (Universities of Athens, Manchester and Sheffield), he has a strong track record of working with industry collaborating companies including Intel Corporation, Coca Cola etc. He is a referee for many leading international journals and is on the editorial board for ISRN Nanomaterials.

Hayes: Recently, completed a postdoctoral fellowship at the University of Athens, he was co-investigator on the EU grant “Consolidation and promotion of Research Capacity in the area of Structure-based Drug Discovery” (€ 970K). He has been on the organising committee and part of the delivery team for several international workshops on computational biophysics and is a referee for most of the leading international journals in his field.

Sen: Work on drug delivery selected among the 25 hottest articles published by Science Direct in Summer-Autumn 2010 and the surface chemistry on SPIONs as a featured letter in Micro & Nano Letters in November 2010. A member of the Editorial board of ISRN Nanotechnology and regular reviewer of research work submitted to many leading journals.

Stec: Analysis of toxic products in fire effluents; analysis and toxicity of nanoparticles from fire atmospheres; analysis of volatile decomposition products from fire retardant polymers. UK Principal Expert on Fire Chemistry and project leader for FTIR Analysis of Fire Effluents (ISO 19702) in ISO TC92 SC3, Fire Threat to People and the Environment. BSI Hazard to Life from Fire technical committee (FSH/16). UK Management Committee Member and UK representative to FLARETEX COST Action MP1105.