Institution: Loughborough University (LU)

Unit of Assessment: B8 Chemistry

A. Overview

This submission represents the research of the Department of Chemistry at LU (Unit). In 2009 the Unit restructured its research to concentrate capability, resource and specialist skills onto 4 key themes. The underpinning inorganic, organic and physical chemistry disciplines, along with the Centres for Analytical Science and Radiochemistry, collaborated within flexible research teams to undertake fundamental research focussed on: **Energy, Environment**, **Health** and **Security**. The collaborative approach extended from the Unit, across LU and into a broader national and international context. This approach led to growth and development in our research.

The Unit has fostered an ascendancy culture, with 7 promotions of our best and brightest, 3 new staff appointments and is part of the £ 60 M "West Park Project"; a world-class integrated science and engineering research facility. Meanwhile, a rolling programme of replacements and upgrades has enhanced and updated the essential underpinning technology.

B. Research strategy

B.1 Vision. Our research vision, a response to national and international priorities.

In 2008 the Unit undertook a comprehensive review of its approach to research. Analysis of: societal drivers/need, the Unit's core-competencies; RCUK priorities; and independent expert reviews (commissioned by the Unit) led to the adoption of 4 research themes.

***Energy*.** New chemistry for energy-generation, -harvesting, -demand reduction & -storage.

Environment. Safe disposal of radioactive waste and translation of this research to the mineral/extractive industries.

Health. Creation of disruptive *in-vivo* health measurements and new therapeutically useful compounds and synthetic methods.

Security. Expansion of the range and nature of evidence available to protect life, safeguard society and confront criminality.

B.2 Strategic aims and objectives.

Strategic research aims:

1. Undertake and disseminate underpinning research in the four themes.
2. Develop outstanding and highly promising research talent at all career stages; and
3. Be a research partner of choice for multi-disciplinary collaborations.

Research Infrastructure Objectives:

1. Sustain and extend the characterisation facilities that underpin synthesis-based research (note that the Unit's facilities are integrated into the LU award winning "Kit Catalogue" scheme which facilitates equipment sharing and therefore enhances research capacity)
2. Complement successful research grants from the EU, NERC and EPSRC and Industry by strengthening collaborations with MRC, NIHR and National funding charities.
3. Sustain and enrich international networks, especially EU consortia-led research.
4. Enhance the Centres for Analytical Science (CAS), and Radiochemistry with the experienced teams of academic and research staff needed to enable the Unit to make distinctive and valuable research impacts, and fully utilise state-of-the-art instrumentation and systems.

B.3. Research themes and teams; activities, achievements and ambitions

The Unit has achieved its strategic research aims, and is making good progress towards its research infrastructure objectives. Since 2008 new research leadership has focused on, and prioritised, research to concentrate this Unit's participation in those areas where the Unit has the assets and specialist expertise to add greatest value. Within the Unit multi-discipline research collaborations are part of the weft-and-warp of the research environment. It is important to emphasise that staff are not allocated exclusively to a single research theme, and teams are created in a responsive and flexible way to strike the right balance and responsiveness to the continuously developing research agenda. Over the REF period the 4 research themes generated: 78% increase in research funding from 40+ research sponsors; £2.4M investment in technical systems; 38% increase in PhD numbers; employed 31 PDRA; collaborated with 38 industrial partners; joined 79 international collaborations; published 650+ journal papers; presented 200+ conference proceedings, as well as books, book chapters patents and reports. The Unit appointed 3 professors and 3 lecturers. The infrastructure imperative noted in the RAE 2008 has been

addressed with the "West Park Project" a massively exciting £60M development; currently ca. 2 yr. into a 5 yr. project. Finally, appointments into CAS and organic synthesis, along with the focus of the Health Research Theme have substantially enhanced the "bio-"offer of this Unit.

Development, promotion and dissemination; 82 projects with 49 different funders

9 Staff contributed to the **Energy** theme notably reporting on the electrochemical activation and incorporation of CO_2 into value added chemical feed-stocks while new quantum approaches to electron transfer theory led directly to high-temperature super capacitor systems. Complementary electrochemistry described electrochromic nickel(oxy)hydroxide films for smart-windows applications and synthesised/developed nano-structured multi-component functional electrodes for solar energy harvesting, conversion and energy storage systems. The **Environment** theme (7 staff) contribution to the UK and wider international community policy and practice in radioactive waste disposal made them strong partners in significant and large collaborative projects on radioactive waste disposal (see Section E). In contrast to waste disposal, the characterisation of new mineral chemistries supported the vital discovery of new transition metal resources; note the collaboration with European Nickel and more recently the Univerzitet u Beogradu.

Chemical synthesis was/is pivotal to the **Health** theme with contributions to enabling methodologies for stereo-, chemo- and regioselective transformations to create chemical complexity. New catalysts, new catalytic-mechanisms and catalytic-mechanisms for atom- and step-economic synthesis included new modes of reactivity such as activation of aliphatic C-H bonds. The total synthesis of natural products and bioactive, often heterocyclic, compounds of pharmaceutical importance, such as anti-HIV, antitubercular, anti-inflammatory and anticancer agents was undertaken along with antimicrobial and antifungal inorganic complexes, as well proteasome inhibitors, and peptidomimetics. CAS, an important part of the **Health** theme, developed new mass spectrometric (MS) and ion mobility (IMS) instrumental techniques and methods for diagnostics, biomarker discovery and personalised medicine; prioritising *in vivo* measurements. CAS has grown to be a world-centre for IMS and reported the world's first: plastic IMS systems, and FAIMS-ToFMS. In collaboration with clinical partners, new MS approaches for personalised Pt-based chemotherapy, therapeutic cell-tracking/-characterisation and bio-imaging were developed. New staff appointments mean added capability for high-specificity pathogens and biomarker detection based on aptamer discovery and new DNA-protein interaction models. CAS biomarker discovery campaigns have reported new candidate markers for growth hormone administration, Alzheimer's and respiratory diseases, psychological and physiological stress. Central to this research has been the development of non-invasive *in-vivo* sampling methods. CAS' emergency-medicine/disaster applications for IMS received world-wide interest. The Health theme is the largest (16 contributing staff).

The **Security** theme (8 contributing staff) developed nano-droplet ionisation for rapid IMS screening of consumer non-durables (e.g. marked fuels and pharmaceuticals), described stand-off detection of metal-free explosive devices with laser spectrometry. Of special interest has been the release of new chemistry for forensic science enabling novel methods for fingerprint and data retrieval from previous untenable media (i.e. thermal printer receipts). This engendered strong multi-agency collaboration led by the Home Office labs at CAST.

Next steps, developing and sustaining longer term research.

Our funding pipeline is healthy (over £1M since 31 July 2013) and the Unit anticipates significant enhancement to its physical infrastructure, accompanied by continued development of the partner and research collaborator network. New facilities for **Energy** research into nano-structured functional materials for photovoltaics (PV); solar-driven hydrogen generation; artificial photosynthesis; batteries and supercapacitors are being built. Fundamental theoretical studies into electron transfer theory will continue, and organo-synthesis combined with analytics has started to produce high-quality fuel stocks from mixed-feedstock pyrolysis of end-of life polymers. Fuel-from-waste is a goal that crosses over to the **Environment** theme where the objective of complete characterisation of radionuclide speciation, solubility, surface chemistry and incorporation in mineral matrices (including non-nuclear radioactive wastes from extractive and mineral processing industries; aka NORM) remains a priority. The Unit will continue to refine its synthetic focus in **Health** by seeking new synthetic routes and new molecules/functional materials with inflammation (molecules, mechanisms and management) very much in mind; personalised medicine will be delivered through "disruptive" analytics for health and patient stratification where CAS will continue its programmes. New molecules/techniques for sensing and imaging

marks/traces continue to be developed in the **Security** theme where explosives, disaster analytics, advanced security labels, and currently intractable physical evidence will fall under this remit.

C. People

C.1. Staffing strategy and staff development

Our three staffing strategy priorities are:

1. sustain research capability through effective succession planning;
2. develop and support research-leadership at all career stages; and
3. consolidate and enhance the 4 strategic themes.

Succession planning.

Continuity in strategically important roles was managed through "handover" periods. The flexible (partial) retirements of Sharp and Creaser (Analytical) to 0.4 FTE were supported by handover lectureships in nano-materials sensing (Platt) and mass spectrometry (Reynolds) respectively. When former head-of-department Warwick (Radiochemistry) retired to head up a new start-up company "Enviras" (co-located with the Unit as part of our Enterprise activity) the resultant handover appointment (Read) ensured Radiochemistry continued to thrive. Malkov's strategic appointment was to strengthen "bio-" capabilities, within organic synthesis.

Develop and support research leadership.

(Also see Section C2). All staff receive resource and opportunities to support their development as research leaders and 9 staff were promoted during the REF period. Currently 2 staff are being supported through probation and 4 are being considered for promotion. LU's Personal Research Planning (PRP) and Performance & Development Review (PDR) processes are key to the development of staff, both as individuals and as research leaders.

Established staff are supported/encouraged into leadership roles. For example, two strategic RCUK Fellowship appointments, Wijayantha and Buckley, provided a strong focus on Energy. Wijayantha (grants ~ £1.5M during this period (as PI and CI) and >35 peer reviewed outputs) was directed to lead the Energy theme and was subsequently identified by LU as an Institutional Energy Theme Champion and recruited to the EPSRC sponsored LU LEADeR research leadership scheme following promotion to Senior Lecturer in 2010, and Reader in 2012. Buckley developed complementary research areas, based in organic synthesis, in carbon capture and novel oxidation methodologies (more than 20 research outputs) and Buckley was subsequently enrolled on the LEADeR scheme, and is now the academic lead for the EPSRC Grand Challenge CO2Chem 'Fuels' cluster. Buckley is currently preparing his case for promotion to Senior Lecturer. Training and preparation for leadership is a central, and developing, strategic element in the consolidation and concentration of the 4 research foci, and the Wijayantha and Buckley case study illustrates how researchers are developed through guidance, support and direction. Indeed the team approach extends to the appointment of teaching fellows in those areas where it is helpful to release staff resource to research; this has happened on two occasions in this reporting period.

Consolidate and enhance strategic themes.

Examples of this strategy in action include: Read's appointment to develop the radiochemistry capability and international collaborator network (e.g. time-resolved laser fluorescence spectroscopy at FZ Dresden-Rossendorf (studies of surface chemistry of depleted uranium); the large ^{60}Co source at the U. of Helsinki (porosity characterisation of rocks and structural materials); and the superplasticiser ADVACast 551 characterisation at Notre Dame U. (USA)); Platt's recruitment to introduce nano-particulate bio-sensing hence translating marker-discovery to sensing and monitoring. Currently Creaser is mentoring Reynolds, a recent lectureship appointment in mass spectrometry, and the Unit is delighted to have appointed Eiceman to further reinforce the Unit's leadership in ion mobility spectrometry, and extend significantly the reach of the collaborator network in this area.

C.2. Supporting researchers

Key principles of the Concordat. The LU 2010 implementation plan to support the Career Development of Researchers in 2009/10 was up-dated in 2012 and received an HR Excellence award. LU's PRP and PDR programmes are supported by personalised development training, for all the Unit staff and research staff. There is a substantial programme of courses run by the LU Graduate School, Careers and Employability Centre, and Staff Development Unit including accredited Leadership and Management programmes.

Early Career Training. This starts with the New Lecturers' Course with emphasis on research culture and support, and is also supported by secondment to institution-wide activities, and engagement with larger projects and international collaborations (e.g. Platt's liaison with Singapore Nanyang Technological U. as part of LU's research focus on inflammation and sensors, and Reynold's secondment to Prof Cooks' laboratory at Purdue University). Importantly, teaching and administration are limited to 1/3, 1/2 and 2/3 of 1 FTE in yrs. 1, 2, and 3 respectively. Mentors provide coaching throughout probation to encourage and support research development. Resources and funding are prioritised for probationary staff, particularly with Institutional studentships, (currently running at between 4 and 5 PhD FTE yr^{-1}) which also come with a senior staff mentor as a co-supervisor. Central funds ensure attendance and representation at appropriate conferences and meetings Academic staff are encouraged to participate in mentoring as mentees and mentors, all of which is augmented by LU's Research Office.

C.3. Fellowships, international recruitment and visiting scholars.

Fellowships. McKee was awarded the Erskine Fellowship (U. of Canterbury, New Zealand) followed by the VELUX Visiting Professorship (U. of Southern Denmark) and Platt was a Marie Curie Intra-European Fellow.

34 PDRA appointments to this Unit have been made since 2008. Their training, contributions and development are manifest in their publication records and progression. Some have taken on expert and leadership roles within leading UK industry, others have transferred into nationally leading institutions and companies and three, Roberto King, Asif Tahir and Sundaram Senthilarasu have been appointed to Lectureships in research-led UK Universities.

International recruitment. Academic and research staff are drawn from all over the world. Currently 21 staff originate from UK/EU nations, 1 from Australia, 1 from Sri Lanka and 1 from the USA. Post-doctoral fellows originate mostly from the UK/EU, but Chinese, Indian and Russian scientists are a strong element of the research community.

International collaboration and scholarly exchange. The international programme hosted 42 researchers from 19 Nations. In exchange, staff and researchers were sent to work in 4 Middle Eastern, 5 Indian and 2 Pakistani institutes. Further east Australia, Japan and New Zealand, and to the west in the USA Florida State U., Georgia Institute of Technology, Purdue U., U. of Florida, U. of Louisville and New Mexico State U all hosted exchanges.

C.4. Equality and diversity

The LU ethical framework and policies are comprehensive and this Unit seeks to establish best practice. Training and awareness are addressed in: the New Lecturers' Course; mandatory equality and diversity training for senior staff involved in recruitment and promotion; and the PDR, a self-critical exercise to identify advancement opportunities, and remove barriers to progression.

LU holds the Athena Swan Bronze Award, and the Unit is working towards to gaining Silver Award status. The Discipline Champion (Kirk) is leading development in this area. The Unit engages with programmes such as the Daphne Jackson Fellowships, and strives to ensure that researchers' developmental needs are properly met at all life's stages, from flexible retirement to work adaptations, support on return from parental leave, and part time working where needed. The intent is to provide the environment all need to thrive and flourish.

C.5.Research students;

Our PhD researchers are at the centre of the discipline and are supported by: RCUK, EU programmes, TSB, Industrial CASE, Industry and LU. External partnership is encouraged with 57 PhD studentships receiving Industrial CASE/Industrial funding. PhD places are preferentially allocated to candidates with high "First Class" MChem degrees and/or a distinction level MSc, following a successful interview; there is a strong competitive element. Continuous supervision and training in Chemistry is complemented by the LU Graduate School, and other services, (a dedicated Careers Advisor, and the Library specialists for example), that support the PhD experience with a programme that includes induction days and advanced skills workshops. The long-established and very successful PG-T programmes deliver specialist training in instrumental techniques where needed, and LU's award winning Maths Education Centre is a vital element. The LU Researcher Development Framework delivers a wide range of workshops and conferences as well as supporting participation at international conferences. The PhD student annual progress review includes: a substantive written report (10,000 words), an up-to-date plan

for project-completion and peer-reviewed publication, all accompanied by a detailed training record. Their supervisor(s), as well as an independent academic, review and assess their research progress based on these deliverables and an interview with the researcher. Critical feedback / praise / encouragement is subsequently presented to the student. During the REF period the research of the PhD cohort has received 25 prizes and awards from learned societies and international conferences.

Total FTE postgraduate research students enrolled on doctoral programmes 2008-2013

Year	'08/'09	'09/10	'10/'11	'11/12	'12/13
Total	60	66	72	72	72

D. Income, infrastructure and facilities: £7.0M research grants

D.1. Specialist Infrastructure and facilities

Characterisation for synthesis. The 12 synthetic chemistry staff are supported by the Analytical Services Group, who operate two 400 MHz multi-element and a 500 MHz solid-state multi-element NMR spectrometers; a complete suite of pulse-programmes is available. 3 X-Ray diffraction systems include cryogenic single crystal, four-circle single crystal, and powder diffractometers with furnace options (Note the extensive international collaborations of Elsegood and McKee with 113 and 90 co-authored papers for their X-ray contributions). Mass spectrometric characterisation is provided by LC-ESI-quadrupole/MS; GC-EI-Quadrupole/MS and an ESI-Orbitrap mass spectrometer equipped with a Nanomate sample delivery system. All the major variants of separation science, including chiral platforms, along with a wide range of spectrometric systems from laser-induced fluorescence to FT-IR are provided in support of synthesis-led research.

Analytical Science. This research is necessarily collaborative in nature involving clinicians, biomedical, materials and sports scientists, chemical engineers, physicists, pharmacists, psychologists, mathematicians and fellow chemists. The skills in CAS encompass: multivariate experimental design, sampling of complex systems, non-invasive *in-vivo* and industrial process sampling, specialist workflows for ultra-trace analysis of VOCs and small molecules and metabolites, heavy metals and other persistent pollutants, surface analysis, DNA extraction and processing, sample processing and preparation including extraction techniques, derivatisation (*in-situ*, in-trap, on/pre/post column), preconcentration, laser-based surface ablation and separation science (GC, HPLC, UPLC). CAS has international recognition for its research in IMS with Profs Eiceman, Creaser and Thomas undertaking collaborative and independent research. Mass spectrometry is at the core of research in CAS, particularly the development of ICP and ambient ionisation techniques, hyphenated systems (GC-MS, LC-MS) and ion-mobility combined with mass spectrometry (IM-MS, FAIMS-MS). Biomimetic nano-particles with aptamer and paramagnetic functionalization, DNA micro-arrays, photolithography, data processing and multivariate data modelling are developing areas of specialist infrastructure and facilities.

Functional Energy Materials. Facilities for the development, construction and testing of high-efficiency and low-cost PV, flexible/mobile solar cells, solar hydrogen-generation devices, electrochromic/smart windows & supercapacitors include systems for nanostructured semiconductor thin film electrode preparation and advanced characterisation. The functional materials suite has prototyping capability using a range of thin film deposition techniques including AACVD, APCVD, ATVD, CBD, electro-deposition, spray pyrolysis, screen printing, hot/cold press technique, ball milling and novel microwave and hybrid radiation assisted materials processing. Other characterisation assets include advanced electrochemical (i.e. EIS, potential modulated transmission), photoelectrochemical (i.e. PEIS, IMPS, transient absorption), and optical (i.e. AFM and contact angle) measurement platforms. Artificial photosynthesis studies are supported by specialist electrochemical/chemical CO_2 utilisation/conversion systems.

Radiochemistry. For research into nuclear radioactive waste management, the radiochemistry assets enable work on isotope forensics (security theme), radiolabelling and more recently, radio-synthesis and radio-labels (Health and Energy themes). The Centre incorporates γ-spectrometry and counting, liquid-scintillation counting, ICP-MS & ICP-OES, HPLC, radon detection, XRD, XRF & measurement of open sources; within and without "hot" glove box environments. α-Spectrometry is available via on-site industrial collaborators (Enviras for example). A fully equipped mobile-laboratory for remote field work completes the asset list.

Services: The LU Equipment Database ("Kit Catalogue") connects the Unit with all equipment and facilities at LU. This invaluable resource provides a rapid introduction to a very wide range of specialists and experts. National services include peer-reviewed awards of beam time and sample allocations at Daresbury Laboratory, Diamond, and ISIS. The EPSRC Crystallography Service (Southampton) and the EPSRC Mass Spectrometry Service (Swansea) have been used extensively as well as the EPSRC high-resolution NMR facilities at Warwick and Durham, supported by the supercomputer service at Imperial College for NMR spectral simulations.

D.2. Current and planned investments

Equipment renewal. £2.4M of new instruments have been commissioned since 2008. The Analytical Services Group (£638k) have benefited from new MS, NMR and X-ray systems. The plans are to: maintain and enhance such equipment; share this resource with collaborators; and facilitate regional and national partnerships that wish to use these facilities. Some upgrades to laboratories (£206k) have enhanced energy, synthesis and radiochemical activity, while a new mobile environmental laboratory, supplemented by high throughput ICP-MS, has extended the capability of Radiochemistry. CAS (£1835k) with a strong emphasis on instrumentation commissioned MS, IMS, separation science and high-performance sampling systems.

Chemistry relocation project. This exciting project, which is in the planning and enabling works phases, will place the Unit into new state-of-the-art facilities co-located with colleagues and researchers from Physics, Materials and Chemical Engineering. With an estimated spend of up to £60M this project is large, significant and ambitious in its scope, involving a bespoke multi-disciplinary and consolidated research centre. The plan is to place researchers into world-class physical and intellectual spaces that will facilitate and foster fundamental and applied research across the 4 strategic themes.

D.3 Research Funding Overview and Highlights

The Unit was awarded £7.4M in 105 grants with an average value of £70k during the REF period that ranged from £0.47M (large research commission; Nuclear Decommissioning Agency(NDA)) to £1K (feasibility study on functional metal oxide films; Sasakwa Foundation). 21 RCUK grants totalling £2.5M spanned all four themes. (Eg. **Energy** £0.62M, various electrochemistry; **Environment** £0.32M Biogeochemistry; **Health** £0.3 M, Synthesis and **Security** £0.25M, Solar Soldier.)

In **Energy** (£1.5M), received significant support from EPSRC for nano-structured functional materials (Wijayantha). **Environment** (£2.2 M) highlights were fundamental biogeochemical studies supported by NERC (£0.32M Evans) and decommissioning research supported by the NDA and EPSRC (£0.47M Evans). **Health** (£2.4M) in addition to the synthesis research, see above, was able to conduct agenda setting instrument development for new health measurements by μ-FAIMS-MS with funding from BBRSC, Owlestone AstraZeneca and Agilent (£0.27M Creaser), and elemental analysis for personalised medicine supported by EPSRC, Charity; ESI New Wave Research, Euromet; TSB and LGC (£0.52M Sharp and Reid). Significant funding in **Security** (£1.3M) included Urban Search and Rescue supported by EU funding (£0.44M Thomas) and new forensic chemistries supported by various UK government agencies (£0.38M Kelly)

The central driver in the strategy was, and will be: focusing resources to deliver critical capacity; a pre-requisite for high impact research.

D4. Future Plans

Consolidating the 4 themes is the objective. From discovery & synthesis, to characterisation and hence to application & formulation requires a strong internationally collaborative ethos; one that reaches out to include colleagues from other disciplines and institutes. Away-days, regular theme meetings and analysis from the theme leaders have shaped and continue to develop a research funding strategy that is coherent, coordinated and collaborative across the department with a strategically managed focus on fundamental research, collaborative translational projects and follow on enterprise and impact.

D.5. Consultancies and Professional services

Consultancy and professional services have been provided to 101 external organisations; 40 of these were based overseas. Specialist scientific support has given to large corporates such as Mars, GE Ltd, Unilever, 3M, Intertek, Park Air Systems, BPI Ltd, and Lubrizol, as well as numerous start-up and SME enterprises. Expertise has been provided to key government agencies, notably AWE, NDA, HOSDB, NMO and MoD. Other significant national organisations

include the Natural History Museum, LGC, NPL, and the NMU. PhD examiners were provided extensively across the UK and to more than 37 overseas universities. World-wide specialist training has been provided, and of special note has been the commitment to the emerging field of IMS where since 2008 the Unit has delivered workshops in 7 countries.

E. Collaboration or contribution to the discipline or research base

E.1. National, international and interdisciplinary research collaborations

All staff collaborated in research; much was multi-disciplinary and multi-national in nature across a variety of rich partnerships with industrial, governmental and academic partners. The largest collaborations have a combined grant income of more than ca. £30M, and a summary of the highlights would include:

Energy: International collaboration has grown a network of high-quality research links (see C3 above) while in the UK, multi-disciplinary collaborations with Cambridge, Imperial College, Bristol, Bath, Glasgow, Birmingham and Nottingham, have resulted in 21 awards. Industrial partners include Schlumberger, TATA, Johnson Matthey Plc., DSTL, Pilkington, Intelligent Energy and EffecTech, and Wijayantha sits on the scientific advisory board of Polysolar Ltd. Buckley was the academic lead for the 'Fuels' cluster of the EPSRC CO2Chem Grand Challenge Network & the 'artificial photosynthesis' of cyclic carbonates are the early results of his collaboration within the East Midlands Energy Consortium. Fletcher's research on quantum designed ionic liquids for extreme chemical inertness has, in conjunction with Aero & Automotive Engineering at Loughborough, led to high-T supercapacitors. The surface coatings research of Mortimer on corrosion protection has led to reduced energy costs in replacing electronics/household goods/cars/aeroplanes/bridges/industrial plant.

Environment. Environmental radiochemistry lends itself to large multi-centre partnerships, for example: Diamond (EPSRC) entails collaboration with Manchester, Sheffield, Leeds, UCL and Imperial College. The BIGRAD, Lucifer and AMASS consortia involve *inter alia* the British Geological Survey and the National Nuclear Laboratory whereas work with the MEL involves NPL and industrial partners. International collaborators are drawn primarily from the major German Swedish, Swiss French and Finnish nuclear research institutes. Other Environmental collaborations include Kirk's leadership in novel mineral chemistries in partnership with the Natural History Museum, European Nickel & more recently the Univerzitet u Beogradu. While collaboration with the National Isotope Geology Laboratory, Keyworth led to new high-performance LA-ICP-MS techniques for isotope ratio characterisation at µm scale U particles.

Health Collaborations with the pharmaceutical sector include proteasome inhibition, anti-HIV, anti-cancer and peptidomimetics (Buckley, Kimber, Jones and Malkov) in various partnerships with Novartis, AstraZeneca, Eli Lilly, UKIERI-UGC Thematic Partnership, Royal Society and RCUK. Academic partners in this area are drawn from the Universities of Sydney, Bath, Birmingham, East Anglia, Strathclyde, Keele, Newcastle, Durham, Nottingham, UCL and Saga University. Novel chemical detectors for plasma medicine are being developed with the Wolfson School at Loughborough and the Linde Group Ltd. Christie's research with the Nottingham University additive manufacturing team and the LU Dept. of Materials and Wolfson School into biocompatible and biodegradable materials for medical applications such as stents and other devices is leading to potentially disruptive technology and Christie is associated with the successful bid for a Centre for Doctoral Training in Additive Manufacturing. Another engineering collaboration, this time between Malkov and Chemical Engineering at Warwick U. is developing a continuous flow reactor for [$^1O_2$] leading to new asymmetric catalytic methodologies.

Sharp and Reid developing of high-performance laser ablation ICP-MS to track single Gd-labelled therapeutic cells to evaluate cellular immunotherapy in solid organ transplantation with colleagues in the U. of Oxford Nuffield Department of Surgical Sciences and University of Regensburg. Creaser and Reynolds, working in collaboration with AstraZeneca, Agilent Technologies and Owlestone Ltd, have developed and characterised novel miniaturised ion mobility mass spectrometry platforms (uFAIMS-MS), a new instrumentation technique with a wide range of applications in the clinical/bioanalytical, and pharmaceutical and petrochemical sectors. Platt's collaboration with Izon Science Ltd, LU Dept. of Mathematics and National Technical U. of Singapore is creating synthetic aptamers for new approaches to bio-marker detection and analysis. Working with the LGC and the European Metrology Research Programme, Sharp and Reid demonstrated single-cell metallomics in relation to chemotherapy, oxidative stress and macular degeneration. Thomas developed a suite of non-invasive sampling and analytical

techniques for clinical analysis to prospect for biomarkers for paediatric asthma, and stress from translational research with U. of Leicester Hospital Inflammatory Group and the Psychology team at the LU School of Sport, Exercise and Health Science.

Security. Kelly has led collaborations with CAST that have multi-agency engagement in the specific development of new mark (e.g. fingerprint) imaging techniques and, more recently, has engaged with partners such as English Heritage in the areas of heritage crime and metal theft. Studies led by Thomas into security labels for non-durable consumer products with John Hogg Technical Solutions resulted in next generation contraband fuel approaches with the development of on-demand dopant modifier systems for ion mobility spectrometry. Worrall's partnership with DSTL is leading to the development of photo-switchable surfaces with substantial potential for chemical and biological protection, while laser-based detection of explosives and mines is undertaken in partnership with the Wolfson and Design Schools at LU. A cross-theme (Security-Energy) collaboration with Dstl, Glasgow and Sheffield Universities has addressed battlefield photovoltaics in the Solar Soldier project. Another cross theme programme (Health-Security) involved disaster recovery research with substantial international through the SGL for USaR project 19 EU partners as well as complementary research with Kings College Hospital.

E.2. Collaboratively informed research and strategy

The Unit seeks to achieve impact by adding value through core chemical and multi-disciplinary collaborative research. The current research portfolio seeks to balance applied, fundamental and translational research activities. This is a necessarily outward-looking research strategy that has, and will, contribute fundamental chemistry research to the collective science, clinical and engineering responses to "Society's Grand Challenges".

E.3. Leadership

The Unit delivered 209 invited lectures across the world, organised/chaired 89 scientific conferences and provided panel members for 26 National and International research funding bodies, including EPSRC, Leverhulme trust and Royal Society, Finnish Academy of Sciences, TSB, ACS petroleum fund, Estonian Science Foundation EU FP7 Australian Research Council, New Zealand Ministry of Science, and Deutsche Forschungsgemeinschaft, National Science Foundation (USA), Science Foundation for Ireland, British Council, Estonian Science Foundation, Qatar Science Foundation, Research Council of Oman, and the National Science Centre (Narodowe Centrum Nauki - NCN)

The Unit's leadership and contribution to learned Societies includes: Dr. Buckley MRSC, FHEA as an elected member of the SCI Young Chemists' Panel; Prof Creaser C.Chem. FRSC, as Vice-Chair and Chair-elect of the British Mass Spectrometry Soc., Dr Elsegood C.Chem. MRSC, as a IUCRj Commission member; Dr Evans, C.Sci, C.Chem. MRSC as Chair of the DNRC of EuCHEMS and Hon. Sec. of the RSC Radiochemistry Group; .Prof Jones C.Sci., C.Chem. FRSC, MACS, as President of RSC Organic Division; Dr Dann, Treasurer of the RSC Solid State Group; ; Prof. Sharp C.Sci., FRSC National Measurement Office Committee for Chemistry and Biology Metrology; Prof Thomas C.Chem. FRSC, MISIMS, MIABR, FHEA, member of the organising committee of ISIMS and Ex-officio President as well as Hon. Treasurer RSC Molecular Spectroscopy Group; Dr Wijayantha MRSC, FHEA as Hon Secretary of RSC Electrochemistry Group; and Dr Worrall, C.Chem. FRSC as President of the European Photochemistry Association, Chair RSC Photochemistry Group, IUPAC Standing Committee on Photochemistry Committee member and finally a Committee member for the East Midlands RSC local section.

The Unit also provided editorial and journal leadership: Elsegood, Co-Ed. *Acta Crystallogr. C*; Evans, Ed. *Env. Chem. Lett*. and *Minerol. Mag*.; Prof Fletcher FRSC, Ed. *J. Power Sources*, *J. Solid State Electrochem*., and *Electrochem. Comm*.; Jones, Ed. *Comp. Heterocyclic Chem. III (10)*, Prof Malkov FRSC, edited *J. Amino Acids* and *Asymm. Organocatal*, lectures; Thomas, Ed.-in-chief of *Int. J Ion Mob. Spectrom*.; and, Worrall, , Ed *Int. J. Photoenergy*

The emerging leadership of recent appointees is of note, i.e. Buckley as Academic Cluster Lead for the CO2Chem EPSRC Grand Challenge Network and Dr Kirk MMS service to SYNTHESYS, for EU funded research with facilities/collections from 20 EU natural history museums, universities and botanical gardens.