Institution: Nottingham Trent University

Unit of Assessment: B15 General Engineering

a. Context: We present impact during the REF period from our excellent underpinning multi-disciplinary Engineering research under two thematic areas: (a) Imaging/Sensing: International deployment of security scanners based on our 3-d x-ray imaging technology *reducing global security risks* and generating revenue through exploitation. Sensing technologies being adopted to *mitigate losses* in the European apiculture industry and reduce *environmental* impact by working to increase reed bed efficiency/longevity. Advanced optical/imaging techniques achieving cultural impacts in international *Art/artefact and UNESCO site Conservation*. (b) Materials: *Economic business product/process improvement* impacts including enhanced processing methods for printed electronics and new photonic materials to *mitigate losses* in security authentication. Staff in our solid/liquid interface and functional materials areas engaged *public interest* at events in India, Korea and the UK; and aided regional *community regeneration* in low HE participation rate schools and our City Centre. These impacts have benefitted end users including: International border security organisations in U.S. (Dept. Homeland Security, Air Force) and U.K. (DSTL, Home Office); Companies with global reach (Rolls Royce, Jaguar Landrover, Merck Chemicals, Schlumberger, LG-Philips); E.U. and U.K. trade associations/SMEs; Museums/Galleries (China, Eire, E.U., U.K.); and Public engagement and Education organisations (e.g. Royal Society, British Science Assoc.).

b. Approach to impact

Institutional support to enable staff to achieve national and international impact: The ***NTU Research Grant Capture Team***, brokers relationships/collaborations and facilitates international project management with industry and other relevant organisations. A dedicated ***Business Development Manager*** coordinates Intellectual Property (IP) identification, protection and exploitation, oversees NDA/CDA/MoUs/I.P. agreements, and interfaces with Venture Capital Investors, e.g. for the creation and development of the x-ray imaging spin out company, HALO Ltd An ***Outreach Officer*** supports public engagement activities, and a ***Charity and Industry Officer*** provided unit-specific grant alerts and funding information. Reward for achieving impact is embedded in the University IP, Consultancy and spin out policies, with a sliding scale *share of net revenue* and consultancy income awarded to staff via remuneration or re-investment. Recognition for such work is one of the key criteria of the University's "Awards and Titles" *promotion regulations* to Readership and Professorship.

Engineering unit initiatives and support: The Engineering Unit Advisory Group allocated QR funds to underpin strategic appointments, including Prof Stevens as a joint chair with STFC, and researchers for fixed-term industry focused projects. Higher Education Innovation Funding (HEIF) established an Academic Enterprise Scheme with business-led staff mentoring/workshops, on which *Cranton* developed "Thin Film Services" (2006/08), widened in 2010 to "***Scientific Services to Industry***" (***SS2i***), which provides access to expertise, facilities and equipment-related services within Engineering, leading to collaborative R&D projects and impact through new process and product development (e.g. TSB grant with Plasma Quest Ltd.) The Unit also utilised HEIF funding for an ***Impact Fellowships*** initiative to host research end-users (e.g. STFC, US Air Force), and support feasibility trials leading to collaborative funding with SMEs.

Evidence-based examples of the strategy's success

(a) Imaging/Sensing: The continuing success of our IP strategy in enabling/delivering impact is exemplified in *x-ray Imaging* Case Study 1. In the current REF period the University provided funding for patent US2010254514 underpinning a new ***spin out company***, HALO Ltd to commercialise materials specific imaging for security and diagnostics, negotiated the overarching IP agreement with Cranfield Univ, attracted support for new IP filings from Lachesis (£25k), East Midlands Innovation Fellowships (£16k) and Germinator (£6k), and this has led to [text removed for publication] development funding from the US Government starting in 2014.

UoA investment support for staff time, facilities and sabbatical funding has underpinned *Liang*'s research impacting on international art conservation, e.g. research on EPSRC EP/E016227/1 and support from Gooch & Housego plc. applied to wall paintings in the Mogao caves (4C-14C UNESCO site on the Silk Road, Dunhuang, China) revealing Sanscrit writing and informing dating for the curators, Dunhuang Academy. Non-invasive Optical Coherence Tomography techniques developed with Leverhulme Trust funding were applied to the Faddan More Psalter (8th century) for a National Museum of Ireland guidebook entry (2011). The Tate Gallery and internal investment

funded a PhD project to develop a microfadometer to inform optimum exhibition conditions, impacting on conservation of: Cray/Lebedev supercomputers [L. Burden, Science Museum, 2012]; and textiles in Audley End House [D. Thickett, English Heritage, 2012].
Industrial engagement, grant and project management support from the NTU Research Grant Capture Team resulted in the ongoing EU-funded "***Research for S.M.E.***" partnerships for the collaborative exploitation of our acoustic technology to monitor honey bee health and swarming likelihood, and the exploitation of our low cost remote MRI technology for reed bed status monitoring.

(b) Materials: Internal PhD funding supported work on electroluminescent displays within two ***Technology Strategy Board*** CRD projects, HESSLIS TP K2514K (Plasma Quest Ltd) and SRELD TP2/ED/6/S/10265 (2007-2010) which were developed from engagements secured through the access to facilities initiatives. Resultant collaborative research led to exploitation via design, manufacture and licensing of Plasma Quest's deposition systems. Orders for equipment were received from UK, US and China [Barry Holton, PQL, 2010]. Photonic processing for printed electronics via a ***Knowledge Transfer Partnership*** has enhanced materials understanding and broadened the process knowledge within Pragmatic Printing Ltd, supporting the establishment of their pilot-scale production at the Centre for Process Innovation during 2012/13 [R. Price, PPL, 2013], and has developed new security phosphors for packaging authentication technology with [text removed for publication]. Sabbatical funding supported this industrial engagement and the collaborative development of the "Handbook of Visual Display Technology" [Springer Verlag 2011, ISBN10 3540795669] with 150 international expert contributors for which *Cranton* is the lead Editor in Chief. In 2012, the work had over 26,000 chapter downloads, making it the 3rd most downloaded e-reference across the entire Springer catalogue.
As part of the approach to industrial engagement through multidisciplinary research, the EPSRC funded ***Cross-Disciplinary Feasibility Account*** "Smart Materials - Designing for Functionality" (EP/I016414/1) led by the Associate Dean for Research (McHale), built upon previous funding outcomes (GR/S34168/01, EP/E063489/1) and on the excellent research in materials/imaging (UoA B15 *Cranton*, *Newton*, *Morris*), and textiles/art/ product design (UoA D34 Breedon, Dias, Fisher). The Account Associates, including *Morris*, co-organised end user engagement and projects through events including "Pack to the Future" held at Nottingham Trent (2011 and 2012) with the East Midlands packaging Society and representatives from Institute of Materials, Minerals and Mining [I. Morris] and The Materials ***Knowledge Transfer Network***. The account supported an Electro-luminescent Paste display for PepsiCo, and the development of a new brewing bag product for Moonshine Drinks Ltd [I. Walker, 2013] being marketed through Lakeland stores.
Expertise in *solid/liquid interfacial science* provided to industry via ***consultancy*** contracts includes: our exploitation of the "Lotus Effect" for aeronautical applications with Rolls Royce Plc which fed into their in-house development programme and two patent filings (US2011147219, US2011151186); [text removed for publication] developed by *Brown* for Merck Chemicals Ltd; and *Wallis* and *Fairhurst*'s research for Kidde (www.kiddefiresystems.com).

Public Engagement*, International*: "Nature's Raincoats" Royal Society and Techfest Mumbai (5,522/85,000 visitors), Case Study 2. LG-Philips English Science Camps (*Martin*, 2009, 2010) and stage shows at Korea Science/Creativity Festivals (250,000 and 310,000 visitors in 2012 and 2013 respectively) attracting Korean national TV (MBC, EBS, SBS) and media coverage. *Martin* will perform a televised 4 lecture Korea Christmas Science Concert in 2013. *UK*: Research inspired master-classes funded by Royal Society Partnership grants in Primary (*Bencsik*) and Secondary (*Morris*) Schools; unit-managed observatory "Open Dome" events for the general public (50 attendees per month since 2008).

c. Strategy and plans. In line with the University strategy to support research with impact, the Engineering Unit will promote and support end-user engagement to realise new applications and exploitation of our research in Imaging/Sensing and Materials along with the development of public engagement activities around these two core themes. Our priority impact objectives include:

(a) Imaging/Sensing *Security*: low footprint security x-ray equipment in production for 3D imaging with ability to discriminate materials and find threat signatures. *Economic/Animal health*: Exploitation of new apiary monitoring product through the FP7 Swarmonitor project to mitigate economic losses and promote honey bee welfare across Europe (*Bencsik*). *Environmental*: exploitation of low-cost sensors widely deployed in reed beds and other environmentally sensitive inaccessible areas through the FP7 Autonomous Reed Bed Installations Research for SMEs project (*Morris*). *Transport*: manufacturing tolerance sensitive vibrometry incorporated in industry standard design software impacting robustness/safety through the FP7 Mid-to High Frequency Modelling of Vehicle Noise and Vibration (MHiVec) Marie Curie project (*Chappell*). *Cultural*: application of non-destructive imaging to reduce exhibition rotation costs and imaging to reduce solvent and water based paint/varnish formulations in production (*Liang*).

(b) Materials**:** *Economic/Animal health*: Commercialisation of bio-available silicon supplements for bone strengthening via spin-out company Si Active Ltd Current pump-priming investment (£140k) from the University, industry (Rushcliffe Environmental, AbVista) and the regional Food and Drink i-NET is supporting animal trials (*Perry*) with the Poultry Research Unit at our rural campus and G. Mann at Nottingham University to demonstrate beneficial activity in animals; *Perry* is working with Cellular Systems Ltd on low environmental impact chemical processing of eggshell waste with TSB funding, leveraging our close links to BioCity Nottingham Ltd (www.biocity.co.uk) the UK's largest bioscience innovation/incubation centre. *Economic/ Manufacturing:* Commercial production of printed and plastic electronics utilising photonic processing, industrial engagement and exploitation via Pragmatic Printing Ltd (*Cranton* with Koutsogeorgis), development of nanomaterial products in bioscience and energy sectors (*Stevens*), and application of conductive polymers (*Wallis*/*Martin*). Our planned pathways and support mechanisms to realise these plans, identify and build additional impact beyond REF 2014, include: ***Nurturing new relationships*** with companies by running multi-disciplinary pilot research projects on our suite of Engineering M-level courses to address industry focused problems and challenges. ***Industry-led Advisory Boards*** will be expanded to support and develop each of our thematic research areas in IP and create technology exploitation opportunities. The ***Impact Fellowship*** scheme will be extended to offer incoming and outgoing industrial placements, with help from our network of former MSc and PhD students and KTP Associates now in high technology companies. We are building from the SS2i HEIF supported initiative to create the ***AXIS*** (Applied x-ray Interaction Studies, Imaging) laboratory and the ***iSMART Centre*** (innovations in Surfaces Materials and Related Technologies). The AXIS re-configurable 200 keV facility is very rare in UK Universities and industry and we have secured the support of Hamamatsu Photonics UK Ltd who see commercial applications for testing and product support in medicine, security product inspection and food safety. iSMART is a high value proof-of-concept and advanced materials R&D hub which is building its infrastructure, resources and networks to support the Life Science and Clean Tech companies based at BioCity, MediCity, Inntropy and Medilink East Midlands by delivering multi-disciplinary R&D projects based on capability in nanomaterials synthesis and deposition technologies with photonic materials processing. This is being supported and developed by an industrial collaboration pipeline of 10 SMEs, and current funding from STFC (ST/K001892/1), EPSRC (EP/G060886/1), TSB (SOHAPS TS/J001449/1), and European Regional Development Funds (ERDF-535, University and ERDF match funding of £389k) plus consultancy funding from Radius Health and Johnson Matthey (*Stevens*). The approach to ***Collaborative R&D*** funding, including European Union funding, will continue to be driven by engagement with businesses brokered by our ***NTU*** *Research* ***Grant Capture Team***.

d. Relationship to case studies. Case study 1: Supported by “VC bursary” and QR-funded PhD studentships, e.g. for: (i) Human factors evaluation of kinetic depth effect imaging as part of a rolling US Dept of Homeland Security grant ($458k); and (ii) science underpinning the Broad Area Announcement (BAA) to USA industry of products manufactured by Astrophysic Inc USA. Prof L. Kaufman (New York Univ) was a co-supervisor (PhD 2009-2012). Case Study 2: Direct sponsorship for the “Nature’s Raincoats” exhibit and website received from EPSRC, “Materials” KTN, and Nottingham Trent and Oxford Universities. Shirtcliffe received Royal Society media training and took part in the video series http://www.test-tube.org.uk/, sponsored by Nottingham Science City. “VC bursary” and QR funded PhD studentships underpinned work on: (i) electrowetting of liquid marbles and wetting gradient super-hydrophobic surfaces (PhD 2005-2010), producing supporting evidence used in the proposal for EPSRC grant EP/G057265/1.