Institution: University of Liverpool

Unit of Assessment: 9 Physics

a. Context

The Physics Department, part of the School of Physical Sciences, has four research groups, in Accelerator Science (AS), Condensed Matter (CM) Physics, Nuclear Physics (NP) and Particle Physics (PP). AS research is performed within the framework of the Cockcroft Institute (CI) which was inaugurated in 2006. CM research was strengthened in 2010 by the establishment of the Stephenson Institute for Renewable Energy (SIRE). The research of all of these groups results in impact, with the most developed cases arising from the long-standing CM, NP and PP programmes. The impact is: Economic: E.g. the development of sensors for NP and PP with companies such as Canberra and Micron has led to commercial benefits for these companies. Healthcare: Studies carried out by the CM group in collaboration with Clinical Engineers and surgeons at the Royal Liverpool and Broadgreen University Hospitals Trust (RLBUHT) have led to new eye surgery products, benefiting the company involved (Fluoron GmbH) and the patients treated. Societal: The Department has an extensive outreach programme which ranges from our annual regional Physics Teachers Conference to presence in the local and national media.

b. Approach to impact

The Department's impact related activities fall broadly into three categories:

1) Strategic Industrial Partnerships: The development of the sensors needed for our research programmes necessitated the building of links with industrial partners, either directly or via institutions such as CERN, e.g. the development of germanium (Ge) detectors for NP experiments required the manufacturing capabilities of Canberra, the instrumentation skills of Liverpool physicists and the facilities of the Liverpool Germanium Characterization Laboratory (LGCL). The partnership, which was brokered by Twin and has been in place since 1993, has benefitted both Canberra, which developed a new and profitable product line (£6.6 million since 2008), and the Department, which obtained the detectors it needed. Similarly, Liverpool expertise and facilities, in the form of the Liverpool Semiconductor Detector Centre (LSDC), were crucial for the development of sensors for the Large Hadron Collider (LHC) with Micron and others (N-in-P case study).

The University's Business Gateway team helps our Department to exploit opportunities which arise from our research findings, e.g. instrumentation development for the Liverpool/Warwick-led XMaS beamline on the European Synchrotron Radiation Facility in Grenoble led to technical innovations which have commercial potential. Nine licence agreements have been established between the two universities and Huber Diffraktionstechnik GmbH (XMaS case).

2) Targeted developments Some technologies arising from our research have specific applications. The Department seeks to develop instruments based on these technologies and has a strong record in obtaining applied research funding. Examples include Compton Cameras for Positron Emission Tomography (PET) and Single Photon Emission Computed Tomography (SPECT) using the Ge sensors developed for NP (Boston, Nolan). The former work has resulted in the STFC funded development of a device for imaging small animals (SmartPET, see http://ns.ph.liv.ac.uk/imaging-group/projects/smartpet/index.php); the latter, funded through an STFC Particle and Nuclear Physics Applied Systems Knowledge Exchange (KE) award (http://ns.ph.liv.ac.uk/imaging-group/projects/medical_compton/index.php) has led to improved high sensitivity SPECT. Further examples are the use of Si detectors developed for the LHCb detector in studies of the proton radiotherapy beam at the Clatterbridge Cancer Centre (CCC – Casse) and the use of a Scanning Near-Field Optical Microscope on the infra-red Free Electron Laser at ALICE (Daresbury Laboratory) to search for early indications of oesophageal, cervical and prostate cancer (Weightman). Imaging software originally conceived for scanning tunnelling microscopy has been used in applications ranging from aeronautics to zoology (http://www.ImageSXM.org.uk – Barrett). BAE Systems funding has been obtained to study a Compton Camera for use on nuclear submarines and portable cadmium zinc telluride gamma-ray detectors for use in hostile environments (e.g. nuclear decommissioning) have been developed,

funded by the DTI (now BIS) and EPSRC under the DTI programme Sensors for Industrial and Environmental Application (http://ns.ph.liv.ac.uk/imaging-group/projects/porgamrays/index.php).

3) Training and outreach activities The experience gained from our contact with commercial organisations and other institutions has resulted in a capacity and capability to deliver targeted training activities, e.g. our NP programme and the resulting industrial contacts led to MSc and Continued Professional Development (CPD) courses in Radiometrics. These typically attract 15 students a year with about half coming from industry. Through our Medical Physics expertise and relationship with RLBUHT, we recognised the need for a Medical Physics training programme, and subsequently won an NHS contract to train 25 Medical Physicists a year, in partnership with the RLBUHT and the CCC. This programme is typically also taken by 5 non-NHS students per year. With the Institute of Physics (IoP), we deliver free In-Service Training (INSET) on NP, PP and CM for physics teachers through our yearly Physics Teachers' Conferences (http://www.liv.ac.uk/~iop/PTC/). The Liverpool Physics Outreach group, established by staff and run with students, offers a range of activities for schools, e.g. Spectrum of Physics and NP and PP Master Classes (http://www.liverpoolphysicsoutreach.co.uk/); their events were visited by 9,400 pupils and members of the public in 2012-13. All our impact-related activities are promoted and coordinated by the research groups. Contributions to impact are discussed with staff in Personal Development Reviews and support is provided through our facilities (e.g. the LSDC, LGCL, and Workshop), and recognition through the Department's workload model. Pump-priming funding is given to cover travel and other expenses to aid the establishment of partnerships. Many of our academic experts engage with the media, from responding to journalist enquiries on headline news, e.g. the discovery of the Higgs particle, to writing opinion pieces and blogs. We also work with the Science Media Centre to help journalists understand complex physics research and have led tours for academic colleagues, journalists, and our alumni to CERN.

c. Strategy and plans

The above 3 approaches have successfully increased the impact of our research and form the basis of our future strategy. We have put in place a framework to underpin the impact developments we plan to bring to fruition over a 5 to 10 year timescale.

1) Applications of Research Techniques and 2) Targeted Developments:

The areas which we believe have the greatest potential for impact are:

i) Healthcare: Liverpool has recognised expertise in the development of detectors for NP and PP. Immediate plans include the further development of the above-mentioned projects as well as the development of new applications. The Ge-based Compton Camera for SPECT is being taken forward to pre-clinical trials (Boston, Nolan), as is the imaging software suite (Barrett). The CCC proton beam studies are being extended to provide monitoring during cancer treatments (http://www.liv.ac.uk/quasar/research/medical-applications/ – Welsch). Liverpool radiation-hard sensors are being used in the Wellcome trust funded Pravda project to develop further instrumentation for proton therapy (http://www.pravda.uk.com – Allport).

ii) Security: Neutrino detectors developed by Liverpool for the ND280 calorimeter of the T2K experiment are being studied as remote monitoring devices for nuclear reactors. Such monitoring is of interest to nuclear proliferation authorities (Coleman, Royal Society and STFC funding). Argon-based detectors are under development at Liverpool for next-generation neutrino experiments. The application of these as neutron detectors for locating nuclear materials is being investigated to prevent smuggling through air and sea ports (Touramanis, EU FP7 funding, Modular Detector System for Special Nuclear Materials). Security applications of extremely sensitive gravitometers under development for a laboratory Dark Energy search are being investigated (Coleman, AWE funding). These could identify very dense materials, such as uranium or plutonium, through their gravitational effects. Novel 'gas curtain' beam monitoring systems that will find application in a range of accelerators, including those for medical use, are being developed (Welsch, EU funding).

iii) Energy The Department and University plan to increase the impact of our work in energy storage and provision. The SIRE was created to further this aim and represents a University investment of £6M in new laboratories and office space plus 5 new staff in Physics and 5 new staff in Chemistry. The Institute has an industrial advisory board, in anticipation of the commercial applications of the photovoltaic and energy storage devices that the SIRE will develop.

To support the activities in the areas 1) and 2) above:

- We have appointed an Innovations Partnership Scheme Fellow (Palumbo). The Fellow is funded jointly by the STFC and the University and has the remit to forge links with industry to aid the transfer of the technologies developed through our research. This remit covers areas where impact has been planned, but also the identification of so far unrecognised opportunities.
- We enhance our staff's capabilities and our facilities, including the Workshop, LSDC and LGCL, to ensure we remain attractive partners for industry, e.g. recent University funding for new metrology equipment and a 5-axis milling machine allowing the manufacture of highly complex mechanical structures and providing further instruments capable of measuring these.
- In partnership with the School of Physical Sciences' KE lead (Raval), we have found, and will continue to seek, potential local and national commercial partners and support, e.g. the recent ERDF funded Open Innovation Hub for Anti-microbial Surfaces (Raval, McGrath).

3) Societal impacts We are extending our training programme by developing new CPD courses in Medical and Nuclear Physics and related areas. We plan to further develop our programme of outreach activities, using Liverpool's world-class Central Teaching Laboratories (CTL) to host NP and PP Masterclasses, the Physics Olympics, the Physics Teachers Conference, Women in Physics and other activities, with two goals, a) to involve all major regional schools and b) to increase the proportion of female applicants to our undergraduate programmes. We work closely with the University's communications team to convey the excitement of our science to the broadest possible audience through local, national and international media.

To achieve these aims we have:

- Appointed an Outreach Officer, funded jointly by the School of Physical Sciences and the Ogden Trust (Sapple), whose role is to co-ordinate and develop our outreach programme.
- Appointed 3 Teaching and Scholarship lecturers to support outreach activities using the CTL.
- Established strategic relationships with NHS training coordinators and Liverpool Health Partners, with the National Nuclear Laboratory and the Nuclear Technology Education Consortium.
- Supported staff who work with the media through funding, recognition of their activities in our workload model and encouraging outreach activities such as MP/researcher exchanges (e.g. Shears).

d. Relationship to case studies

The case studies illustrate the three approaches to impact described in **b** above. The "Strategic Industrial Partnerships" approach has led to the N-in-P and XMaS cases. These developments were made together with industry, which has had benefits for both the companies involved and the Department. The "New Silicon Oils" case illustrates the "Targeted Development" approach. Finally, the "Training and Outreach" approach is illustrated by the Particle Physics Outreach Case.