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Report

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Proposed NMS Programme for Acoustics and Ionising Radiation Metrology - October 2007 to September 2010: Public Comment Document

Editors: Mr N Roberts, Dr S Duane, Dr S M Judge, Mr P de Lavison, Dr D Rayner, Dr D J Thomas, Dr B Zeqiri

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dti
National Measurement System

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Quality of Life Division

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Approved on behalf of the Managing Director, NPL
by Dr Martyn Sené, Director, Quality of Life Division

How to use this document

As a Public Comment Document, all interested parties are invited to provide comments to DTI on the programme described in this document. Those wishing to comment are advised to:

- read Sections 1 to 3 (the first 9 pages) to get a broad understanding of how the programme is expected to benefit the eight chosen user communities;
- scan through Section 4 (pages 10 to 15) to get an overview of the themes and projects, to identify which projects are likely to be of particular interest;
- review the 3 to 4 pages describing each of those projects in Annex A (N.B. the template used for the project descriptions is itself described at the start of Annex A);
- identify any projects on which your organisation may wish to collaborate with NPL;
- check the provisional outline for the follow-on work in 2010-2013, given in Annex B, for any theme that is of particular interest to you.

Both NPL and DTI wish to encourage participation in the programme by organisations collaborating with NPL, including where this may extend the scope of the work through co-funding in kind and/or in cash (co-funding in kind would be through provision of staff time or facilities paid for by the collaborating organisation or from sources other than this DTI programme). Each project description in Annex A gives an indicative list of potential collaborators. These lists indicate the types of organisation with which NPL has collaborated in the past in the area and/or would expect to collaborate in this programme. Whether or not your organisation is included in these lists, please indicate in any comment to the DTI if you feel your organisation would wish to collaborate with NPL on one or more projects in the proposed programme.

Executive Summary

This report is one of a series of programme documents to be developed for the Formulation of the 2007-2010 NMS Acoustics & Ionising Radiation Programme. It has been produced for the public consultation stage of the formulation process. It describes a set of potential activities that would cost somewhat over 125% of the expected budget for the 2007-2010 programme. Note that this programme brings together what were previously two separate NMS programmes on Acoustics and Ionising Radiation.

This report consists of a short body focussing on the eight user communities to be addressed, followed by Annex A clarifying the proposed projects grouped by technical theme. Annex B gives an initial outline of the potential follow-on programme for 2010-2013. It is anticipated that some of the items of work that are cut from the programme for 2007-2010, in order to bring the programme within budget, will be added for consideration to the outline programme for 2010-2013.

The body of this report describes, in Section 3, how we expect the programme to impact each of the relevant user communities, addressing their highest priority metrology needs. Although acoustical metrology and ionising radiation metrology involve very different measurement technologies and techniques, the body clarifies how both areas address essentially the same user communities. There then follows, in Section 4, an overview of the Themes. There are four substantial technical Themes (Acoustics, Dosimetry, Neutrons and Radioactivity) plus two shorter more general Themes (Knowledge Transfer (KT) and Programme Management).

In Annex A. Projects by Theme, information on each project is provided in the form of a standard template. For each project the following information is provided:

- the relevant user communities;

- the user community needs addressed by the project – many of these were identified from the extensive consultations held between May and October 2006 with the relevant user communities, whilst others were identified from analysis of relevant roadmaps;
- the expected impact to be achieved by the product, particularly the impact on quality of life, innovation and economic benefits;
- the sub-projects that make up the project;
- the products to be delivered within each sub-project.

A roadmap provides a graphical representation of how a given area of research and development is foreseen to develop over, say, the next 10 years in order to meet what are seen as the major technological changes and the major changes in user community needs. The roadmaps considered for this programme formulation came from two sources. One set was developed in Europe, arising from the iMERA (implementing Metrology in the European Research Area) activity. The other set was developed in conjunction with DTI's Measurement and Standards for Emerging Technologies (MSET) programme.

Annex B. Outline of 2010-13 programme, outlines the 2010-2013 programme, again in the form of standard templates, this time one per theme. For each theme, the following information is provided:

- the expected projects;
- for each project, the expected topics to be addressed (at the sub-project level).

This Public Comment Document is subject to a three-month public consultation period. Following this period, there will be a Decision Conference, to be held in late June or early July 2007to determine the final content of the new programme. Following that meeting, NPL will develop the document further to create the final programme document, including a refinement of the outline for 2010-2013. It is only at this final stage that we will be able to finalise the start and end dates for each sub-project, showing which activities will be run in parallel and which in sequence.

Acknowledgements

We gratefully acknowledge that the work to create this report was funded by the DTI NMS Acoustical Metrology programme 2004-2007 and the DTI NMS Ionising Radiation Metrology programme 2004-2007.

The editors are indebted to the many contributions made to this report from the staff in the Acoustics, Radiation Dosimetry and Radioactivity & Neutrons teams within the Quality of Life Division of NPL – far too many staff to name individually. In addition, we also gratefully acknowledge the contributions from the Knowledge Transfer and Corporate Assurance teams at NPL.

CONTENTS

1. Introduction to NMS Acoustics and Ionising Radiation

In the past, the NMS Acoustical Metrology Programme has supported the realisation and dissemination of primary measurement quantities, the most important being the pascal, which have provided and still provide the wide range of users with the key traceable measurements demanded by regulation or specification standards.

Measurements of acoustical quantities are made very widely, by companies in manufacturing and service industries, authorities responsible for occupational and environmental health, hospitals and clinics, and by defence services, for many different applications. Examples include the noise emitted by sources such as aircraft and industrial machinery, the noise exposures of workers in their occupational environment and the general public where they live, an individual's hearing sensitivity, the ultrasonic sound energy produced by medical therapeutic and diagnostic equipment and by industrial devices such as ultrasonic cleaning baths, and the sound fields radiated or received by underwater acoustical systems. The purposes of these measurements include the collection of information for product specifications and contracts, demonstration of compliance with regulations, access to markets, assessment of public nuisance, comparison with safe exposure limits, ensuring accurate diagnosis and effective therapy, and enabling accurate underwater positioning, mapping and detection. The principal objectives of the NMS activities in Acoustical Metrology are:

- to provide, develop and disseminate primary acoustical standards for realising the pascal for sound in air and water;
- to ensure that UK measurement standards in acoustics are harmonised with those of the UK's trading partners;
- to develop innovative new methods of acoustic measurement to meet identified UK private and public sector needs, and promote international standardisation of these methods;
- to promote knowledge transfer from the programme and the adoption of good measurement practice.

Increasingly, the requirements of users are such that conventional acoustical measurement methods are inadequate to meet their needs. Thus, in the 2004-2007 programme, work began on new methods of acoustic measurement based on Micro-Electro-Mechanical Systems (MEMS) and wireless communications technology. A new generation of acoustical measuring instruments is being developed that are physically small (initially 'matchbox' sized but ultimately with dimensions about 10-15 mm) and based on a silicon acoustic sensor integrated with on-chip signal processing capability. Work on this technology and these instrument developments will need to continue as a major thrust of the future NMS Acoustics activities.

The aim of the NMS activities in Ionising Radiation is to enable all users of ionising radiation in the UK to carry out measurements for radiation dosimetry, radioactivity and neutrons to an accuracy that is fit for purpose and at the forefront of good practice internationally. To that end, the Ionising Radiation programme has always sought to provide primary measurement standards, associated services and knowledge transfer mechanisms, and to support UK industry and user communities in the innovation of instrumentation and measurement methodologies in line with government policy.

The NMS work in Ionising Radiation enables the benefits of using ionising radiation in medicine and industry to be realised, while assessing and minimising the associated health risks. It seeks to achieve this through facilitating accurate radiation dosimetry, radioactivity measurements, and neutron metrology, so that the radiation exposure of patients, workers and the general public is known to be within acceptable limits. With such health concerns in mind, the use of ionising radiation is heavily regulated. Much of the NMS work is therefore concerned with supporting the relevant regulations (such as the Ionising Radiations Regulations 1999) and Codes of Practice.

2. Merging the two programmes

It should be noted that the Orientation and Consultation phases of Programme Formulation were carried out quite separately for the two unit programmes on Acoustics and Ionising Radiation. The decision to merge the two programmes was made relatively late in the Consultation phase. Common to both Consultations was the emphasis on identifying the priority needs of the selected user communities.

In addition to consulting with the selected user communities, a set of relevant roadmaps was inspected in order to identify the priority user community needs to be addressed. A roadmap provides a graphical representation of how a given area of research and development is foreseen to develop over, say, the next 10 years in order to meet what are seen as the major technological changes and the major changes in user community needs. Within iMERA, separate roadmaps have been developed for the two fields of metrology[1]. These roadmaps indicate the strategic direction for European coordinated activities in these fields and provided a major input into this programme formulation. However, the iMERA roadmaps are not the only ones relevant to the formulation. The roadmaps developed for DTI's Measurement and Standards for Emerging Technologies (MSET) programme have also been taken into account[2].

When we came to consider the structure of the combined programme, it became clear that there are two different dimensions to be considered. One dimension is concerned with the different user communities to be addressed by the programme. The other is concerned with the different types of capability and expertise required to deliver the programme. The following sections give an overview of the proposed programme from these two different perspectives.

3. User Communities addressed

3.1 Selection of User Communities

At a meeting held at DTI, involving NMSPU and the two NPL formulators of the Acoustics and Ionising Radiation programmes, the specific process for bringing the two Consultation Processes together to create a single Programme Document, was discussed. A key part of this involved establishing the two respective sets of User Communities, which the two NMS programmes addressed, and merging these in a

[1] See www.npl.co.uk/formulation/ionrad/downloads/johansson_ir_orientation_roadmaps.pdf

[2] See www.technology-roadmaps.co.uk/home.php

sensible and coherent way. Immediately after this initiation meeting, the following eight merged User Communities were agreed:

1. Defence and security
2. Energy (generation and conservation)
3. Environment (including Decommissioning)
4. Healthcare
5. Manufacturing (including advanced materials)
6. Radiation Processing Industry
7. Safety (including Radiation Protection)
8. Instrumentation and testing

Key drivers and rationale behind the need for traceable metrology in these eight areas, relevant to the combined Acoustical and Ionising Radiation metrology programme, will be briefly summarised in the remainder of this Section. This is not meant as a comprehensive description of needs, but illustrates the impact of the newly unified Programme over a diverse set of User Communities.

3.2 Defence and security

Neutron facilities are used for instrument calibration and development in the defence and security sectors, and neutron expertise is important in developing security devices such as portable monitors etc.

The installation of **radioactivity** monitors, for both gammas and neutrons, at points of entry to the UK ('Project Cyclamen') has highlighted the need for reference materials that demonstrate that the monitors are working and there is a requirement for rapid methods to assay **radionuclides** that are impossible to detect with direct measurement.

Defence applications of **underwater sound** include active and passive sonar, stealth technologies, weapons systems and mine hunting. These applications cover the frequency range from tens of hertz to many hundreds of kilohertz, and the performance of transducers, systems and stealth materials may critically depend on temperature and depth. A current priority is that of detecting mines in shallow coastal waters, both during and after conflicts. These environments pose significant challenges for **acoustic technologies** as they are noisy, highly reverberant and may have substantial bubble content due to breaking waves.

3.3 Energy (generation and conservation)

Future growth areas for **underwater acoustics technology** lie in deep and ultradeep water offshore oil and gas markets, with the development of sub-sea processing and new technologies. These deep-water activities increasingly require the use of autonomous underwater vehicles (AUVs), where **acoustic technology** plays a key role in visualisation, and in their location and positioning. With strong growth in world energy demand, an average growth of 8% in subsea oil wells is predicted over the next five years. With the relatively poor performance of other technologies in the marine environment such as those based on electromagnetic transmission, **Acoustics** is an essential enabling technology, playing a vital role in applications such as geophysical surveying, positioning, navigation, echo-sounding and communications.

In addition, in the area of **marine renewable energy**, concern over the environmental impact of the offshore windfarm, tidal and wave energy technology with regard to noise pollution has led to the need for standard assessment methods.

Non-destructive testing (NDT) technologies are used in industry to help ensure the integrity and reliability of products being provided to end users, and prolong the lifetime of key structures. Core NDT technologies are evolving in important ways and are more and more user friendly. The applications in which NDT is used are also expanding rapidly. The potential market for non-destructive testing equipment continues to expand with emphasis on product quality, lean manufacturing, just-in-time inventory practices, and advances in nanomaterials and related manufacturing and testing. Of the various technologies used in NDT, **acoustic emission and ultrasonics** have shown a consistent higher annual growth rate, typically about 6%.

The ability to measure **ionising radiation** is important to operators of nuclear power stations, fuel fabricators, reprocessors and waste storage and disposal facilities. This ability is required both for controlling the operations and for radiation protection of the personnel. The activities are regulated by the Nuclear Installations Inspectorate for compliance with the Atomic Energy Act and with the Ionising Radiations Regulations, mainly for on-site activities. Discharges and the movement of radioactivity from sites are the responsibility of the two Environment Agencies, EA and SEPA, under the Radioactive Substances Act mainly. Less obviously, other energy producers have an interest. Oil exploration uses a variety of well logging tools that use radioactive sources and they also have problems with NORM (Naturally Occurring Radioactive Material), both at the extraction stage and post combustion. Hence they attract the attention of HSE, EA and SEPA. The problems they encounter cover **X-ray, gamma, and neutron dose rate**, surface contamination, discharges to air and water and bulk contamination.

3.4 Environment (including Decommissioning)

Over the next few decades, the UK faces the problem of **decommissioning** and clearing its legacy nuclear sites. To give an indication of the scale of this problem, by 2005 the UK had safely packaged only 8% of legacy radioactive waste. In 2002, there was 75,000 m^3 of intermediate-level waste in store and 2000 m^3 of high-level waste. By 2050, intermediate level waste is expected to be 250,000 m^3; the Sellafield site has an estimated 20 million m^3 of contaminated land. The strategy document issued by the Nuclear Decommissioning Authority states ‘We do not yet have a full understanding of the extent and nature of the contamination on all of our sites’.

Accurate and traceable measurement of the **radioactivity** content of waste materials is needed to ensure they are consigned to the correct waste stream. There is a need to develop special reference materials needed to calibrate the instruments used by the industry.

The regulatory framework for UK nuclear decommissioning and site clearance is principally the **Ionising Radiation Regulations 1999**, the **Radioactive Substances Act 1993** (and in particular the ‘Substances of Low Activity’ Exemption Order to the latter) and the transport regulations for radioactive substances. Also, guidance is being developed at the European level (e.g. by the IAEA), which will influence UK policy in the future. NMS-funded work in this area would address the needs of a wide range of users. For example, nuclear site operators and NDA contractors need to carry out radioactivity measurements on, and then dispose of, a wide range of materials at

minimal cost; this would be aided by the availability of traceable standards and reference materials with low uncertainties, and by guidance and training (e.g. on the accurate monitoring of surfaces). Regulatory bodies (e.g. the Environment Agency) and environmental pressure groups want to see a robust national measurement framework in place so that doses to the public can be better estimated and compliance with the law can be demonstrated – all of which would promote public confidence in the industry. Instrument manufacturers, too, need standards from within this framework to calibrate and test their equipment, and other government departments and Local Authority bodies have an interest in demonstrating to their stakeholders that the work of the industry has a sound metrological footing.

Measurements of **neutrons** are important for the nuclear industry in support of normal operation, **decommissioning**, fuel transport and waste assay. If anything, this will be enhanced if new nuclear power stations are constructed.

Noise is recognised by statute to represent both a cause of nuisance and a hazard to hearing. There is an extensive body of regulations in place in the UK to control noise and to limit its emission from specific sources such as aircraft, motor vehicles, and industrial and domestic machinery, many of which enforce EC Directives. In addition, there are a large number of British and international specification standards defining **methods of noise measurement and testing** and also the performance and methods of calibration of acoustical measuring instruments. It is estimated that UK industry spent £120M on environmental noise protection in the year 2001. Regarding **industrial noise**, Directive 96/61/EC concerning Integrated Pollution Prevention and Control (IPPC) sets out the general obligation of all installations covered by its Annex I to take all appropriate preventive measures against pollution - including noise - in particular through the application of best available techniques.

Government policy on **radioactive discharges** into the environment from the **nuclear industry** and other users of **radioactivity** is to 'progressively and substantially reduce discharges'. The policy is enforced by a system of licensing discharges and compliance with this policy is monitored by a network of about 100 laboratories (some run by the nuclear site operators, some former government laboratories, some based at universities and some commercial companies). To demonstrate that measurements are accurate and traceable to national standards, most of these laboratories are accredited to ISO17025 by UKAS. There is a need to develop standards to support environmental monitoring, including primary standards for **gaseous discharges of radioactivity**.

Exposure of marine life to **underwater man-made noise** is an issue of growing concern as the effects of **noise pollution** in the ocean begin to be understood. Regulation is providing a driving force in this area, for example from the EU Habitats' Directive 92/43/EC, and from EC Directive 2001/42/EC implemented in the UK as the Environmental Assessment of Plans and Programmes Regulations 2004. Increasingly, an Environmental Impact Assessment is required before activities that may generate underwater acoustic noise commence. For example, the DTI Offshore Petroleum Activities (Conservation of Habitats) Regulations 2001 (PON 14) require that the acoustic source level and dominant acoustic frequencies are reported for any geophysical surveying or drilling. Recently, particular concern has been expressed over the impulsive noise produced by construction activities such as marine piling. Although regulation is beginning to be introduced, the underpinning metrology and standardisation is still not fully established. For example, the methodology for

measuring noise sources *in-situ* and quantifying exposure levels requires further work to assess validity and accuracy in the methods.

Additionally, **underwater acoustics** continues to play an important role in the study of the marine environment within oceanographic science, ranging from tomographic measurements of ocean currents and temperature (e.g. for climate monitoring) to measuring sediment transport processes (e.g. to assess coastal erosion).

3.5 Healthcare

The healthcare sector depends on **ionising radiation metrology** at all levels, from industrial processing (in the sterilisation of single-use medical goods) down to radiological protection (of staff and patients). **Radiotherapy services** have a critical dependence on measurement standards for **radiation dosimetry**: external beam **radiotherapy** demands greater measurement accuracy than any other application. This is primarily delivered by photon or electron beams, but there are also important applications for proton beams. We can expect strong growth in various forms of Intensity Modulated Radiotherapy (IMRT) and Image Guided Radiotherapy (IGRT), and at some point the UK can be expected to follow the international growth in proton therapy. Each of these newer forms of radiotherapy poses new problems for accurate dosimetry. It is also very important to have accurate dose measurements associated with high and low dose brachytherapy and the use of radioactive eye plaques. In contrast, awareness of the need for accurate dosimetry in **Targeted Radionuclide Therapy** is only just beginning to develop. In **diagnostic radiology**, accurate dosimetry is less critical, but remains an important factor in optimising procedures and reducing overall risk to patients.

One of the major uses of **radionuclides** is in medicine, for diagnostic imaging or for therapy. There are approximately 670,000 administrations of **radioactive pharmaceuticals** in the UK per year, and the use of these drugs has grown by 30% over the last ten years. This growth is likely to be maintained in the long term, due to an investment in **Positron Emission Tomography** centres for diagnosing and staging cancer. Developments in biotechnology are also driving the development of new cancer treatments that use novel compounds (such as monoclonal antibodies) to deliver **radionuclides** to treat diffuse tumours.

As a known carcinogen itself, any **radioactivity** injected into the patient must be the minimum quantity necessary for medical efficacy. New primary standards, and the mechanisms to disseminate their use, are required to enable medical physicists to comply with guidance from the Health Protection Agency and their professional body (IPEM) on the use of the instruments needed to assay the activity before injection.

Neutron measurements must be performed around hospital LinAcs for protection of staff and patients, requiring very specialist **neutron measuremen**t expertise. LinAcs used for **radiotherapy** generate **adventitious neutrons**, which contribute to staff and patient doses that have to be monitored. Similarly, air travel results in advanced doses from **cosmic rays,** which have a strong **neutron** component. An understanding of the level of this exposure is essential in characterising risks to flight crew and passengers. **BNCT** may also become an important issue.

Medical uses of **ultrasound** include foetal monitoring, diagnostic imaging, Doppler blood-flow studies, physiotherapy, the non-invasive destruction of kidney stones

(lithotripsy) and also tissue ablation using High Intensity Focussed Ultrasound (HIFU). In all of these areas, the principle concern is the safe and effective use of this equipment. This is particularly true in the case of **obstetric scanning**, where the potentially sensitive developing foetus is exposed to ultrasonic energy. In line with the majority of the western world, virtually all pregnancies within the UK are the subject of at least one ultrasound examination. An accurate knowledge of the **acoustic pressures and powers** generated, and consequent tissue heating, is crucial for this assessment. Similarly, effective therapy and lithotripsy depend on well-characterised treatment systems.

Hearing loss has been a prescribed occupational disease eligible for compensation by the Department of Social Security (DSS) since 1974. In fact, deafness is the second most common disability in the society generally, affecting an estimated 9 million people, about one in seven of the population UK in total. The proliferation of electronic accessories including the now widespread use of in-ear devices such as personal stereos and mobile phones, high powered entertainment systems, noisy cars and motorcycles, power tools etc. has led to the noisiest lifestyle of any generation so far. There is already evidence that this is having a significant effect on hearing. In the USA, 8% of people aged 30 were recently found to have a hearing impairment. **Audiometric measurements** to detect hearing loss in an objective and standardised manner are therefore critical.

3.6 Manufacturing (including advanced materials)

Noise emission measurements are now a common requirement for UK industry. As an indication of **noise emission** measurement practice:

- All civil aircraft types, including helicopters, business and leisure aircraft have to be type certificated for noise;
- Road vehicles and motorcycles are also subject to type noise approval, in line with EC Directives, before being allowed to enter the market;
- A wide range of construction plant and equipment has to be type noise certificated and meet noise limits given in EC Directives;
- The EC Machinery Directive requires manufacturers of all types of industrial machinery to measure and state the sound pressure level at the position of the operator, and in some cases the emitted sound power level.

Within the **Medical Ultrasound** area, the US Food and Drug Administration requires manufacturers to comply with **acoustic output limits** for specific clinical applications. Alternatively, manufacturers may choose to meet a higher limit provided that they give on-screen indications of thermal and non-thermal indices which are related to potential for tissue heating and cavitation, and which allow clinical staff to make a professional judgement. Compliance with US FDA regulations by UK manufacturers is essential for access to the US market, and now specification standards to support the EC Medical Devices Directive place similar requirements on manufacturers to declare acoustic output levels.

Ionising radiation is used extensively in the polymer industry to initiate polymerisation and cause effects such as cross-linking and degradation. These applications generally rely on measurement of the effect achieved as a method of process control rather than dosimetry. There is evidence that the requirements of documented quality systems and the necessity to move processes from plant to plant

may be driving the requirement for dosimetry in these areas. A related area is the testing of electronic components for **radiation hardness** as required in the aerospace industry. This is mainly carried out using pulsed **electron beam irradiation** and requires specialist dosimetry techniques on pulses with rapid (ns) rise times and narrow and well-defined energy spectra.

Within the area of industrial **ultrasonics**, high-power applications of sound include cleaning, materials processing and sonochemistry. Applications of **high power ultrasound** are continuing to proliferate, a prime example lying in its use within the waste-water treatment area where novel devices generating acoustic powers in the range of 10 – 100 kW are being used to break down sewage sludge. There is considerable interest in further developing this technology, and major capital equipment of value £100 - £200k is starting to be implemented within plants, driven by the operational benefits accruing from improved sludge de-watering, gas production and solids reduction. Both this, and the wider development and application of high power ultrasound demands reproducible measurements, both due to the need to successfully replicate and scale-up industrial processes from pilot-plant level, but also in order to monitor and control processes effectively.

3.7 Radiation Processing Industry

The Radiation Processing Industry uses **ionising radiation** in industrial processes such as the sterilization of medical devices and pharmaceuticals and the irradiation of foodstuffs. **Radiation sources** used range from low energy (100 keV) electron beams incorporated into production lines to large-scale irradiation facilities for boxes and pallets of material. The latter generally use **gamma rays** from ^{60}Co or megavoltage accelerated **electrons** as the radiation source, although megavoltage **X-rays** are increasingly being used.

The **medical device**, **pharmaceutical** and **food irradiation** industries are all subject to stringent national and international regulation, for example under the EU Medical Devices Directive, and there is a general requirement that dose measurements are traceable to appropriate national or international standards. Approximately 50% of single use medical devices are currently **sterilized** by **ionising radiation** and this fraction continues to increase. Novel product development is taking place in areas such as the use of low energy **electron beams** for surface treatments and irradiation at cryogenic temperatures to achieve specific biological and materials effects. These processes require the development of new dosimetry techniques ensuring both process control and compliance with regulations. Prediction of dose distribution using mathematical modelling techniques is also a rapidly developing area that can improve efficiency by minimising dose mapping measurements and increasing overall process efficiency.

3.8 Safety (including Radiation Protection)

Whilst the methodology for **radiation protection** is largely defined for external **gamma exposure**, a need remains for straightforward calibration facilities. However, there remain significant problems in the **neutron** area both for area survey measurements and personal dosemeters. Readings can easily be in error by factors of 2 or more. There is a need for type testing facilities for developing new devices.

There are approximately 250,000 workers in the UK exposed to **ionising radiation**, including approximately 40,000 Classified Persons whose radiation doses are closely

monitored. Employers must comply with the Ionising Radiations Regulations, which include a requirement to monitor the workplace for surface contamination of **radioactivity** (if open **radioactive sources** have been used). The instruments used for these measurements have to be tested annually, and there is a network of about 20 secondary standards laboratories carrying out these tests. Primary standards are needed for traceability for these tests, covering **beta**, **alpha** and **photon-emitting radionuclides**.

Radiation protection for **neutrons** is significantly more complex than for photons, many problems remain to be solved, not least that of deriving suitable devices to measure the dose, and work is continuing on device development in this area. Materials and detectors are changing and it is important for UK industry to be able to change the materials they use and develop new monitoring equipment, particularly for measurement at lower dose rates and for security purposes. These developments are impossible without facilities to test their properties.

One area of increasing concern is the need for standards for **radioactive aerosols** to calibrate and test monitors for **radioactivity-in-air** in the workplace.

Occupational noise exposure is controlled in the UK by the Noise at Work regulations, which implement Directive 86/188/EC. Noise levels of at least 85 dB(A) (the first action level under the regulations) are thought to be present at more than 80,000 workplaces throughout Britain.

Acoustic shock is a phenomenon of increasing concern for the approximately 900,000 people working in UK call-centres: the effects of sudden noises through headsets can be profound, including permanent ringing in the ears, various types of hearing difficulty and psychological symptoms. In the UK alone, this has led to over £2M in out-of-court settlements. **Acoustic shock** can be caused by sounds which are much quieter than those guarded against by the Control of Noise at Work Regulations 2005. The mechanisms involved are as yet very poorly understood.

3.9 Instrumentation and testing

The UK is Europe's leading producer of **underwater acoustical systems**, with some 20 companies involved in manufacturing sonar systems. Accurate measurement of system performance is crucial for ensuring unambiguous specification and acceptance testing.

The UK has developed a worldwide reputation as a manufacturing source of key measurement instrumentation within the **water-borne sound** area. A prime example of this lies in the membrane hydrophone, originally produced developed by Marconi, whose development revolutionised measurement capability within the area of **ultrasonics**.

Through the need to undertake dosimetric measurements of **neutrons**, there comes a strong underpinning requirement for instrument testing facilities for **neutrons**. The instruments cover **radiation protection** devices, and all other **neutron** measuring devices including those used in reactor control.

Ionising radiation is regarded both as a useful tool and as a hazard to be strictly controlled. It is heavily regulated and monitored. There are two major sets of regulators. One is the HSE and its branch, the Nuclear Installations Inspectorate, who enforce the Ionising Radiations Regulations 1999. The other set comprises the two environment agencies, EA and SEPA, who enforce the Radioactive Substances Act

and its various Exemption Orders. To demonstrate compliance, users of **ionising radiation** have to perform effective measurements with an acceptable uncertainty. **Radiation monitoring** equipment manufacturers and test houses need the NMS to provide a wide variety of standards and guidance on metrology. They also need an appropriate range of cost-effective calibration services.

4. Overview of the Themes

4.1 Introduction

The Projects in Annex A are organised into Themes appropriate to the delivery of the programme and hence related to capabilities and expertise. The Themes for the combined programme are as follows:

1. Acoustics Theme
2. Dosimetry Theme
3. Neutrons Theme
4. Radioactivity Theme
5. Knowledge Transfer Theme
6. Programme Management Theme

4.2 Acoustics Theme

The aims of the Acoustics Theme are as follows:

- provision and dissemination of primary standards for sound pressure in air;
- research into new test methodologies underpinning calibration, audiometric and airborne noise measurement applications;
- provision and dissemination of primary free-field measurements for underwater acoustic and ultrasonic hydrophones;
- development of unique facilities providing a wide range of acoustic measurement capabilities to the health sector and industry;
- undertaking leading edge metrological research leading to the development of novel instrumentation to meet UK user community requirements;
- undertaking appropriate KT activities, including representation on standards committees and dissemination of the results of the research and development.

The Projects of this theme are summarised in the following table (the detail being given in Annex A):

Project no.	Project title
A1	Airborne noise exposure and hearing
A2	Novel technologies for the measurement of sound in air
A3	Underwater acoustics in the marine environment
A4	Medical applications of ultrasound
A5	Industrial applications of ultrasound
A6	Acoustics knowledge transfer

The details of these projects can be found in Annex A at A.1 Acoustics Theme.

4.3 Dosimetry Theme

The aims of the Dosimetry Theme are as follows:

- provision and dissemination of primary standards for absorbed dose;
- provision and dissemination of primary standards for air kerma;
- development of new calorimeters and calorimetry techniques;
- research and development of radiation dosimetry techniques, instruments and dosimeters for healthcare applications, particularly newer modalities of radiotherapy;
- provision and development of standards, dosimeters, irradiation facilities, modelling and calibration services for high-dose industrial radiation processing applications;
- provision and maintenance of supporting facilities for protection, diagnostic, therapy and industrial level applications;
- undertaking appropriate KT activities, including representation on standards committees and dissemination of the results of the research and development.

The Projects of this theme are summarised in the following table (the detail being given in Annex A):

Project no.	Project title
D1	Calorimetry for radiotherapy
D2	Ionometry standards and services
D3	Novel dosimetry techniques
D4	New healthcare applications
D5	Industrial dosimetry
D6	Facilities
D7	Dosimetry knowledge transfer

The details of these projects can be found in Annex A at A.2 Dosimetry Theme.

4.4 Neutrons Theme

The aims of the Neutrons Theme are as follows:

- provision and dissemination of primary standards for neutron radionuclide source emission rate via the manganese bath, and for neutron fluence and neutron dose equivalent standards produced using a range of well-characterised neutron sources and a charged particle accelerator;
- maintenance and development of neutron spectrometry systems for field measurements in areas such as healthcare, the nuclear industry and defence;
- research into areas of concern such as cosmic ray dosimetry for aircrew and neutron exposure at medical LinAcs;
- maintenance and development of accelerator-based monoenergetic, thermal, and simulated workplace neutron fields, one of only 3 NMIs to offer these;
- undertaking appropriate KT activities, including representation on standards committees and dissemination of the results of the research and development.

The Projects of this theme are summarised in the following table (the detail being given in Annex A):

Project no.	Project title
N1	Primary neutron standards
N2	Development and innovation in neutron metrology
N3	Neutron knowledge transfer

The details of these projects can be found in Annex A at A.3 Neutron Metrology Theme.

4.5 Radioactivity Theme

The aims of the Radioactivity Theme are as follows:

- provision and dissemination of primary standards for radioactivity metrology using conventional coincidence counting techniques, as well as newer developments;
- maintenance and development of best combination of radionuclide metrology and radiochemistry facilities at any NMI;
- standardisation of routinely used radionuclides for diagnostics and therapy in nuclear medicine;
- measurement infrastructure, via the standardisation and dissemination of solution standards and reference materials for environmental monitoring of radioactivity;
- provision of infrastructure to counter the illicit use of radioactive materials by implementing suitable proficiency tests and generation of measurement standards;
- provision of infrastructure to ensure accurate measurement of the radioactive waste arising from nuclear decommissioning by providing reference materials in appropriate matrices;
- evaluations and measurements to provide nuclear data to improve the quality and accuracy of applications of ionising radiation;
- undertaking appropriate KT activities, including representation on standards committees and dissemination of the results of the research and development.

The Projects of this theme are summarised in the following table (the detail being given in Annex A):

Project no.	Project title
R1	Primary Measurement Standards and Systems
R2	Infrastructure for Secondary Measurement Standards of Radioactivity
R3	Provision of measurement infrastructure for nuclear medicine
R4	Infrastructure for Environmental Radioactivity Standards
R5	Measurement infrastructure for radiation protection
R6	Measurement Infrastructure for Nuclear Decommissioning
R7	Radioactivity Theme Knowledge transfer

The details of these projects can be found in Annex A at A.4 Radioactivity Theme.

4.6 Knowledge Transfer Theme

The aim of the Knowledge Transfer Theme is to complement the technical themes by providing additional means for disseminating the knowledge generated by the programme to the relevant user communities to maximise the impact of the programme. It covers both activities that should be led by KT professionals rather than by scientists and training activities that need to be delivered collaboratively by the relevant scientists and KT professionals. It includes the development and delivery of face-to-face training courses. This is in recognition of the fact that consultation has revealed that training is considered to be one of the most effective means of creating real impact in the user communities. However, many of those who could benefit from the training are unable to attend face-to-face, often hands-on, training courses. Thus, there is a need to take the training material from such established courses and make it available for e-learning or other forms of distance learning to maximise the impact.

There is just a single Project in this theme – K1: Programme Knowledge Transfer - the detail is given in Annex A at A.5 Knowledge Transfer Theme.

4.7 Programme Management Theme

The aim of the Programme Management Theme is as follows:

- overall programme management, including provision of all required information to DTI and the MAC WG to monitor progress;
- programme formulation, including both rolling formulation and new programme formulation, as required by DTI;
- activities necessary to comply with regulations regarding ionising radiation, especially safety and security and the provision of a Radiological Safety Advisor.

The Projects of this theme are summarised in the following table (the detail being given in Annex A):

Project no.	Project title
M1	Programme Management and Formulation
M2	Activities for compliance with radiation protection regulations

The details of these projects can be found in Annex A at A.6 Programme Management Theme.

Annex A. Projects by Theme

This annex contains details of all the proposed projects. They are presented by Theme in the following order:

1. Acoustics Theme
2. Dosimetry Theme
3. Neutron Metrology Theme
4. Radioactivity Theme
5. Knowledge Transfer Theme
6. Programme Management Theme

Each project description is presented in tabular form. Each project table contains the following elements:

- Theme name, e.g. “Acoustics”
- Project number, starting with the initial letter of the theme name, e.g. “A1”
- Project title, e.g. “Airborne noise exposure and hearing”
- User communities – a listing of the relevant user communities taken from the eight user communities addressed by the programme
- Needs – text describing the identified user community needs being addressed by the project – these are taken from the priority needs identified by the consultation process and/or the analysis of the relevant roadmaps
- Potential collaborators – an indicative list of organisations and types of organisation that might collaborate with NPL on the project
- Expected impact – text describing the impact that the project as a whole is expected to have on the relevant user communities
- Specific impact areas – text describing more specific types of impact that are expected to arise from some part of the project, perhaps a single sub-project or one or more individual products
- Sub-project number, e.g. “A1.1”
- Sub-project title, describing the part of the project that will give rise to the list of products that follows the title, e.g. “Measurement systems and provision of standards”
- Product number within a sub-project, e.g. “P1”
- Product description, describing a particular output resulting from the sub-project

A.1. Acoustics Theme

<table>
<tr><th colspan="3">ACOUSTICS</th></tr>
<tr><td>A1</td><td colspan="2">Airborne noise exposure and hearing</td></tr>
<tr><td colspan="3">User Communities:
Healthcare, Safety, Environment, Instrumentation and Test Laboratories, Defence & Security, Manufacturing, Energy.</td></tr>
<tr><td colspan="2">Needs:
Airborne sound continually impacts the whole hearing population and its measurement is vital to protect the environment we live and work in, as well as to control the damaging effects and annoyance of noise. New technology brings with it new noise hazards, such as exposure to airborne ultrasound; and new measurement requirements, for example phase calibration of microphones. These span survey-grade applications through to the innovative and to those demanding state-of-the-art accuracy.

UKAS laboratories present further requirements to support their role in the NMS. Similarly, advances in the measurement of hearing demand new approaches to calibration. The Universal Neonatal Hearing Screening Programme (UNHSP, screening every newborn) now in place in the UK uses objective audiometric methods that require a different approach to calibration. Digital hearing aids similarly place new demands on testing protocols in order to maximise benefits to the hearing impaired user and inform high-volume purchasing decisions.

The prevalence of the use of headsets both in and out of the workplace (more than 1 million people in the UK are now employed in call-centres) presents new measurement challenges to ensure the acoustic safety of the headset and the equipment it connects to.

All facets of this work (including the performance specification of measurement equipment, approaches to noise control and hearing conservation), require representation at the international level to define and shape the IEC and ISO standards underpinning and regulating measurement practices, to express, and often argue in favour of, UK stakeholder interests.</td><td>Potential Collaborators:
• Institute of Sound and Vibration Research, University of Southampton
• Acoustic Safety Programme
• European Hearing Instruments Manufacturers Association
• EURAMET (especially NMIs from Germany, Denmark, France, Italy, Poland)
• Health & Safety Executive
• Telecoms equipment manufacturers (Plantronics, GN Netcom, Senneisser, C3)
• UKAS Calibration laboratories
• Peter Mapp & Associates
• IAC (Industrial Acoustics Corporation)
• BBC
• Delta Acoustics (Denmark)
• Institute of Hearing Research (Manchester)</td></tr>
<tr><td colspan="3">Expected Impact:
Accurate acoustic measurements have a direct impact on;
• the quality of the environment through reliable measurements of noise in all its forms, leading to</td></tr>
</table>

ACOUSTICS	
A1	**Airborne noise exposure and hearing**

informed decision making and noise policy;

- our ability to diagnose and correct (or avoid) hearing impairment, avoiding the consequent enormous detriment to quality of life.

Specific impact areas:

- Primary standards underpin all noise measurements carried out with traceable equipment, enabling, for example, environmental noise surveys in accordance with BS 4142 and allowing measurements demonstrating compliance with Noise at Work regulations to be carried out. (A1.1 - P1, and all other products)
- Measurement standards for airborne ultrasound enable safety criteria and exposure guidelines to be established and identifying people potentially at risk. (A1.2 - P1)
- Development of calibration methods appropriate for secondary laboratories enables the scope of widely available calibration techniques to be increased. (A1.1 - P5, P8 & P9)
- Appropriate transient calibration of ear simulators increases effectiveness of UNHSP (A1.3 P1 & P2)
- Improved productivity in call-centres through improved working conditions and reduced absenteeism and industrial injury claims from acoustic shock. (A1.3 P7, P8 &P9)
- Greater benefit for users of hearing aids by enhancing the ability to match instruments to users' particular hearing impairment. (A1.3 P3, P5, P6 & P9)
- Enables high-volume purchasing of hearing aids (e.g. by NHS) to be carried out on a more informed basis. (A1.3 - P5 &P6)
- Scientific innovation in audiometry based on non-invasive in-ear measurement. (A2.3 P10)

Sub-projects & Products

A1.1	**Measurement systems and provision of standards**
P1	State-of-the-art primary calibration facilities supporting top-class, UKAS accredited where necessary, calibration services
P2	Updated and sustainable calibration facility for the pressure calibration of working standard microphones from 63 Hz to 20 kHz
P3	Key comparison results and CCAUV participation, supporting CMC entries in MRA database
P4	Expert representation in IEC TC29 (WG4, WG17) and ISO TC43 (WG8) and BSI EPL 29
P5	New and revised draft IEC standards for sound calibrators and SLMs
P6	New ISO standard for the evaluation of free-field rooms
P7	New calibration Service for the phase calibration of microphones
P8	Simplified free-field calibration demonstrator system

ACOUSTICS	
A1	**Airborne noise exposure and hearing**
P9	New low cost calibration service for pressure and free-field calibration of non-standard microphones with a typical uncertainty less than 0.5 dB
A1.2	**Measurement standards for airborne ultrasound**
P1	Calibration method for transducers operating in air between 20 kHz to 100 kHz.
A1.3	**Hearing measurement and conservation**
P1	UKAS accredited calibration Services for the impulse response of ear simulators
P2	Expert representation in IEC TC29 WG13 and BSI EPL 29
P3	New and revised draft IEC and ISO standards for ear simulators, audiometric equipment, hearing aids and hearing thresholds
P4	Three reports outlining IEC specification requirements for new ear simulators and bio-simulators
P5	Study underpinning a report to IEC TC29 on objective test methods to specify the operational performance of DSP hearing aids
P6	Study and report to IEC TC29 on objective test methods to specify the benefits to users of DSP hearing aids
P7	Definitions of performance parameters for acoustic limiters used in telephone/communications systems
P8	New facilities to provide ear simulator measurement services for the telecoms industry
P9	A scientific paper on new metrics for speech intelligibility and quality in sound reproduction systems coupled closely to the ear.
P10	A study and scientific paper on the feasibility of audiometry based on in-ear sound pressure

<table>
<tr><th colspan="2">ACOUSTICS</th></tr>
<tr><td>A2</td><td>Novel technologies for the measurement of sound in air</td></tr>
<tr><td colspan="2">User Communities:
Environment, Energy, Defence & Security, Instrumentation & Test Laboratories, Safety, Manufacturing.</td></tr>
<tr><td>Needs:

The previous NMS programme established a link between a number of complex measurement challenges and the need for a new breed of low-cost measuring instrument with a measurement grade performance. Such challenges, often arising from EU directives on noise exposure and pollution include: noise dose measurement on an extensive scale, distributed measurement to better characterise noise fields (e.g. low frequency noise), cost-effective deployment of large sensor arrays for example for urban noise mapping and noise measurement solutions to support renewable and sustainable energy generation.

Alongside the new role of novel sensors in these areas, there is also a need for guidance in both emerging and long-standing noise issues (particularly wind farms, both on- and off-shore, and infrasound). Microfabricated sensors offer the potential for mass production, but currently fall short of the level of performance required for measurement. However the widespread benefits of realising such instrumentation and the depth of the resultant impact has resulted in great interest from a range of industrial sectors including environmental monitoring (especially related to transportation and renewable energy), industrial noise control, healthcare and security. Indeed the requirements of these sectors are helping to drive the development of sensors with the required specification. The economies offered by mass production will lead to new ways of conducting measurement, and consequent implications for developing new approaches to calibration, focussing on bulk calibration and the consideration of transducer arrays, rather than individual devices.

New calibration techniques are therefore required, extending right up to the primary level, where optical techniques continue to offer the greatest potential for interrogating an acoustical field non-invasively to directly quantify the field parameters.</td><td>Potential Collaborators:

• QinetiQ
• Hoare Lea
• Castle Group
• Coventry University
• Newcastle University
• Cardiff University
• MNT Packaging Centre
• University of Edinburgh
• University of Le Mans
• Imperial College, London
• Serco Assurance
• AcSoft
• Campbell Associates
• Environment Agency
• Highways Agency
• Building Research Establishment
• DEFRA
• Geoff Leventhall (low frequency noise specialist)</td></tr>
<tr><td colspan="2">Expected Impact:

Measurement of noise (and other sound) is set for significant changes with many interested parties keen to investigate the potential advantages of new technology in their business. Impact will therefore extend across industrial sectors and will have economic, environmental and commercial elements.</td></tr>
</table>

ACOUSTICS	
A2	**Novel technologies for the measurement of sound in air**

Specific impact areas:

Potential new application areas include

- personal noise exposure evaluation and mitigation (A2.1 - P1, P2 & P3,)
- condition monitoring in harsh environments (A2.1 – P1, P2 & P3; A2.2 - P3, P4 & P5)
- community noise monitoring to tackle anti-social behaviour (A2.1 – P1, P2 & P3; A2.2 - P3, P4 & P5)
- noise mapping & strategic planning from *measurement* rather than only predicted data (A2.3 - P6, P7 & P8)

Other benefits include

- Reduced environment impact of noise from a wide spectrum of sources (e.g. transport infrastructure) (A2.1 - P5, A2.2 – P6, P7 & P8, A2.4 all products)
- Improvements over predictive noise mapping which tends to overestimate, thereby placing unnecessary restrictions on the expansion of road and air infrastructure (A2.2 – P6, P7 & P8)
- Increased environmental protection from a better understanding of infrasound and the associated measurement issues (A2.4 - P1)
- Support for the development of renewable energy, reduced environmental impact of new offshore wind-farms, thereby contributing to UK aims to reduce reliance on non-renewable energy. (A2.4 - P2)
- Increased acceptance of wind farms through reduced noise levels. (A2.4 - P3)
- Support for a technology thrust, providing an opportunity for UK business to take the lead in the exploitation of MEMS based measurement devices. (A2.1 all products, A2.2 all products)
- New calibration methods leading to expanded measurement capability and a greater application of sensor networks. (A2.2 - P1 & P2)
- Optical techniques for calibration will lead an international shift away from current reciprocity-based method. (A2.3 all products)

Sub-projects & Products

A2.1	**Development of new transducers to underpin novel or improved measurement techniques**
P1	New sensors and transduction mechanisms
P2	Second-generation autonomous and wireless sensor for stand-alone use and in networks.
P3	A scientific paper on the development of products P1 and P2
P4	Advanced wireless package for second-generation sensor
P5	General and application specific demonstrator systems
P6	Application specific guidance on the use of new transducer technology
P7	Expert representation in IEC TC 29 WG5 – microphones; new draft IEC standards on secondary free-field calibration.

ACOUSTICS	
A2	**Novel technologies for the measurement of sound in air**
P8	Expert representation in ISO TC 43 – Acoustics
A2.2	**Development of networked sensors to underpin novel or improved measurement techniques**
P1	New calibration capability for microphone array
P2	Technical publication related to 'bulk' calibration
P3	Autonomous and wireless sensor network capability
P4	Scientific paper on the development and application of P3
P5	Packaging suitable for prolonged outdoor for wireless sensor
P6	Microphone network demonstrator system
P7	Application notes and guidance on the use of sensor networks in measurement.
P8	Facility for use by/for third-parties for survey/monitoring/mapping purposes
A2.3	**Next generation primary calibration of microphones and other optical techniques for imaging acoustic fields**
P1	Optical system for primary microphone calibration
P2	Comparison with existing microphone standard
P3	Conference paper
P4	Technical *paper* submitted to peer-reviewed Journal PR Journal, describing field-imaging method.
P5	Capability for two-dimensional scanning of imaging loudspeaker fields
P6	Conference paper presented at suitable conference
P7	Technical paper submitted to peer reviewed Journal, describing field imaging method
A2.4	**Environmental Noise from offshore wind farm construction and infrasound**
P1	Infrasound noise guide
P2	A validated predictive model of airborne noise fields generated by offshore wind farm construction (piling)
P3	Knowledge transfer to Promulgate model (e.g., webpage)

ACOUSTICS	
A3	**Underwater acoustics in the marine environment**

User Communities:

Environment, Defence & Security, Energy, Instrumentation and Test Labs, Manufacturing.

Needs:

Increasing environmental concerns over the exposure of marine life to man-made noise has led to the requirement for environmental impact assessments before offshore activities may commence. The drivers for this come from EC legislation such as the Habitats Directive (92/43/EEC) implemented as UK legislation in 2001 (*UK Offshore Petroleum Activities (Conservation of Habitats) Regulations 2001*) and administered by DTI and DEFRA. To assess noise impact, it is first necessary to have agreed methods of characterising noise sources (not a simple matter for some sources such as marine piling and construction work). This issue is set to increase in importance in the future, with regulations that need underpinning by well-founded metrology. The issue has a direct impact on the *Renewable Energy* industry (offshore windfarms, wave and tidal power) where inability to accurately assess environmental impact is a serious impediment to progress in achieving the stated UK aims of 20% power from renewable sources.

In the offshore industry, acoustic systems provide a crucial underpinning technology without which civil offshore operations could not function. Here, there is a clear trend toward working in deeper water as the shallower coastal waters become more heavily harvested of oil and gas reserves. This is setting new challenges as acoustic systems are required to work at greater depths and over greater ranges. For defence and security applications, in the post cold-war environment, interest has moved away from deep cold-water applications toward applications in coastal waters, for protection of ports and harbours from mines and potential terrorist threats. This provides its own challenges, one of which is ensuring the acoustic performance of materials over a range of different water temperatures and depths. In oceanographic science, acoustic methods are used to study ocean properties that affect the global environment. Applications include seabed mapping, biomass evaluation, ocean acoustic tomography, and the study of sediment processes.

The UK continues to be the most active European country in manufacturing of underwater acoustics systems, with UK industry supplying worldwide markets with systems for positioning, communications, navigation, echo sounding, sub-sea control, seismic measurements, water quality measurement, sonar, and weapons systems. In general, within underwater acoustic metrology, there is a lack of "headroom" between the best measurement capability of national primary standards and the general capability in industry. This places limitations on the ability to disseminate accurate standards. For the most demanding industrial applications, the accuracy requirement can push the boundaries of the primary standard accuracy.

Potential Collaborators:

- Institute of Sound and Vibration Research, University of Southampton
- National Oceanographic Centre, Southampton
- University of Loughborough
- QinetiQ
- DSTL
- HAARI, China
- Drumgrange Ltd
- NEL
- R&V Hazelwood Assoc.
- Istituto di Acustica, Rome
- EURAMET partners (Italy, Turkey…)
- Ultra Electronics
- IEC TC87 WG15 partners (USA, Japan, Russia, Germany…)
- BAe
- St Andrews University (SMRU)
- SEA
- Society for Underwater Technology
- Institute of Acoustics

ACOUSTICS	
A3	**Underwater acoustics in the marine environment**

Expected Impact:

Accurate measurements for marine acoustics have a direct impact on:

- The ability of industry to conduct EIAs for the effect of noise on the marine environment by: (i) underpinning the regulations with valid metrology; (ii) developing improved measurement methodologies; (iii) contributing to the development of methods for mitigating the effect on marine life;
- The ability of UK manufacturing industry producing marine acoustic systems to trade in the UK and overseas by providing: (i) the measurement infrastructure and traceability to demonstrate performance specification; (ii) internationally recognised test and calibration certificates;
- The ability of industry, academia and OGDs to assess the full performance of underwater acoustic systems over a range of environmental conditions by use of the world-class national facilities maintained by NPL.

Specific impact areas:

- Primary standards underpin all UK underwater acoustic measurements carried out with traceable equipment (A3.1; A3.2 & A3.3)
- Improved accuracy and extended frequency range of dissemination methods for low frequencies is of direct benefit to industrial users such as manufacturers of towed arrays for geophysical surveying, defence contractors manufacturing passive sonar arrays, and manufacturers of measuring hydrophones and transducer (A3.1)
- Improved provision of standards at simulated ocean conditions provides industry and OGDs with an extended and unique test capability for transducers and materials which reduces the need for expensive sea-trials (up to factor of 10 cost saving) (A3.2)
- Next generation of measurement methods based on optical techniques will provide improved primary standard (leading ultimately to improved hydrophone calibration services) and have potential for rapid acoustic field mapping which would be of direct benefit to manufacturers of high frequency sonars (A3.3)
- Standards for measurement of underwater noise will benefit those attempting to measure radiated noise as well as those undertaking environmental impact assessments and wishing to mitigate the effects of noise on marine life (A3.4)
- Improved understanding of hydrophone performance in sediment will directly benefit oceanographic research (A3.3 – P6)
- Online technical guides, KT events and contribution to new international specification standards are of benefit to the user community as a whole (A3.4 – P7)

Sub-projects & Products	
A3.1	**Provision and dissemination of free-field standards for hydrophone and transducer calibration**
P1	Provision of primary standard for range 1 kHz to 500 kHz
P2	Provision of traceable free-field calibration services in the range 1 kHz to 1 MHz

ACOUSTICS	
A3	**Underwater acoustics in the marine environment**
P3	Air-pistonphone service maintained (5 Hz to 315 Hz)
P4	Improved uncertainties in free-field services at Wraysbury facility (new best UKAS capability of 0.9 dB)
P5	Extended low frequency hydrophone calibration service at Wraysbury (50 Hz to 250 Hz)
P6	Improved understanding of free-field uncertainties and contribution to work of EURAMET and IEC TC87 WG15
P7	New Service for in-air hydrophone calibrations in duct or free-field chambers.
A3.2	**Provision and dissemination of standards at simulated ocean conditions**
P1	Maintained coupler reciprocity primary standard for the frequency range 20 Hz to 1 kHz
P2	Provision of standards for simulated ocean conditions including traceable free-field calibration services in the range 1 kHz to 500 kHz
P3	Improved capability for materials characterisation (panels) in APV and improved Service using novel sensing methods and off normal incidence capability
P4	Completion and publication of joint journal paper on panels work
P5	Completion and publication of conference paper on low frequency calibrations in APV
P6	Development of new stable reference hydrophone (jointly with industry)
P7	Key Comparison final report and KCDB entry
P8	New low frequency service using travelling wave tube (Sims tube)
A3.3	**New and improved methods for hydrophone and sonar characterisation**
P1	Uncertainty assessment of optical interferometer for hydrophone calibration
P2	Validation of optical interferometer by comparison with other methods (and other interferometers)
P3	Conference presentation and peer-reviewed publication detailing the accuracy of optical hydrophone calibration
P4	Adoption of new method for primary standard calibration method for hydrophones
P5	Tomographic capability for three-dimensional imaging of high-frequency sonar fields in the near field
P6	Determination of the effect of burial in sediment on hydrophone performance and submit joint publication

ACOUSTICS	
A3	**Underwater acoustics in the marine environment**
A3.4	**Development of standards for underwater noise measurement**
P1	Joint publication on methods for measuring noise in situ in shallow water sites including comparison of methodologies for simplified propagation models for shallow water noise (e.g. to estimate source level and to predict impact zones)
P2	Joint journal publication on methodologies for measuring underwater radiated noise in reverberant environments (e.g. test tanks)
P3	Guidelines on methods for characterising and parameterising impulsive noise sources and contribution to standards committees
P4	Joint paper on assessment of mitigation methodologies for noise (bubble curtains, soft starts, slow starts, acoustic deterrents, etc.)
P5	Joint publication on standard methods for measuring underwater radiated noise of vessels and platforms using portable ranges
P6	Launch 3 new technical guidance notes on the NPL web pages and host Underwater Acoustics Course at NPL (organised by Seiche Ltd)

ACOUSTICS	
A4	**Medical applications of ultrasound**

User Communities:

Healthcare (Safety), Manufacturing, Instrumentation and Test Laboratories, Defence and Security.

Needs:

Ultrasound has transformed medical practice since its introduction. It is one of the most common imaging modalities with 6 million scans undertaken in the England in 2005 – 2006. Nearly all pregnancies in the UK are subject to at least one screening test using ultrasound, and approximately 2 million obstetric scans are undertaken within the NHS each year. Approximately 30 lithotripters (high pressure amplitude devices used to non-invasively shatter kidney stones), 2,500 ultrasound scanners, 10,000 ultrasonic foetal heart beat detectors and 20,000 physiotherapy units are employed within the NHS. The range and capabilities of diagnostic equipment is rapidly improving, bringing with it the need to determine the key characteristics of the applied acoustic field over a wider range of frequencies. The ability to undertake these measurements in a meaningful, traceable, way is key in ensuring the safety and efficacy of medical ultrasound applications.

Additionally, there are now an increasing number of new therapeutic modalities that involve the application of extremely high acoustic intensities essentially to burn cancerous tissue. The heating potential of these systems raises stringent requirements for developing new measurement techniques that are able to quantify the applied acoustic powers, acoustic intensities and the spatial distribution of these quantities. Within all areas of medical ultrasonic applications, to aid risk assessment and clinical management, it is essential to gain a better understanding of how ultrasound behaves in tissue. This will allow appropriate measurement methods to be developed which will provide improved estimates of exposure and dose to be made, ensuring the safety of obstetric ultrasound as well as optimised treatment planning.

Potential Collaborators:

- Department of Health
- Institute of Cancer Research
- Newcastle General Hospital
- Precision Acoustics Ltd
- Acoustic Polymer Ltd
- Royal United Hospital Bath
- Western General Hospital
- Kenelec Ltd
- Institute of Sound and Vibration Research, University of Southampton
- PTB

Expected Impact:

Acoustic output measurements of medical ultrasonic equipment are required for manufacturers to comply with the US FDA 510 (k) regulatory requirements, IEC 61157 and IEC 61689. Primary beneficiaries of the project are:

- UK manufacturers of ultrasonic devices who will have better tools and services for product development and access to markets;
- clinical users who will have greater confidence in the diagnostic and therapeutic equipment thy use;
- healthcare patients who will be able to receive benefits of the latest developments in medical ultrasound whilst having confidence in its effectiveness and safety.

Specific impact areas:

- A4.1 will support the continuing development of novel measurement devices, such as improved spatial resolution hydrophones of wider bandwidth i.e. fibre-optic hydrophones;
- the CCAUV Key Comparisons (A4.1 & A4.2) will play a key role in underpinning the Mutual Recognition Arrangement;

ACOUSTICS	
A4	**Medical applications of ultrasound**
• the buoyancy and pyroelectric power measurement methods (A4.2) are novel metrological developments which should provide significant advantages over conventional measurement methods allowing manufacturers to better optimise transducer designs; • easier to use measurement instruments and protocols will stimulate more effective and relevant quality control within hospitals and industry, leading to novel products and healthcare solutions. The development of the Mechanical Index/Thermal Index Test System (A4.3) is an example and should lead to a product which is potentially used throughout UK Hospitals as a QA and demonstration/training tool, raising awareness of the potential bio-effects of ultrasound, particularly temperature rise; • the range of new characterisation techniques under investigation within A4.4 will allow manufacturers and researchers of therapy equipment to optimise their clinical systems in ways not currently possible; • A4.5 will promote an understanding of the way ultrasound interacts with tissue, enabling a better prediction of bio-effects; • the piloting of the new measurement techniques investigated under A4.4 offers the prospect of considerably faster and simpler measurements at appropriate clinically relevant levels; • the majority of current ultrasound characterisation techniques are water-based and extrapolation from this simple liquid to a *tissue* environment is not well understood. A4.5 will develop a better understanding of the behaviour of ultrasound in tissue and will allow the development of standardized techniques more immediately relevant to the assessment of safety and efficacy of medical applications of ultrasound.	
Sub-projects & Products	
A4.1	**Provision, enhancement and dissemination of hydrophone calibration standards and services**
P1	Measurement services related to the calibration of ultrasonic hydrophones (primary standard & dissemination facilities)
P2	Hydrophone International specification standards that develop and evolve to the best interests of UK plc
P3	Start of CCAUV Key Comparison for ultrasonic hydrophone calibrations
P4	Extended Measurement Services related to high frequency calibration of hydrophones (> 60 MHz)
P5	Extended Measurement Services related to low frequency calibration of hydrophones (< 200 kHz)
P6	Two technical papers submitted to high impact peer-reviewed Journal relating to the extended frequency ranges for calibration of hydrophones
A4.2	**Provision, enhancement and dissemination of hydrophone and ultrasonic power standards and services**
P1	Primary and secondary standard radiation force balances; calibration and Measurement Services for ultrasound power
P2	Final Report summarising NPL's contribution to the CCAUV ultrasound power Key comparison

ACOUSTICS	
A4	**Medical applications of ultrasound**
P3	Two web-based guides related to issues of ultrasound power measurement
P4	Paper for peer-reviewed Journal on the buoyancy method as a potential new primary ultrasound power standard
P5	Measurement method (pyroelectric) resulting in improved measurement uncertainties for ultrasound power at mW power levels
P6	Paper submitted to peer-reviewed Journal summarising development of simple methods for quantifying non-uniformities in acoustic fields (including pyroelectric effect)
A4.3	**Provision and dissemination of ultrasonic field and characterisation Services**
P1	Five Measurement Service facilities: Beam-plotting Facility; Ultrasound Beam Calibrator; Materials Characterisation facility; Propagation Speed Rig and Thermal Test Rig
P2	Maintenance cycle revisions completed for at least two IEC IC87 WG8 standards, and convenorship of at least one TC87 WG
P3	Representation of NPL at 5 Committee meetings (across BSI, IEC TC87 and TC62, AIUM, ISTU and WFUMB)
P4	Paper submitted to a peer-reviewed Journal, describing the development and performance of an economical Mechanical Index/Thermal Index Test System and the results of trials involving collaboration with at least 3 UK Hospitals
P5	Review of ultrasonic methods of nano-particle characterisation, producing recommendations for potential future study
A4.4	**Development of methods for characterising high amplitude ultrasonic fields in water**
P1	Extended measurement services which includes IEC61949 procedures for nonlinear acoustic fields
P2	Paper on the application of fibre-optic hydrophones as a robust system for measuring acoustic pressure and temperature
P3	Paper on investigation of acousto-optic/ vibrometric methods of acoustic pressure measurement
P4	Completed assessment of a range of methods which could form the basis of quick, qualitative methods of assessing heating distribution (i.e. visualisation)
P5	Report of a feasibility study for making measurements in the presence of cavitation
A4.5	**Development of methods for quantifying ultrasonic dose in tissue and tissue-like environments**
P1	A computational model for predicting the heating distribution generated by radially symmetric, nonlinear ultrasonic fields including the temperature variation of acoustic and thermal properties of tissue

ACOUSTICS	
A4	**Medical applications of ultrasound**
P2	Evaluation of the thermal and acoustic (including nonlinearity parameter) properties of tissue-mimics compared to the properties of tissues
P3	A Thermal Test Object for High Intensity Focussed Ultrasound fields
P4	Paper describing *in-vitro* evaluation of heating distributions from scanned therapy ultrasound fields using a thin-film thermocouple array
P5	An evaluation of different methods for monitoring the occurrence of acoustic cavitation in tissue

<table>
<tr><th colspan="3">ACOUSTICS</th></tr>
<tr><td>A5</td><td colspan="2">Industrial applications of ultrasound</td></tr>
<tr><td colspan="3">User Communities:
Healthcare (Safety), Manufacturing, Instrumentation and Test Laboratories, Energy.</td></tr>
<tr><td colspan="2">Needs:

Ultrasonic cleaning is widespread across industry and healthcare, with over 20 UK manufacturers turning over £40M, and a worldwide market of £2Bn. The driving force behind the cleaning process is acoustic cavitation, and this is now being harnessed by new processors in the pharmaceutical and food industries in the control of crystallisation processes, and in wastewater treatment to break down sewage sludge. However, there are no standardised, traceable cavitation measurement techniques; indeed, existing NHS Standards require use of something as simple and qualitative as aluminium foil to characterise the performance of ultrasonic vessels used in surgical instrument cleaning. There is a strong user demand for the development of suitable standardised measurement methods, leading ultimately to an accepted unit of cavitation. In turn, this will lead to an improved fundamental understanding of cavitation processes, with consequent improvements to the optimised application of cleaning and manufacturing processes. Developed techniques would also enable scale up of new technology applications particularly in the pharmaceutical industry.

The use of liquid pumps is inherent in flow systems of all types, and the UK market alone is worth around £900M. Cavitation in pumps is well known: it causes process inefficiencies, and leads to costly failures of industrial systems. Pumps are estimated to consume 14% of the UK's total electricity, so there is a clear need to develop reliable methods for quantifying cavitation occurring in flow systems, which should lead to extensive energy savings through better pump selection, installation and operation. Reliable cavitation detection methods are also required on ships, where failures can result in dry-dock repairs with costs of £100k per day.

Acoustic Emission sensors are established in condition monitoring of safety-critical systems (such as engines and pressure vessels), and are finding increasing utility for real-time structural integrity monitoring of airframes during take-off, landing and flight. To underpin their performance, there is a critical requirement for traceable measurement, and the provision of calibration methods for sensors and measurement systems.</td><td>Potential collaborators:

• Ultrawave
• Institute of Sound and Vibration Research
• University of Southampton
• Prosonix
• Sonic Systems
• Coventry Sonochemistry Centre
• University of Bath
• Lloyd's Register of Shipping
• British Pump Manufacturers' Association
• Precision Acoustics Ltd
• Cranfield University
• Cavisys
• Specac Ltd
• National Engineering Laboratory
• Airbus UK
• Cardiff University
• KRISS
• Physical Acoustics Ltd</td></tr>
<tr><td colspan="3">Expected Impact:

The applications of acoustic cavitation span healthcare to materials synthesis, and the problems posed by hydrodynamic cavitation affect applications as fundamental as power generation and water supply. The development of cavitation measurement techniques, leading to consensus and standards, would represent a significant technical advance in a challenging scientific discipline, and the principal beneficiaries would be:

• Manufacturers and users of cleaning vessels, providing them with a measurement capability applicable to development, QA and servicing;</td></tr>
</table>

ACOUSTICS	
A5	**Industrial applications of ultrasound**

- Users of high power ultrasound processors in manufacturing (in particular, pharmaceuticals), providing them with the capability to optimise and scale-up processes, leading to innovation and wealth creation;
- Pump and aerospace manufacturers and users, who should gain access to measurement techniques enabling them to operate systems efficiently, leading to significant energy savings.

Specific impact areas:

- Developing an alternative NHS process recommendation based on a quantitative measure would improve the QA of vessels used in the cleaning of surgical instruments;
- The establishment of an active Cavitation Measurement Users club in A5.1 would provide a regular forum for debate, and would increase interaction and collaboration between industry and academia;
- In A5.2, developing a recognised measure for cavitation would enable UK manufacturers and users of high power ultrasound equipment to compare equipment and report process improvements on a traceable basis, and it would also position the UK strongly as a technology provider in the international marketplace;
- The trialling exercise described in A5.2 would give an extended network of UK users access to cavitation detection capability already developed under the DTI Measurements for Innovators scheme;
- Developing a retro-fit measurement solution for pump and flow systems under A5.3 will provide a process 'health check' capability, leading to improvements in safety and efficiency, and reduced failures;
- Introducing traceability into acoustic emission should build confidence in the technique when used in aerospace, and potentially see it utilised in a wider range of applications, leading to innovation.

Sub-projects & Products	
A5.1	**Characterisation methods for ultrasonic cleaning systems - development and dissemination**
P1	Draft protocol for testing the performance of ultrasonic vessels used in cleaning medical instruments, to include technique design and development, and a trial at least 2 user sites
P2	Technical paper submitted to a high impact peer-reviewed Journal, and presentation at a key international conference describing development of technique and results of trialling
P3	Technical Meeting at NPL for at least 40 High Power Ultrasound users
P4	High Power Ultrasound Measurement Club, and 2 annual meetings
A5.2	**Development of methods towards establishing a measurement unit of cavitation activity/dose**
P1	Advisory Group, of at least 4 members
P2	New multiple frequency reference facility for acoustic cavitation
P3	3 technical papers submitted to peer-reviewed Journals, describing development of techniques suitable for standardisation; establishment of new reference facility; and improvements to NPL Cavitation Sensor

ACOUSTICS	
A5	**Industrial applications of ultrasound**
P4	At least 2 presentations at key international conferences
P5	Technology trial of JIP-developed Cavimeters and sensors with at least 4 users
A5.3	**Development of methods for quantifying damaging cavitation applicable to pumps and propellers**
P1	Scoping study with collaborators providing recommendations for experimental programme
P2	Measurement methods developed at NPL, including experimental test facility, and trialling at partner sites
P3	Technical paper submitted to peer-reviewed journal describing scoping study, developed techniques and testing process
A5.4	**Development and dissemination of measurement standards and services for acoustic emission sensors**
P1	New calibration Service for acoustic emission sensors
P2	Comparison of commercial sensor sensitivities for both out-of-plane and in-plane displacement
P3	Technical paper submitted to peer-reviewed Journal
P4	Web-guide on Acoustic Emission basic principles and its use
A5.5	**Enhancement of characterisation techniques for acoustic emission sensors**
P1	Provision of reference source transducer
P2	Demonstration of calibrated device in an industrial environment
P3	Technical paper submitted to PR Journal, demonstrating use of traceable reference source

<table>
<tr><th colspan="3">ACOUSTICS</th></tr>
<tr><td>A6</td><td colspan="2">Acoustics theme knowledge transfer</td></tr>
<tr><td colspan="3">User Communities:
Healthcare, Defence & Security, Energy, Environment, Manufacturing, Safety, Instrumentation and Test Laboratories.</td></tr>
<tr><td colspan="2">Needs:
Promote awareness of work undertaken within the Acoustics Theme to the relevant user communities, increasing its impact;
Disseminate the outputs of the work undertaken within the Acoustics Theme to the relevant user communities.
Representation of UK on relevant international and European committees.
An authoritative source of technical advice on acoustical measurements.</td><td>Potential collaborators:
• IPEM – Non-ionising Radiation Special Interest Group
• Health Protection Agency
• Institute of Acoustics
• Institute of Acoustics – Physical Acoustics Group
• British Medical Ultrasound Society
• British Pump Manufacturers Association
• Ultrasound Industry Association</td></tr>
<tr><td colspan="3">Expected Impact:
Many aspects of this KT project have the potential to improve quality of life: the output of standards committees and advisory groups influences emerging regulations, and the technical enquiry service allows both industry and members of the public to find solutions to problems that concern them.

Specific impact areas:
• P1 will support active contribution to national, international and European committees for development of relevant standards and other documentation
• P2 will support visits to NPL for a wide variety of users
• P3 will support external visits by NPL staff to user organisations where appropriate
• P4 will support production of papers and reports that promote the whole theme rather than just the results of an individual project
• P5 will support staff in the review of papers for appropriate international journals, providing an important mechanism both for professional development of the scientists and the dissemination of best measurement practice
• P6 will support the provision of a responsive technical enquiry service, providing guidance and advice to industries, hospitals and other users in matters related to measurement</td></tr>
</table>

ACOUSTICS	
A6	**Acoustics theme knowledge transfer**
• P7 and P8 will allow meetings to be attended and hosted which address the requirements of specific and appropriate user communities, providing a mechanism for key results of the theme to be disseminated.	
Sub-Projects & Products	
A6.1	**Acoustics theme knowledge transfer**
P1	Active participation in national, international and European committees to develop standards and documentation relevant to acoustical metrology (e.g. BSI, IPEM, ISO)
P2	Visits by users to the acoustics facilities and staff at NPL for training and advice
P3	Visits by NPL staff to users for training, advice and promotion of the programme
P4	Publication of general papers and reports on acoustical metrology
P5	Refereeing of papers for peer-reviewed journals relevant to acoustics
P6	Technical enquiry service on acoustical metrology topics (providing an initial response to each enquiry within 5 working days)
P7	General presentations on acoustical metrology at national and international meetings and attendance at key conferences for networking purposes: those not covered by technical projects in this theme
P8	Organising relevant scientific meetings and exhibiting at relevant meetings for promotion and awareness, in collaboration with the IoA

A.2. Dosimetry Theme

<table>
<tr><th colspan="3">DOSIMETRY</th></tr>
<tr><td>D1</td><td colspan="2">Calorimetry for radiotherapy</td></tr>
<tr><td colspan="3">User Communities:
Healthcare, Radiation Processing Industry.</td></tr>
<tr><td colspan="2">Needs:

Radiotherapy dosimetry for cancer patients requires traceability to primary standard absorbed dose calorimeters. Continued dissemination of the quantity “absorbed dose” will require a transition from existing calorimeters near the end of their life, to an improved calorimeter for high-energy photon and electron beams.

A growing number of patients are treated each year with other modalities for which dosimetry procedures have not been well established. Among these, proton therapy (mainly in mainland Europe, US and Japan) and brachytherapy can benefit from improvements in dosimetry where NPL has taken a lead by developing new calorimeters.

Primary standards realising absorbed dose to graphite require a conversion to dose to water. There remains a need to improve the uncertainty of this conversion for electrons and protons.

The high dose industrial reference standards (project D.5) are traceable to the therapy level primary standards.</td><td>Potential Collaborators:

• McGill University and NRC, Canada
• Clatterbridge Centre of Oncology
• Slovak Office of Standards, Metrology and Testing
• METAS and PSI, Switzerland
• BIPM brachytherapy working party members (PTB, LNHB, NIST, NMi, BIPM)
• EURAMET project partners
• IAEA Coordinated Research Project partners
• Other NMIs</td></tr>
<tr><td colspan="3">Expected Impact:
The existing and new calorimeters underpin dosimetry for the delivery and improvement of about 150,000 cancer treatments in the UK per year.</td></tr>
</table>

DOSIMETRY	
D1	**Calorimetry for radiotherapy**

Specific impact areas:

D1.1 – D1.3: The existing and new calorimeters for photon and electron beams are the basis of the IPEM Codes of Practice and approved calibration services. The new primary standard will improve the consistency of dosimetry in electron and photon beams.

D1.4 – D1.5: The new proton and HDR brachytherapy calorimeters will improve consistency in the delivery of both therapy modalities and are unique instruments that will keep NPL at the forefront of innovation in dosimetry of proton beams and brachytherapy sources.

D1.6 P1: Published values for beam quality correction k_Q, based on NPL's large database of calibration data, will contribute to possible reductions in uncertainties and costs, an extension of the scope of the existing calibration services and will have a direct impact on the delivery of accurate radiation dose to cancer patients.

D1.6 P2: Improvements in the conversion from absorbed dose to graphite to absorbed dose to water for charged particles will benefit all therapy delivered with electron and proton beams.

Sub-projects & Products	
D1.1	**Photon beam calorimetry**
P1	The high-energy photon beam absorbed dose standard, maintained for the calibration of transfer standard ionisation chambers.
P2	International comparisons via key and supplementary comparisons with the BIPM.
P3	Publish k_Q values for Farmer type chambers in high-energy x-ray beams.
D1.2	**Electron beam calorimetry**
P1	The high-energy electron beam absorbed dose standard, maintained for the calibration of transfer standard ionisation chambers and diodes, including contingency chambers and diodes.
P2	Bilateral international comparisons with other NMIs.
P3	Publish k_Q values for recommended electron chamber types in high-energy electron beams.
D1.3	**New electron-photon primary standard therapy level calorimeter**
P1	Full tests and characterisation of the new calorimeter.
P2	Determination of all correction factors for the new calorimeter.
P3	Comparisons of the new calorimeter with existing primary standards in electron and photon beams.
P4	A full report on the development and use of the new calorimeter.

DOSIMETRY	
D1	**Calorimetry for radiotherapy**
D1.4	**Proton beam calorimetry**
P1	Tests of the proton calorimeter in proton beams.
P2	Determination of correction factors for the test beam and for a general low-energy and a general high-energy proton beams.
P3	Comparison of the calorimeter with ionisation chambers in a low-energy and a high-energy proton beam.
D1.5	**Brachytherapy calorimetry**
P1	Fully commissioned HDR brachytherapy calorimeter at primary standard level.
D1.6	**Absorbed dose to graphite to absorbed dose to water conversion for charged particles**
P1	Stopping power ratios between graphite and water, with reduced uncertainties, for electrons and protons.
P2	Perturbation factors for ion chambers, with reduced uncertainties, in electron and proton beams

<table>
<tr><th colspan="3">DOSIMETRY</th></tr>
<tr><td>D2</td><td colspan="2">Ionometry Standards and Services</td></tr>
<tr><td colspan="3">User Communities:
Healthcare, Safety (Radiation Protection).</td></tr>
<tr><td colspan="2">Needs:

UK law and IPEM and IAEA codes of practice require the maintenance and dissemination of ionometry standards in very low, low and medium energy x-ray beams, and in therapy and protection level ^{60}Co, ^{137}Cs and in HDR Brachytherapy ^{192}Ir.

Improvements to therapy, diagnostic and protection level ionometry- based calibration services will improve uncertainties, reduce costs and extend the scope of these services and so maximise the number of customers and viability of the services.

There is a requirement to measure the impact of changes in dosimetry standards and their dissemination in the UK and report on the state of national dissemination for therapy level dosimetry (high-energy photons and electrons, and kV x-rays), and its effect on patient doses. Urgent user requirements for audit require an immediate/emergency response.</td><td>Potential Collaborators:
• Other Primary Standard Dosimetry Laboratories
• BIPM
• RRPPS
• IPEM RTSIG audit group
• NHS / private radiotherapy departments</td></tr>
<tr><td colspan="3">Expected Impact:
Ionometry-based standards and calibration services have a direct impact on:
• Accurate delivery of radiation dose to cancer patients and adherence to Codes of Practice
• Research into new and development of existing radiotherapy techniques
• Protection level dosimetry and the infrastructure for compliance with current legislation
• Dosimetry for diagnostic x-rays and the infrastructure for compliance with the Ionising Radiation (Medical Exposure) Regulations

Specific impact areas:
▪ Dosimetry audit visits improve confidence in the correct delivery radiotherapy to patients. Audits will be linked with regional hospital interdepartmental audits to provide a more in-depth investigation going beyond the headline result. (D2.6)
▪ Emergency response audits allow radiotherapy departments to resume patient treatments sooner than would otherwise be possible. (D2.6)
▪ Development of a protection level secondary standard chamber that will realise Ambient Dose Equivalent directly will have improved uncertainties over current commercially available chambers. (D2.5)</td></tr>
</table>

DOSIMETRY	
D2	**Ionometry Standards and Services**
Sub-projects & Products	
D2.1	**Development and maintenance of 50kV Free Air Chamber**
P1	Therapy level 50kV free air chamber maintained.
P2	Report describing reassessment of primary standard and calibration uncertainties.
P3	Report on commissioning of protection level 50kV free air chamber.
P4	Comparison of protection level 50kV free air chamber with therapy level chamber and with BIPM.
D2.2	**Development and maintenance of 300kV Free Air Chamber**
P1	300kV free air chamber maintained.
P2	Calibrated transfer chambers.
P3	Report on correction factors and uncertainties.
P4	Large aperture commissioned for protection level qualities.
P5	Two bilateral comparisons with other PSDLs completed.
P6	Report on all bilateral comparisons undertaken.
D2.3	**Development and maintenance of Primary Standard Cavity Chambers**
P1	Maintain existing primary standard cavity chambers (including HDR brachytherapy primary standard cavity chamber).
P2	Complete commissioning of new primary standard cavity chambers, compare with existing standards and with BIPM and report.
P3	Measurements to validate wall study investigation within D6.7.
P4	Characterise upgraded (version 3) HDR Brachytherapy source.
D2.4	**Development of healthcare calibration services**
P1	Carry out investigation into calibration technique for Practical Peak Voltage and type test commercially available meters.
P2	Move to offering calibrations for Practical Peak Voltage meters in clinical beams.
P3	Following up work establishing P2, move to offering diagnostic and mammographic calibrations in clinical beams.
P4	Extend diagnostic and mammographic calibration service to cover current standard IEC 61267.

DOSIMETRY	
D2	**Ionometry Standards and Services**
P5	Investigate applicability of HDR brachytherapy calibration service for other source types.
P6	Extend LDR brachytherapy calibration service to at least 10 other source designs by determining calibration factors for the NPL secondary standard.
D2.5	**Development and maintenance of protection and environmental calibration service**
P1	Provision of a calibration service for protection and environmental level instruments on an annual basis.
P2	Develop, test and optimise Ambient Dose Equivalent chamber and liase with manufacturer to produce commercial chamber.
P3	Investigation into secondary standard response for the protection level ISO Low Air Kerma Rate series.
D2.6	**Measuring the impact of changes in the dosimetry standards in the UK**
P1	Minimum of 40 planned and emergency response visits covering therapy level electron, MV photon and kV x-ray dosimetry.
P2	Report and present on the state of national dissemination in the UK.
P3	Audit each department using electron therapy in the UK (using the new electron code of practice) in collaboration with University of Surrey.

DOSIMETRY	
D3	**Novel dosimetry techniques**

User Communities:

Healthcare, Safety (Radiation Protection), Radiation Processing Industry, Environment.

Needs:

Present day calorimeters operate at the limit of their sensitivity in measurements for external beam radiotherapy. Future needs for absorbed dose measurements at low dose rates such as LDR brachytherapy, nuclear medicine and radiation protection will require the development of novel thermometry methods to increase the sensitivity of calorimetry.

Radiotherapy treatment verification, diagnostics, the radiation processing industry and measurements for environmental and radiation protection all have some need for quantitative measurement of spatial dose distributions. Examples include 3-dimensional dose mapping around small brachytherapy sources and for complex treatment deliveries using small field segments such as IMRT and tomotherapy, quantitative non-reference dosimetry at a point for radiotherapy treatment verification and imaging for diagnostics. Absorbed dose levels for this wide range of applications vary over 15 orders of magnitude and require NPL to develop and maintain its expertise in a wide variety of point-, 1D-, 2D-, and 3D-dosimetry systems.

The importance of modelling in dosimetry, radiotherapy treatment and diagnostics require NPL to develop and expand modelling capabilities to support the UK and international communities in new areas of modelling and provide workshops and training courses.

Regarding the increasing use of external beam radiotherapy with protons and ions where the treatment outcome is not longer proportional to absorbed dose, BIPM and other organisations have highlighted the need to introduce new biologically relevant response quantities, and standardised measurement will require the development of biosensors.

Potential Collaborators:

- Quantum Metrology Group (NPL)
- Biotechnology Group (NPL)
- Clatterbridge Centre of Oncology
- University of Surrey
- University of Birmingham
- University of Liverpool
- Harwell Dosimeters Ltd
- EURAMET project partners
- Risø National Laboratory, Denmark
- Ghent University, Belgium
- Geant4 collaboration

Expected Impact:

This project will contribute to improvements in the delivery of about 150.000 cancer treatments in the UK per year as well as to advances in dosimetry for diagnostics, the radiation processing industry and environmental and radiation protection.

DOSIMETRY	
D3	**Novel dosimetry techniques**

Specific impact areas:

D3.1: New thermometry methods will extend the scope of direct absorbed dose measurements and will develop and maintain NPL's expertise and world-leading status in thermometry for calorimetry.

D3.3: Development of research in 3D dosimetry techniques and new dosimeters for point, 1D- and 2D-dosimetry will continue to expand NPL's capabilities being developed under 2004-07 NMS IR programme and enhances NPL status in therapy-level dosimetry through the investigation and recommendation of more suitable dosimetric detectors for new treatment techniques as well as in diagnostics, the radiation processing industry and environmental and radiation safety.

D3.5: Modelling to support the community will improve accuracy and consistency in treatment planning and dose delivery to the patient and will enhance NPL's existing reputation as a centre of modelling expertise in this field. It will enhance NPL's capabilities in benchmarking of treatment planning systems, detector simulations, microscopic modelling, and multi-scale modelling (e.g. for biosensors), and it will enable opportunities for further collaborations.

D3.4: The highly innovative development of biosensors, linking NPL's expertise in ionising radiation with its science strategy objectives on biotechnology, will lead to improved consistency in biologically relevant quantities between different treatment modalities, the result being a unique instrument that could trigger industrial biosensor development.

Sub-projects & Products	
D3.1	**New calorimetry and thermometry methods**
P1	Prototype implementation of non-contacting thermometry methods (microwave resonance thermometers or whispering gallery microwave thermometers) in calorimetry.
P2	Prototype micro-bolometer for use as a micro-dosimeter.
D3.2	**New dosimeters**
P1	Dosimetry systems for small fields, traceable to primary standards.
P2	Investigate diamond detectors.
P3	Investigate radiochromic film.
P4	Investigate LiF/fibre optic luminescent systems.
D3.3	**Development of 3D dosimetry techniques**
P1	Quantitative optical tomography system for readout of 3D-dosimeters.
P2	Gel based dosimeters.
P3	Investigation into dosimeters based on radiochromic dyes in polymers.

DOSIMETRY	
D3	**Novel dosimetry techniques**
D3.4	**Biosensors**
P1	Identified technologies for developing a biosensor.
D3.5	**Modelling to support the community**
P1	Host at least one training course in the UK on a popular Monte Carlo radiation transport code (e.g. EGSnrc, Geant4).
P2	Significant involvement in the Monte Carlo community (Geant4 collaboration, EGSnrc) and enhanced NPL capability through (i) the provision of good experimental data and benchmarking of new and relevant applications (and associated physical models), (ii) collaborations with other institutions, and (iii) representations on appropriate committees.
P3	Report detailing preliminary investigations into the Monte Carlo benchmarking of radiotherapy treatment planning systems used in the UK.
P4	Significant contribution into the Monte Carlo benchmarking of proton treatment planning systems.
P5	Report reviewing existing efforts to extend macroscopic Monte Carlo codes towards micro-dosimetric calculations.
P6	Contribution to the CONRAD WP4 workshop and preparation of data for publication.

<table>
<tr><th colspan="3">DOSIMETRY</th></tr>
<tr><td>D4</td><td colspan="2">New healthcare applications</td></tr>
<tr><td colspan="3">User Communities:
Healthcare (Radiotherapy).</td></tr>
<tr><td colspan="2">Needs:
New evolving radiotherapy modalities which increasingly depend on small treatment fields such as IMRT, tomotherapy, stereotactic radiosurgery, intra-operative radiotherapy and ophthalmic radiotherapy require the development of new dosimetry standards, protocols and definition of new reference conditions under which dosimetry can be made traceable to primary standards in order to ensure consistency in dosimetry between these new techniques and conventional radiotherapy.

Also in proton therapy the need for improvements in reference dosimetry, relative dosimetry, treatment planning and imaging is high and this need requires further investigation of ionization chambers, alanine, film and solid-state dosimeters as well as improved evaluation of interaction data. This is in particular the case for laser induced proton beams and scanned proton beams where accurate nuclear interaction data are essential. Scanned proton beams are in fact another dose delivery modality that depends on overlapping small fields requiring specific (and serious) dosimetry issues to be resolved.

Other recent developments are the increased use of imaging in the verification and correction of dose delivery in radiotherapy (IGRT), the use of time dependent data of patient movement (4D therapy), in vivo-dosimetry and the re-introduction of grid-therapy, which require dosimetry related research and guidelines.</td><td>Potential Collaborators:
• Clatterbridge Centre of Oncology
• Slovak Office of Standards, Metrology and Testing
• Copenhagen University
• METAS/PSI
• IAEA Coordinated Research Project partners
• LIBRA (Laser Induced Beams of Radiation and their Applications) project partners (EPSRC)
• University of Birmingham
• IMRT users
• Other NMIs
• EURAMET project partners
• IPEM</td></tr>
<tr><td colspan="3">Expected Impact:
Directions outlined in iMERA road map should be followed. Support for innovative radiotherapy will be provided.</td></tr>
</table>

DOSIMETRY	
D4	**New healthcare applications**

Specific impact areas:

The sub-projects on small field and IMRT dosimetry will lead to traceable user measurements for these modalities resulting in better accuracy and better consistency with conventional radiotherapy dosimetry resulting in improved outcomes for cancer patients. They will further develop NPL's ability to underpin innovative radiotherapy techniques, extend the application of alanine dosimetry at therapy-levels and establish NPL as a world-leading centre in this field by contributing to the definition of reference conditions for IMRT dosimetry and improve understanding of small field and IMRT dosimetry. The development of a calorimeter specifically for IMRT will result in a unique instrument enabling the direct measurement of absorbed dose resolving much of the uncertainty which is in at present associated with these measurements.

The sub-projects on proton beams will lead to improved consistency in proton therapy delivery and maintain NPL's world-leading expertise in clinical proton beam dosimetry. They will result in improved data on perturbation correction factors for ionisation chambers and other detectors, improved interaction data providing a more robust foundation for international protocols for proton dosimetry and improved understanding of scanned proton beam dosimetry resolving much of the present associated uncertainty. These sub-projects will substantially contribute to an upgrade of IAEA TRS-398, an IAEA Coordinated Research Project on Nuclear Data of Charged-Particle Interactions for Medical Therapy Applications and new technology (laser induced proton beams) which will have a wide impact on reference dosimetry, relative dosimetry, treatment planning and imaging.

Novel radiotherapy techniques such as IGRT, 4D therapy, in vivo-dosimetry and grid-therapy are high profile emerging technology and the sub-project in this field will further develop NPL dosimetry capability in parallel with emerging radiotherapy techniques and provide dosimetry solutions.

Sub-projects & Products	
D4.1	**Small-field dosimetry**
P1	A validated protocol for traceable absorbed dose measurement in small fields.
P2	Pilot audit of user measurements in small fields.
P3	Evaluation of alternative routes to provide a service to the user community.
D4.2	**IMRT reference dosimetry**
P1	An agreed definition of valid reference conditions under which dosimetry standards can be compared and disseminated to users making measurements in IMRT fields.
P2	Developed alanine dosimetry service with better uncertainty
P3	Postal alanine audit and report offered to each UK radiotherapy department, including treatment planning systems and IMRT.
D4.3	**Small field and IMRT calorimeter**
P1	Design requirement identified for small field & IMRT calorimeter

DOSIMETRY	
D4	**New healthcare applications**
P2	Calorimeter design completed, based on identified requirements and modelling
P3	Prototype calorimeter built and tested
P4	Publication of results of measurements made using the prototype calorimeter in an IMRT beam
D4.4	**Clinical proton beam dosimetry**
P1	Improved perturbation correction factors for ionisation chambers and other detectors in proton beam dosimetry.
P2	Identification and investigation of dosimetry problems in scanned proton beams
P3	Contribution to laser-induced proton beam dosimetry
D4.5	**Nuclear interaction data for protons**
P1	Attenuation-experiment with Clatterbridge Centre of Oncology.
P2	Attenuation-experiment in a high-energy proton beam.
P3	Calculation of ionisation chamber perturbation due to nuclear interactions.
D4.6	**Dosimetry for novel radiotherapy techniques**
P1	Review of novel radiotherapy techniques in clinical use in the UK and study of the underlining physics and dosimetry issues.
P2	Investigation into the most suitable instrumentation for dosimetry for such techniques.
P3	Recommended generic measurement procedure for accurate dosimetry for such techniques.

<table>
<tr><th colspan="3">DOSIMETRY</th></tr>
<tr><td>D5</td><td colspan="2">Industrial dosimetry</td></tr>
<tr><td colspan="3">User Communities:

Radiation Processing Industry, Healthcare, Defence and Security.</td></tr>
<tr><td colspan="2">Needs:

There is a need to develop and disseminate standards of absorbed dose at industrial dose levels in order to meet the requirements of the EU Medical Devices Directive, UK/EU Food Irradiation Regulations and FDA regulations.

Over 50% of single-use medical devices used in the UK are sterilised by ionising radiation, using both Co-60 and electron beam sources. Innovation in, for example, the use of cryogenic irradiation and “in-line” low energy electron beam and x-ray sources is driving a need for enhanced dosimetry techniques. Mathematical modelling of dose distributions in industrial irradiation processing is a rapidly developing field that is building on techniques developed in the radiotherapy and primary standards areas.

Radiation hardness testing of electronic devices is needed in the defence and aerospace industries and requires specialist irradiation and dosimetry techniques, particularly with respect to the rise time and spectra of pulsed electron beam irradiations.</td><td>Potential Collaborators:

• Industry associations (Panel on Gamma and Electron Irradiation)
• Risø National Laboratory, Denmark
• Industrial irradiation plant operators - access to large-scale facilities for experimentation.</td></tr>
<tr><td colspan="3">Expected Impact:

Provision of standards and services necessary for compliance with UK, EU and FDA regulations for the sterilisation of medical devices and the irradiation of foodstuffs.

Facilitation of innovative industrial processes by, for example, the development of dosimetry techniques required for cryogenic irradiations and low energy (100 keV) electron and x-ray irradiations.

Provision of enhanced facilities and dosimetry techniques for the radiation hardness testing of electronic devices.

Specific impact areas:

D5.2 P2 Extension of the alanine mailed reference dosimetry service to include correction factors for cryogenic irradiations.

D5.3 P1 Absolute calorimetric measurements in high dose rate industrial electron beam plants that will validate the use of alanine under those conditions and provide a direct link to the primary standards operating at lower dose rates.

D5.3 P2 A new primary standard for low energy (100 keV) electron beams will reduce uncertainties to the level required for processes such as surface sterilisation. (Work will be undertaken in collaboration with Risø National Laboratory, Denmark.)

D5.4 P1, P2 The efficiency of industrial radiation processing and the potential to treat novel products will be enhanced by the development of validated mathematical modelling codes based on techniques developed under previous NMS programmes for smaller scale applications.</td></tr>
</table>

DOSIMETRY	
D5	**Industrial dosimetry**
Sub-projects & Products	
D5.1	**Provision and development of high dose (industrial) irradiation standards**
P1	Provide calibrated high dose ^{60}Co and high-energy electron beam irradiation fields with traceability to NPL primary standards.
P2	Maintain three self-shielded ^{60}Co irradiators.
P3	Undertake preparatory work necessary for re-sourcing Gammacell irradiator in late 2010 / early 2011, including securing new long-term supply of ^{60}Co.
P4	Conduct regular comparisons of high dose standards with other NMIs.
P5	Optimise LinAc short pulse performance (rise time, spectrum) for radiation hardness studies.
D5.2	**Provision and development of high dose (industrial) reference dosimeters and services**
P1	Provide on-demand mailed reference dosimetry services to radiation processing industry with UKAS accreditation.
P2	Extend dose range, operating temperatures and applicable radiation qualities for reference dosimetry services.
P3	Replace obsolete hardware and software related to alanine/EPR equipment.
D5.3	**Development of industrial dosimetry standards**
P1	Perform absolute calorimetry measurements in industrial electron beam irradiators to validate the response of reference dosimetry systems under these conditions.
P2	Develop 2nd generation primary calorimeters for low energy (~100 keV) electron beam irradiation to reduce uncertainties to level required by industry. In collaboration with Risø National Laboratory, Denmark.
D5.4	**Development of mathematical modelling techniques for industrial irradiation facilities**
P1	Develop modified programs and front ends optimised for modelling dose distributions in industrial radiation processing plants. (In collaboration with industry associations.)
P2	Develop enhanced validation techniques, using both real time and static dosimetry methods, and carry out studies to validate the output of mathematical models in industrial irradiation plants. (In collaboration with industry associations).
D5.5	**Support for and collaboration with industrial dosimetry user groups**
P1	Actively participate in the work of industrial user groups, such as the Irradiation Panel.

DOSIMETRY	
D5	**Industrial dosimetry**
P2	Provide training on dosimetry and regulatory aspects of radiation processing.
P3	Develop software to implement uncertainty based statistical process control techniques in collaboration with industry associations.
P4	Provide dosimetry proficiency tests for industrial radiation processing.
P5	Revise NPL Report “Guidelines for the calibration of dosimeters for use in Radiation Processing”, CIRM 29, 1999.

<table>
<tr><th colspan="3">DOSIMETRY</th></tr>
<tr><td>D6</td><td colspan="2">Facilities</td></tr>
<tr><td colspan="3">User Communities:
Healthcare (Therapy & Diagnostic); Defence & Security; Energy (Power Generation); Manufacturing; Industrial Radiation Processing; Instrumentation and Test Laboratories; Safety (Radiation Protection).</td></tr>
<tr><td colspan="2">Needs:
• To provide electron and photon radiation fields to enable the rest of the Programme to be fulfilled and simulate fields in the user communities.
• LinAcs (Linear Accelerators) for primary standard reference dosimetry, calibration services, research and provision of electron and photon radiation fields. Enhance range of fields with clinical relevance.
• To provide x-ray beams covering Half Value Layers in the range from 0.024 – 20 mm Al.
• To provide a typical therapy ^{60}Co beam (Theratron facility) and ^{60}Co, ^{137}Cs and ^{241}Am sources of varying activities (Mainance facility) and develop facilities.
• To upgrade and maintain HDR Brachytherapy unit and develop method for checking anisotropy of HDR Brachytherapy sources. Maintain the facility used for calibrating ophthalmic applicators.
• There is a requirement to maintain, develop and calibrate equipment used on all of the facilities that underpins all of the work carried out by the group. This equipment includes secondary standards, voltage standards, current sources, micrometers, barometers, thermistors, thermometers etc.
• To maintain and enhance the modelling capabilities and facilities to support the increasing and diverse modelling requirements in the development of standards and facilities in Radiation Dosimetry.</td><td>Potential Collaborators:
• Hospitals, e.g. Royal Surrey Hospital, Guildford
• Other NMIs e.g. NRC Canada and PTB
• NMS SSfM-4 programme
• Technical System Limited</td></tr>
<tr><td colspan="3">Expected Impact:
• Vital for radiotherapy cancer care within the UK.
• Indirect impact on the delivery of accurate radiation dose to cancer patients especially on evolving treatment techniques making increased use of small fields.
• Will support the introduction of novel calorimetry techniques that will result in an adsorbed dose based protocol, leading to reduced uncertainty and improved dose delivery for brachytherapy patients.
• Indirect impact on the delivery of accurate radiation dose to cancer patients, on improved dosimetry for diagnostic x-rays and on ensuring safe working and living environments for thousands of employees and the general public
• Vital for operation of primary standards, calibration services etc and world standing of NPL radiation dosimetry group.</td></tr>
</table>

DOSIMETRY	
D6	**Facilities**

- The innovation impact is through the projects dependent on the existing and planned new facilities
- Support and development for the introduction of absorbed dose based brachytherapy calibrations.
- Extend the scope of Monte Carlo modelling to new applications in radiation transport

Specific impact areas:

- Essential underpinning for the vast majority of projects in Radiation Dosimetry
- Full utilisation of the NPL grid will enable comprehensive and complex radiation modelling to be carried out in all areas of Radiation Dosimetry that has not before been possible.

Sub-projects & Products	
D6.1	**Development and maintenance of existing LinAc**
P1	High-energy electron beams (6 MeV to 19 MeV) and high energy X-rays (6 MV to 19 MV).
P2	Quality assurance measurements to monitor beam qualities to ensure suitability for development of primary standards and calibration services.
D6.2	**New LinAcs**
P1	Acceptance of clinical LinAc
P2	Commissioned clinical LinAc for primary standards dosimetry
P3	Commissioned clinical LinAc for calibration services
P4	All other options of clinical LinAc commissioned e.g. treatment planning system, multi-leaf collimator, small fields, etc.
P5	Work instructions & local safety rules in place
P6	High-energy electron beams with specified energies
P7	High-energy x-ray beams with specified energies
P8	Quality assurance measurements to monitor beams to ensure suitability for development of primary standards, calibration services & research
P9	Robust research LinAc with quality assurance measurements to monitor beams to ensure suitability for development of primary standards, calibration services and research
D6.3	**Development and maintenance of x-ray facilities**
P1	X-ray facilities and the diagnostic and mammographic x-ray facilities developed and maintained.
P2	New 50 kV x-ray generator installed and commissioned.

DOSIMETRY	
D6	**Facilities**
D6.4	**Development and maintenance of source based facilities**
P1	Therapy facility (Theratron) developed and maintained for use in research, training and measurement services.
P2	Characterisation of new Theratron source.
P3	Protection facility (Mainance) developed and maintained for use in research, training and measurement services
D6.5	**Development and maintenance of HDR Brachytherapy and Beta Ray facilities**
P1	New upgraded brachytherapy unit.
P2	Source replacements for brachytherapy unit (6 during the 3 years).
P3	Measurement software for brachytherapy facility.
P4	New beta ray source calibration jigs.
P5	Quality assurance beta ray applicator
D6.6	**Maintenance and calibration of ancillary equipment**
P1	Maintained and calibrated equipment
P2	New equipment purchased and calibrated
D6.7	**Modelling to support standards and facilities**
P1	Full utilisation of the NPL grid for our modelling requirements for primary calorimetry and ionometry standards and facilities.
P2	Configuration, validation and acceptance testing of new releases (and upgrades) of Monte Carlo radiation transport codes needed by other subprojects.
P3	A report or paper investigating the propagation of uncertainties in Monte Carlo radiation transport simulations (in collaboration with the NMS Software Support for Metrology (SS*f*M-4) programme).
P4	A report or paper detailing investigations using a wall study chamber
P5	Capability to model X-ray tubes including full experimental validation of the models

<table>
<tr><th colspan="2">DOSIMETRY</th></tr>
<tr><td>D7</td><td>Dosimetry knowledge transfer</td></tr>
<tr><td colspan="2">User Communities:
Healthcare (Therapy & Diagnostic), Radiation Processing Industry, Safety (Radiation Protection).</td></tr>
<tr><td colspan="2">Needs:
Knowledge transfer on radiation dosimetry through communication with the user / customer and peer scientists. Particularly the healthcare and radiation processing user communities look to NPL to make authoritative contributions to national and international committees in their development of relevant standards, codes of practice and other guidance material. To be effective this requires NPL to maintain close links and an ongoing dialogue with these user communities. There is also a need for an authoritative source of technical advice on radiation dosimetry.

The Radiotherapy Standards Users' Group is a forum for those who are interested in the NPL's radiotherapy dosimetry services and enables members to: hear about and influence the dosimetry research programme; learn about measurement techniques, Regulations and Codes of Practice, and the use of dosimetry standards; exchange views on the calibration services offered; and learn about the radiation dosimetry facilities at the NPL.

Potential Collaborators:
• IPEM
• BIR
• CCRI
• Medical Physics users
• Industrial dosimetry users
• Radiation protection users
• Other NMIs
• IAEA</td></tr>
<tr><td colspan="2">Expected Impact:
Indirect impact on the delivery of accurate radiation dose to cancer patients, on improved dosimetry for diagnostic x-rays and on ensuring safe working and living environments for thousands of employees and the general public. These knowledge transfer activities are vital to ensure that there is continual engagement with the user communities, listening to their needs and responding to them with advice, guidance and other products from the theme.

Specific impact areas:
• P1 will support development of new or revised codes of practice, standards and guidance documents. In particular, a new code of practice on HDR brachytherapy and a guidance document on small field dosimetry are expected.
• P2 will provide a means for interacting directly with the radiotherapy community on relevant dosimetry issues and developments
• P3 will support production of papers and reports that promote the whole theme rather than just the results of an individual project
• P4 will support staff in the review of papers for appropriate national and international journals, providing an important mechanism both for professional development of the scientists and the dissemination of best measurement practice
• P5 will support visits to NPL for a wide variety of users
• P6 will support external visits by NPL staff to user organisations where appropriate
• P7 will support the provision of a responsive technical enquiry service, providing guidance and advice to industry, hospitals and other users in matters related to measurement</td></tr>
</table>

DOSIMETRY	
D7	**Dosimetry knowledge transfer**
• P8 and P9 will allow meetings to be attended and hosted which address the requirements of specific and appropriate user communities, for example those involved in radiotherapy, providing a mechanism for key results of the theme to be disseminated.	
Sub-projects & Products	
D7.1	**Dosimetry knowledge transfer**
P1	Active participation in national and international committees to develop standards, codes of practice etc relevant to radiation dosimetry (e.g. BSI, IPEM, BIR, CEN, ASTM, ISO, CCRI, IAEA).
P2	Radiotherapy Standards User Group meetings every 18 months.
P3	Publication of general papers and reports on radiation dosimetry: those not covered by technical projects in this theme
P4	Refereeing of papers for peer-reviewed journals relevant to radiation dosimetry
P5	Visits by users to the radiation dosimetry facilities and staff at NPL for training and advice
P6	Visits by NPL staff to users for training, advice and promotion of the programme
P7	Technical enquiry service on radiation dosimetry topics (providing initial response to each enquiry within 5 working days)
P8	Exhibit at two significant exhibitions within the 3 years, for promotion and awareness
P9	General presentations on radiation dosimetry at national and international meetings and attendance at key conferences for networking purposes: those not covered by technical projects in this theme

A.3. Neutron Metrology Theme

<table>
<tr><th colspan="3">NEUTRON METROLOGY</th></tr>
<tr><td>N1</td><td colspan="2">Primary neutron standards</td></tr>
<tr><td colspan="3">User Communities:
Healthcare (Dosimetry services), Defence & Security, Energy Production, Safety (Radiation Protection), Instrumentation and Test Laboratories.</td></tr>
<tr><td colspan="2">Needs:
There is a continuing and ever growing need for routine calibration and testing of all neutron measuring devices used, for example, in radiation protection, reactor control, safeguards, etc., in the nuclear industry, defence, around high energy accelerators, and for applications in national security. These are usually performed using radionuclide sources measured in the manganese bath, which is the primary standard for neutron source emission rate measurements.

The NPL manganese bath is one of a very small number worldwide. NPL has a formal agreement with PTB in Germany, and an informal agreement with AIST in Japan to provide traceability for neutron source emission rate standards in those countries.

Neutron detecting instrumentation is in many cases far from being fit for purpose so that facilities for investigating and type testing new and innovative devices are a very important capability for a UK NMI. These capabilities are provided by Van de Graaff accelerator, which can provide monoenergetic neutrons, thermal neutrons, and simulated workplace fields.</td><td>Potential Collaborators:
• Other NMIs, in particular the other two metrology labs in Europe (PTB and IRSN) who have similar facilities with whom we have a collaboration agreement
• AWE Aldermaston for 14 MeV standards
• Instrumentation firms for reactor instruments</td></tr>
</table>

NEUTRON METROLOGY	
N1	**Primary neutron standards**

Expected Impact:

- Confidence that radiation protection measurements for all persons in the UK who encounter neutron radiation fields are valid and traceable to national standards, for compliance with the Ionising Radiation Regulations.
- Type testing capabilities, which can give UK manufacturers a competitive advantage in proving the superior performance of their neutron measuring devices.
- Improved neutron dosimetry arising from the ability to characterise the performance of new instruments and dosemeters using the range of available neutron fields at NPL.

Specific impact areas:

- Access for users to a wider range of monoenergetic neutron fields for device investigation and type testing.
- Reduced uncertainty in the response of neutron measuring devices in the intermediate energy region.
- The ability to satisfy the requirement of IEC standard 61005 for over-range testing of neutron measuring devices.

Sub-projects & Products	
N1.1	**Maintenance of NPL radionuclide source standards**
P1	Neutron emission rate standards for all types of radionuclide neutron sources ranging from 10^3 to 10^9 neutrons per second.
P2	Radionuclide sources with accurately known emission characteristics for calibrations at NPL.
N1.2	**Improvements to radionuclide source standards**
P1	Peer-reviewed journal paper on recent improvements/developments to manganese bath facility. Implementation of any recommendations from the CCRI and CONRAD comparison exercises. Improved values for parameters used in the analysis of manganese bath measurements (e.g. pipe-time, transit time) from new measurements and/or Monte Carlo calculations.
P2	Improved values for the doses delivered to dosemeters on a phantom giving better agreement with the ICRU quantity personal dose.
P3	A more streamlined anisotropy measurement method, making more efficient use of the main bay and requiring less staff time
N1.3	**Validation and improvement of accelerator-based neutron standards**
P1	Neutron fluence and dose equivalent standards for: monoenergetic fast neutrons, thermal neutrons, and a simulated workplace field with predominantly intermediate energy neutrons.
P2	Improvements to the ways in which these standards are realised and delivered.
P3	Regular validation of 14 MeV standards at AWE

NEUTRON METROLOGY	
N1	**Primary neutron standards**
N1.4	**Extension of energy range of monoenergetic neutrons**
P1	Extension of monoenergetic fluence standards to energies below 50 keV
P2	Extension of monoenergetic fluence standards to energies above 15 MeV
N1.5	**Extension of current thermal neutron irradiation capabilities**
P1	Enlargement of the hole at the centre of the NPL thermal pile facility making it useable by larger devices. Characterization of the field in the enlarged hole in terms of: absolute fluence rate as a function of height in the hole, cadmium ratio, and gamma component).
P2	Investigation of the feasibility of using a radionuclide source to boost the thermal fluence in the central hole.
N1.6	**Utilisation of time-of-flight techniques**
P1	Better knowledge of contaminant components in the nominally monoenergetic neutron spectra from our targets.
P2	Correction factors for contaminant neutrons in monoenergetic fields.
P3	A test bed for high-resolution neutron spectrometers and for neutron / gamma discrimination systems.
P4	An accelerator target that produces a broad spectrum of neutron energies, allowing detector responses to be measured at a large number of energies simultaneously by time-of-flight.
N1.7	**Extension of intermediate energy and high intensity neutron standards**
P1	Knowledge of the angle dependence of the NPL simulated workplace field and improved knowledge of the energy spectrum thus making the field suitable for personal dosemeter calibrations and tests at intermediate neutron energies.
P2	A high dose rate neutron field for overload testing and checking of device alarm settings. Such a facility can be devised based on the neutron-producing target used for the simulated workplace field.
N1.8	**Maintenance of the Van de Graaff facility**
P1	Well-characterised charged particle beams available for neutron production or any other application requiring such beams with energies up to 3.5 MeV.
N1.9	**Development of the Van de Graaff and low-scatter facility**
P1	A new interlock system for the whole low-scatter area covering work with the accelerator and with radionuclide sources.
P2	An upgrade to the detector transport system in the low-scatter area.

NEUTRON METROLOGY	
N1	**Primary neutron standards**
P3	Upgrading of the vacuum system, many parts of which are more than 25 years old.
P4	An investigation of the production of low-energy deuteron beams.
P5	New mounting arrangements for novel detectors.
P6	Improvements to the gas handling system to reduce the loss of insulating gases from the accelerator tank.

<table>
<tr><th colspan="3">NEUTRON METROLOGY</th></tr>
<tr><td>N2</td><td colspan="2">Development and innovation in neutron metrology</td></tr>
<tr><td colspan="3">User Communities:
Healthcare, Defence and Security, Energy, Manufacturing, Safety, Instrumentation & Test Laboratories.</td></tr>
<tr><td colspan="2">Needs:
• A continued neutron spectrometry capability, in order to evaluate neutron doses correctly despite the rapid change of quality factor with energy. This is a capability that will be used within NPL and at workplaces where neutron fields are encountered.
• Improved reliability and usability of neutron spectrometers, particularly in problematic applications such as mixed n / γ fields, dosimetry around novel pulsed accelerators, or checking for illegal sources.
• Continued demonstration of the equivalence of NPL neutron standards to those of other national laboratories.
• Reliable dosimetry for aircrew and around high-energy radiotherapy facilities.
• Improved ways of coping with directional neutron fields, and with neutron dose meters that are calibrated for normal incidence but used in rotationally symmetric fields.
• Improvements to neutron EPDs (electronic personal dosemeters), to give more reliable real-time personal neutron dosimetry.</td><td>Potential Collaborators:
• NMIs.
• Universities (including Lancaster, Surrey, Liverpool, and Birmingham)
• Neutron instrument manufacturers (including BAE Systems, Centronics).
• MSSL, Selex, DSTL
• Airlines.
• Hospitals (including Queen Elizabeth Hospital, Maidstone).
• Health Protection Agency.
• Neutron users (Energy industry, MoD, AWE).
• Dosimetry service providers</td></tr>
<tr><td colspan="3">Expected Impact:
• Better dose measurements in complex fields (e.g. in nuclear power plants, around therapy facilities, and in aircraft exposed to cosmic rays). This is likely to reduce costs by reducing the need for precautionary action such as dose overestimates and operational restrictions.
• Improved security due to better ways of checking for contraband nuclear material.
•
• Improved radiation protection through increased use of real-time personal neutron dosimetry.

Specific impact areas:
• Improved safety and operational efficiency in nuclear power, radiotherapy and aviation.
• More useable and more reliable scanning instruments for homeland security.
• Benefit to UK plc in the area of instrument manufacture.</td></tr>
</table>

NEUTRON METROLOGY	
N2	**Development and innovation in neutron metrology**
Sub-projects & Products	
N2.1	**Maintenance and regular checks of spectrometers**
P1	A suite of reliable, well-characterised spectrometers that is available at short notice for use in-house or for external customers.
P2	A programme of gradual replacement of obsolescent electronics.
N2.2	**Spectrometer developments**
P1	New response matrices for the NPL NE213 spectrometers.
P2	Maintenance of the SpectBib library of neutron spectra to keep it up-to-date.
P3	Refurbishment of the existing ^{3}He gridded ion chamber spectrometer, in support of sub-project N 1.7 (high intensity fields).
P4	A review of how to make the best use of available detection and data handling technologies (including digital signal processing) in neutron spectrometers.
P5	A prototype spectrometer demonstrating novel technologies and their advantages.
N2.3	**Comparisons and demonstration of equivalence**
P1	Completion of CCRI thermal neutron comparison.
P2	Completion of CCRI evaluation of source emission rate comparison (circulated Am-Be source).
P3	Completion of EURAMET survey instrument calibration comparison
P4	Participation in other comparison exercises organized by CCRI Section III over the period of the programme.
P5	Maintenance of UKAS accreditation.
N2.4	**Capabilities for cosmic ray and high energy dosimetry**
P1	Expansion of NPL's solar flare dose monitoring service (Flarewatch), including supporting calculations, in time for the peak in solar activity.
P2	Maintain capability for high energy, mixed field dosimetry using TEPCs, including support for MSSL project to develop permanently installed in-flight TEPC (in conjunction with SELEX)
N2.5	**Capabilities for neutron dosimetry in the Healthcare sector**
P1	An improved method of measuring neutron dose in intense photon fields.
P2	An advisory service/good practice guide on maze design and measurement techniques.

NEUTRON METROLOGY	
N2	**Development and innovation in neutron metrology**
P3	A fully characterised miniature TEPC capable of measuring neutron and photon dose in therapy fields.
N2.6	**Measurement of the angle dependence of dose equivalent in workplaces**
P1	A feasibility study into developing a suitable instrument.
P2	The development of the above instrument.
N2.7	**Neutron personal dosemeter angle dependence of response**
P1	Compare personal dosemeter responses measured in unidirectional and multidirectional neutron fields.
P2	Publish above work in peer-reviewed journal.
N2.8	**Feasibility study of novel electronic personal dosemeters**
P1	A feasibility study into developing a suitable instrument, possibly based on organic semiconductors.
P2	Investigation into pulse-shape analysis of silicon-based semiconductors as a potential dosimetric tool.

<table>
<tr><th colspan="3">NEUTRON METROLOGY</th></tr>
<tr><td>N3</td><td colspan="2">Neutron theme knowledge transfer</td></tr>
<tr><td colspan="3">User Communities:

Healthcare; Defence & Security; Energy; Environment; Manufacturing; Radiation Processing Industry; Safety; Instrumentation and Test Laboratories.</td></tr>
<tr><td colspan="2">Needs:

The presence of neutron radiation in various environments, e.g. the nuclear industry, aircraft flight altitudes, MoD facilities, around radionuclide neutron sources and around high energy accelerator facilities, requires specialist knowledge and good practice to measure and minimise exposure. This can only be achieved by keeping the community informed of best practice, by identifying current and future issues within that community and by providing an authoritative source of technical advice on neutron metrology.

Evidence for the above nee can be found in the attendance at the Neutron Users' Club. A few years ago this was of the order of a dozen, but over the last couple of years has been between 40 and 50.

There is strong evidence that end users and those responsible for interpreting results from neutron area survey measurements require guidance on the properties of these devices and the correct way to use them. Inappropriate use of these devices can lead to incorrect dose measurements, which may become a safety issue, and time wasted trying to understand conflicting results.</td><td>Potential Collaborators:

• User community (co-authorship of GPG)
• Instrument manufacturers
• Health physicists</td></tr>
<tr><td colspan="3">Expected Impact:

The primary impact of this project is in improving quality of life. Regular meetings of the user community allow the dissemination of good practice in a number of areas, often from within the community itself, from issues with instrument responses to problems with computer simulation codes. Work on new standards and output from advisory groups can impact on the content of future regulations. The provision of a technical enquiry service allows NPL insight into problems facing industry, and to provide advice and/or solutions.

Improved awareness of issues relating to the measurement of, and exposure to, neutron radiation means more reliable personal dosimetry.

Specific impact areas:

N3.1 will provide a means for interacting directly with the neutron user community on relevant metrology issues and developments. The community have frequently stated that the NPL Neutron Users' Club is important because it is the only forum in the UK for discussing neutron matters.</td></tr>
</table>

NEUTRON METROLOGY	
N3	**Neutron theme knowledge transfer**

In N3.2:

- P1 will support development of new or revised standards and guidance documents.
- P2 will support the provision of a responsive technical enquiry service, providing guidance and advice to industry, hospitals and other users in matters related to measurement
- P3 will support visits to NPL for a wide variety of users
- P4 will support external visits by NPL staff to user organisations where appropriate
- P5 will support production of papers and reports that promote the whole theme rather than just the results of an individual project
- P6 will support staff in the review of papers for appropriate national and international journals, providing an important mechanism both for professional development of the scientists and the dissemination of best measurement practice
- P7 will allow meetings to be attended that address the requirements of specific and appropriate user communities, providing a mechanism for key results of the theme to be disseminated.

In N3.3:

- P1 and P3 will provide better understanding of the correct use and interpretation of neutron area survey meters, improving safety and saving time, effort and money.
- P2 will provide better understanding of the characteristics of certain novel neutron-measuring devices. It will provide feedback to manufacturers and raise awareness in the user community of the positive and negative aspects of these devices, enabling manufacturers to produce better instruments in the future.

Sub-projects & Products	
N3.1	**Meetings of the Neutron User community**
P1	Annual meeting of the neutron user community.
N3.2	**Neutron theme knowledge transfer activities**
P1	Active participation in Standards Committees (ISO, IEC, etc.), EURAMET working groups, governmental and international advisory groups.
P2	Technical enquiry service on neutron metrology topics (providing initial responses to each enquiry within 5 working days).
P3	Visits by users to the neutron metrology facilities and staff at NPL for training and advice
P4	Visits by NPL staff to users for training, advice and promotion of the programme
P5	Publication of general papers and reports on neutron metrology: those not covered by technical projects in this theme
P6	Refereeing of papers for peer-reviewed journals relevant to neutron metrology

NEUTRON METROLOGY	
N3	**Neutron theme knowledge transfer**
P7	General presentations on neutron metrology at national and international meetings and attendance at key conferences for networking purposes: those not covered by technical projects of this theme
N3.3	**Developing good practice in the use of neutron survey instruments**
P1	Produce Good Practice Guide on use of area survey meters
P2	Characterise and publish response data for new neutron survey instruments
P3	Organise workshop on use of area survey meters

A.4. Radioactivity Theme

<table>
<tr><th colspan="3">RADIOACTIVITY</th></tr>
<tr><td>R1</td><td colspan="2">Primary Measurement Standards and Systems</td></tr>
<tr><td colspan="3">User Communities:
Healthcare; Defence & Security; Energy; Environment (including Decommissioning); Manufacturing; Radiation Processing Industry; Safety (Radiation Protection); Instrumentation and Test Laboratories.</td></tr>
<tr><td colspan="2">Needs:
Compliance with the Mutual Recognition Arrangement (MRA) meets NPL’s obligations to link radioactivity measurements in the UK to the international measurement system. The equipment & methods for primary standardisations underpin the NMS.
This project involves improving and extending primary counting systems to enable the standardisation of new radionuclides required by the user community and to improve accuracy and the range of radionuclides standardised for the MRA.
Improvements involve, for example, increasing counting efficiency on detectors, employing “new” techniques to have alternatives to the more classic methods, and upgrades to existing software. A reduction in staff time and more reliable measurements can also be achieved by increasing the use of digital methods.
Standardisations are currently performed on a variety of matrices, such as solutions and gases. There is a recognised need to develop new primary standardisation methods for radioactive aerosols as they form the major mechanism of inhalation dose, both in nuclear applications (Plutonium) and for natural radioactivity (Radon daughters).
Part of the improvement of primary standards comes from the use of consistent set of nuclear decay data (half lives, and photon and particle emission probabilities). Currently users in the UK and overseas use different decay data for certain important radionuclides and there is a need to harmonise.</td><td>Potential Collaborators:
• BIPM and other NMIs
• Universities
• Instrumentation companies
• Specialist consultants
• Regulators
• Other government bodies</td></tr>
<tr><td colspan="3">Expected Impact:
• Compliance with the Ionising Radiations Regulations (radiation protection of workers) and the Radioactive Substances Act (protection of the public and the environment)
• Metrology in a field of high public visibility and concern
• Sustained recognition in the international community via compliance with the MRA.</td></tr>
</table>

RADIOACTIVITY	
R1	**Primary Measurement Standards and Systems**
Specific impact areas: Techniques for digital signal processing may be exploited by instrumentation companies to replace expensive analogue systems. Reports from consultation meetings indicate that time is being spent in the nuclear industry attempting to resolve measurement discrepancies that are eventually traced to differences in the nuclear decay data used. Radon is the largest component of the dose to the UK population, and the only one where it is possible at present to identify a segment of the community which suffers early death as a consequence.	
Sub-projects & Products	
R1.1	**Compliance with the Mutual Recognition Arrangement**
P1	Results submitted to BIPM for Key Comparisons (1 or 2 per year, to BIPM timetable)
P2	Submission of primary standards to the SIR system
P3	Extension of SIR system to short-lived radionuclides and beta-emitting radionuclides
R1.2	**Development and validation of methods for primary standards of radioactivity**
P1	Replacement high-pressure proportional counter (including digital coincidence counting)
P2	Standardisation of 'difficult' radionuclides (^{55}Fe and ^{63}Ni) by TDCR including development of analysis software
R1.3	**Development of digital counting techniques**
P1	New software implementing extending dead-time systems for coincidence counting
P2	Implementation of digital methods for anti-coincidence counting and correlation counting
R1.4	**Nuclear decay data evaluations**
P1	Decay data for ^{232}U, ^{231}Pa and ^{228}Ac provided for the IAEA Co-ordinated Research Programme
P2	Provision of an advice service
P3	Publication on the web of NPL recommended decay data
P4	Publication of decay data in a format compatible with commercial γ spectrometry systems
1.5	**Feasibility studies for new primary standards**
P1	Report on novel detector materials and applications in metrology
P2	Report on the recommended approach to establishing a UK primary standard for radioactive aerosols

RADIOACTIVITY	
R1	**Primary Measurement Standards and Systems**
1.6	**Primary standards for radioactivity-in-gas**
P1	Standardised tritium cylinders (to replace stock)
P2	Validated tritium cylinders as reference materials (investigation of issue of trapped tritium in steel)
P3	Optimised systems and procedures for rig operation
P4	Validated primary standards (e.g. ^{85}Kr)
1.7	**Radon metrology**
P1	Radon primary and secondary standards

<table>
<tr><th colspan="3">RADIOACTIVITY</th></tr>
<tr><td>R2</td><td colspan="2">Infrastructure for Secondary Measurement Standards of Radioactivity</td></tr>
<tr><td colspan="3">User Communities:
Healthcare; Defence; Security; Energy; Environment (including Decommissioning); Manufacturing; Radiation Processing Industry; Safety (Radiation Protection); Instrumentation and Test Laboratories.</td></tr>
<tr><td colspan="2">Needs:
The equipment and methods for secondary standards enable primary standards to be disseminated to the user communities.
Many of the needs are internal to other projects within the Radioactivity theme and include:
The production of high quality sources to underpin the work
Reduction of problems arising from source preparation.
Increasing throughput.
Supply of chemically pure carriers and radiochemicals.
In addition, external needs include:
Dissemination of secondary standards.
Demonstration of agreement between NMIs and other national and international laboratories on the measurement of Tritiated water.
Dissemination of advice and best practice in correcting for true coincidence (cascade) summing in high-resolution γ-ray spectrometry in order to reduce measurement bias.
Demonstration that the measurement standards and reference materials generated, maintained and disseminated by of the Radioactivity Metrology Group are compliant with ISO Standards 9001:2000 and 17025:2005, as well as ISO Guides 34:2000 and 43:1997 (Part 1).</td><td>Potential Collaborators:
Other NMIs and BIPM
Imperial College Reactor Centre,
University of Birmingham Cyclotron facility,
Delft University of Technology,
Nuclear Research Centre, Rež</td></tr>
<tr><td colspan="3">Expected Impact:
Provision of metrology infrastructure and measurement traceability in a field of high visibility and concern within the UK Healthcare, Defence, Security, Energy, Environment, Decommissioning, Manufacturing, Radiation Processing, Safety, Instrumentation and Test Laboratories sectors in order to be able to demonstrate compliance with the statutory legislation and site licensing, including the Ionising Radiations Regulations and the Radioactive Substances Act.
This enhances the ability of UK companies active in these sectors to compete in the world market</td></tr>
</table>

RADIOACTIVITY	
R2	**Infrastructure for Secondary Measurement Standards of Radioactivity**
Specific impact areas: Internally, work in this project facilitates provision of other projects in order to realise other measurement standards and reference materials to the UK (and other) markets UKAS Accreditation for calibration, testing, proficiency test provision and reference material production further enhances the quality of radioactivity measurement within the UK Organisation of, and participation in the proposed Tritiated water comparison would underpin measurements of Tritiated water both nationally and internationally. Furthermore, since Tritium measurement is the basis of the CIEMAT/NIST secondary standardisation technique, this further enhances the provision of pure β particle emitting radionuclides	
Sub-projects & Products	
R2.1	**Development and Validation of Methods for Secondary Standards of Radioactivity**
P1	Calibrated gamma spectrometers
P2	Validated ionisation chambers
P3	Validated large area reference source counter
P4	Calibrated support equipment (e.g. balances)
R2.2	**Upgrade of source preparation facilities**
P1	Upgraded source preparation laboratory
P2	Software for the data collection and analysis for source preparation
R2.3	**True summing corrections for γ-ray spectrometry (cascade summing)**
P1	Modelled and validated total efficiency calibration curve for environmental γ-ray spectrometers
P2	Implemented and tested true summing correction factors for NPL γ-ray spectrometers
P3	Published Good Practice Guide on 'True Summing Corrections for Environmental γ-ray Spectrometry'
R2.4	**Radiochemical Support to Radioactivity and Neutron Team**
P1	Ensure stocks of carriers and other chemicals are maintained throughout the programme
P2	Respond flexibly and in a timely manner to requests from the Radioactivity and Neutron Team
P3	Preparation of targets for irradiation when required for radionuclide production
P4	Work with Neutron Metrology Group to carry out low flux irradiations at NPL

RADIOACTIVITY	
R2	**Infrastructure for Secondary Measurement Standards of Radioactivity**
P5	Identify and build working relationship with neutron and charged particle irradiation facilities (cover loss of Imperial College Reactor and Hammersmith Cyclotron Unit)
P6	If necessary, work with Neutron Metrology Group on alternative for ^{56}Mn production
P7	Maintain facilities, resources and expertise to realise products P1 to P6
R2.5	**International comparison of Tritiated water**
P1	Preparation of participant sources
P2	Distribution of sources
P3	Collation and analysis of data
P4	Publication of comparison report and paper
R2.6	**Enhancement of ionisation chamber systems**
P1	Automatic sample-changing system to speed data collection and save costs
P2	Method to ensure high-accuracy stability tests of system for long term, replacing fragile ^{226}Ra check sources that can no longer be produced
P3	A resistive feedback electrometer to improve accuracy of measurement of high currents to assay high activity sources
P4	Automatic range-changing electrometer to avoid errors due to operator error
R2.7	**Maintenance and Extension of UKAS Accreditation**
P1	Maintain LRQA registration to ISO 9001:2000 at twice-yearly surveillance visits.
P2	Maintain and extend UKAS accreditation to ISO 17025:2005 at annual surveillance visits, updating and generating new procedures as required.
P3	Maintain UKAS accreditation to ISO Guide 43-1 at annual surveillance visits, updating and generating new procedures as required.
P4	Achieve UKAS accreditation to ISO Guide 34:2000 in 2008, and maintain accreditation at annual surveillance visits, generating new procedures as required

<table>
<tr><th colspan="3">RADIOACTIVITY</th></tr>
<tr><td>R3</td><td colspan="2">Provision of measurement infrastructure for nuclear medicine</td></tr>
<tr><td colspan="3">User Communities:
Healthcare (approximately 250 hospitals); Manufacturing (radiopharmaceutical producers - e.g. GE Healthcare, Alliance Medical, Pet-Net); Instrumentation and Test Laboratories</td></tr>
<tr><td colspan="2">Needs:
Traceability to the SI system for assays of radioactivity content of radiopharmaceuticals for regulatory compliance (cGMP and ARSAC certification). This project therefore includes the provision of primary standards and studies of current measurement problems.
Support for accurate patient dosimetry for novel cancer treatments using targeted radionuclide therapy.
The continued provision of best practice to the nuclear medicine community.
Being responsive to the needs of the user community for radionuclide measurement.</td><td>Potential Collaborators:
• Other NMIs
• Key UK Cancer treatment centres
• Medical device manufacturers
• Regulatory bodies
• IPEM
• Royal Marsden Hospital
• University Hospital Ghent, Belgium
• Other potential Framework 7 partners</td></tr>
<tr><td colspan="3">Expected Impact:
The introduction of new radiopharmaceuticals relies on accurate knowledge of the radiological properties of the drug. Primary standardisations will facilitate the acceptance of such developments, and optimisation of administered doses.
The dissemination of best practice encourages compliance with regulations (GMP for manufacturing, conditions of ARSAC licences for clinics), and increases the overall quality of the process.
Better quality assurance in Nuclear Medicine departments, leading to more accurate dispensing of radiopharmaceuticals, thus minimising unnecessary patient dose.
In an increasingly international field, extension of our capability helps the UK to demonstrate that it is at the forefront of patient care.

Specific impact areas:
Supports Government initiatives in cancer diagnosis (e.g., expansion of PET) and treatment.</td></tr>
</table>

RADIOACTIVITY	
R3	**Provision of measurement infrastructure for nuclear medicine**
Sub-projects & Products	
R3.1	**Nuclear medicine - developments**
P1	Primary standards of radionuclides used in nuclear medicine (e.g., ^{177}Lu, ^{111}In)
P2	New measurement service for ^{125}I brachytherapy seeds
P3	Validation of correction factors for ionisation chambers (the use of Cu-filters to improve accuracy of measurements of particular radiopharmaceuticals)
P4	A recommended electronic method to check the linearity of electrometers used on ionisation chambers
P5	Extended availability of calibration figures for NPL ion chamber for non-standard geometries and short lived isotopes
R3.2	**Nuclear medicine – Targeted radionuclide therapy**
P1	A report on quantification of images from nuclear medicine scans
R3.3	**Nuclear medicine – Knowledge Transfer**
P1	Two meetings of the Radionuclide Calibrators User Forum
P2	Revised Measurement Good Practice Guide on *Protocol for Establishing and Maintaining the Calibration of Medical Radionuclide Calibrators and their Quality Control*
P3	Development of web-based information system for the quality control of radionuclide calibrators
P4	Presentations at conferences and attendance at IPEM committee meetings

<table>
<tr><th colspan="2">RADIOACTIVITY</th></tr>
<tr><td>R4</td><td>Infrastructure for Environmental Radioactivity Standards</td></tr>
<tr><td colspan="2">User Communities:

Defence; Security; Energy (environmental monitoring of radioactivity); Environment (including Decommissioning); Instrumentation and Test Laboratories.</td></tr>
<tr><td colspan="2">Needs:

The user community make use of a wide range of instrument calibration standards, yield tracers and reference materials to:

• assure the quality of their work,
• demonstrate traceability to the appropriate primary standards,
• validate new procedure and
• demonstrate the quality of their data to their customers

Calibration standards for various single and mixed nuclides are required by users for accurate and rapid calibration of instruments used for sample measurement. Reference materials are required for radiochemical process validation as well as instrument calibration.

Such standards are usually supplied in aqueous solution, but this does not reflect the wide range of matrices encountered in practice and so the need is to augment aqueous based standards with standards and reference materials in other matrices that match the range of solid samples that environmental laboratories usually measure in both composition or density.

Underpinning this is the provision of primary standards for radionuclides needed for environmental monitoring.

Proficiency tests enable measurement laboratories to provide direct and straightforward evidence that their analytical and measurement systems are capable of producing the correct results to internal customers, UKAS and their funding bodies. In practically all cases, internal and external auditing runs on a yearly basis and thus aligning PT schemes with auditing cycles is to the advantage of testing laboratories and their clients.

User forums and GPGs are a recognised way of disseminating good practice within, and gaining feedback from the user community.</td><td>Potential Collaborators:

• Imperial College Reactor Centre (Ascot)
• Rež Cyclotron unit, Czech Republic
• University of Birmingham Cyclotron Unit
• Reactor Institute Delft (RID), Netherlands
• The High Flux Reactor (HFR) in Petten</td></tr>
<tr><td colspan="2">Expected Impact:

The provision of suitable matrix and/or density matched reference materials and calibration sources enables users to make better, more accurate measurements of samples. This leads to more confidence on the part of regulators and other stakeholders that radioactive materials have been well managed.</td></tr>
</table>

RADIOACTIVITY	
R4	**Infrastructure for Environmental Radioactivity Standards**
Specific impact areas: Better assessment of population dose Improved compliance with statutory discharge limits More accurate sentencing of radioactive waste arising from normal operations, as well as decommissioning the UK nuclear legacy, leading to reduced costs and better utilisation of the limited low-level waste facilities available.	
Sub-projects & Products	
R4.1	**Development of a solid standard for calibration of γ spectrometers**
P1	Issue of solid matrix mixed radionuclide standard (bi-annually)
R4.2	**Provision of low-level standards for environmental applications**
P1	Issue of aqueous matrix mixed radionuclide standard (bi-annually)
P2	One issue of natural Uranium aqueous standard
P3	Maintain capability to issue organically bound tritium standards
P4	One issue of Polonium chemical yield tracer (^{208}Po or ^{209}Po)
P5	One issue of aqueous ^{241}Pu standard
P6	One issue of aqueous ^{227}Ac standard
R4.3	**Primary standards for environmental applications**
P1	Primary standard of ^{208}Po or ^{209}Po for use in sub-project R4.2
P2	Primary standard of ^{241}Pu for use in sub-project R4.2
P3	Primary standard of ^{227}Ac for use in sub-project R4.2
R4.4	**Development of non-aqueous reference materials for radioactivity monitoring**
P1	Decision on which matrices and radionuclides to provide
P2	Production and certification of first reference material
P3	Production and certification of second reference material
P4	Technical paper submitted to Applied Radiation and Isotopes, and at suitable meetings.
R4.5	**Annual Environmental Radioactivity Proficiency Tests**
P1	Preparation of participant sources (annually)

RADIOACTIVITY	
R4	**Infrastructure for Environmental Radioactivity Standards**
P2	Distribution of sources (annually)
P3	Collation and analysis of data (annually)
P4	Organisation of follow up meeting (annually)
P5	Publication of report (annually)
P6	Technical paper submitted to Applied Radiation and Isotopes, and at suitable meetings
R4.6	**Environmental Knowledge Transfer**
P1	Deliver user forum on environmental measurement matters (annually)
P2	Deliver user forum on site operation measurement matters (annually)
P3	Publish Good Practice Guide on sampling techniques for environmental and other measurements, utilising current statistical practice

RADIOACTIVITY	
R5	**Measurement infrastructure for radiation protection**

User Communities:

Defence & Security, Energy; Environment (including Decommissioning), Manufacturing; Safety (Radiation Protection), Radiation Processing Industry, Instrumentation and Test Laboratories, and Healthcare (Hospitals and Cyclotron Units) plus Regulators.

Needs:

This project is aimed at providing traceability for those radioactivity measurements that underpin estimates of occupational or public doses. It addresses six specific areas:

1. Provision of UK primary standards for large area photon-emitting reference sources in compliance with ISO8769 part 2. (Note: this work is carried out AWE Aldermaston under separate contract). These standards are used to calibrate and test surface contamination monitors for photon-emitting radionuclides.
2. Provision of advice on best practice for radiation metrology for compliance with the Ionising Radiation Regulations.
3. Reported activities on air filters and surface wipes are generally based on measurements of surface emission. The relationship between surface emission and activity is complicated when dealing with porous materials. This project aims to investigate this relationship.
4. The accurate measurement of airborne Tritium is essential in calculating occupational radiation exposures. This radionuclide is often measured using ionisation chambers, but airborne Tritium may exist as a gas (HT) or a vapour (HTO) and the response of ionisation chambers to these two forms is not known. If they were indeed different, that would reveal a need for a service for the calibration of Tritiated water vapour monitors.
5. The medical imaging technique Positron Emission Tomography (PET) is increasingly used in UK hospitals, and the associated cyclotron facilities are legally required to report activities of any stack discharges of gaseous positron emitters. To this end, NPL is already developing a primary standard for positron-emitters in gas, but a service for disseminating this standard to the user base is still needed.
6. It is not usually possible to accurately identify and determine α-emitting and β-emitting radionuclides directly in samples. Analysis usually requires lengthy chemical separations (typically several days) to extract the radionuclides of interest in a form suitable for assay. There is a need for very rapid analytical techniques for use following in-field measurements to facilitate the rapid and accurate sentencing of waste or following the explosion of a radiological bomb. A feasibility study of using nanotechnology for rapid or real time *in situ* radiochemical assays will address this issue.

Potential Collaborators:

- Speakers at Forums and contributors to Good Practice Guides are drawn from the user community (e.g. the nuclear industry, contractors, academia, hospitals)
- BIPM and other NMIs via the Consultative Committee (CCRI)
- Nuclear site operators
- Regulators
- Government departments
- Instrumentation companies
- Society for Radiological Protection
- Universities
- Radiation protection service companies

RADIOACTIVITY	
R5	**Measurement infrastructure for radiation protection**

Expected Impact:

The provision of the large-area reference source service would underpin compliance with the Ionising Radiations Regulations (regarding radiation protection of workers) and the Radioactive Substances Act (regarding protection of the public and the environment). This is a field of high public visibility and concern.

Knowledge Transfer, in the form of the IRMF and Good Practice Guides, will lead to better measurement of radiation throughout the UK and worldwide and better understanding of equipment limitations, leading to higher quality and lower cost of measurement. It will enable organisations to comply with the Ionising Radiations Regulations.

The filter/wipe project would lead to increased confidence in reported stack discharges and surface activities, resulting in improved knowledge of public exposure and a reduction in waste disposal costs. Similarly, the airborne Tritium project would result in greater confidence in doses to the public from this radionuclide.

The positron-in-gas service would underpin compliance with the Radioactive Substances Act and again ensure that discharges to the environment are accurately known. It would also be a world first for NPL – the first NMI to offer a calibration service of this type.

If successful, the technology arising from the rapid radiochemical assay project will inform decisions on actions to be taken by the emergency services following radioactive contamination. The technology may be patentable.

Sub-projects & Products	
R5.1	**Provision of photon emitting large area reference source standard**
P1	Maintenance of primary standards
P2	Replacement of obsolete equipment
R5.2	**Radiation Protection Knowledge Transfer**
P1	Continued provision of the Ionising Radiations Metrology Forum (bi-annually)
P2	Continued provision of the Airborne Radioactivity Monitoring Users' Group (annually)
P3	Further Good Practice Guides and updating of existing Guides to meet user requirements
P4	Co-ordinating IRMF comparison exercises
R5.3	**Comparison of true and apparent activities on stack discharge filters and surface wipes**
P1	Procurement of active filters and wipes along with data on exposure (e.g. weight gain, total air flow)
P2	Measurement of emission rate from monitoring and activity from radiochemical analysis
P3	Analysis of data and preparation of report

RADIOACTIVITY	
R5	**Measurement infrastructure for radiation protection**
P4	Dissemination to users (e.g. via presentations) and published paper
R5.4	**Assessment of response of instrumentation to Tritium gas in different chemical forms (HT and HTO)**
P1	Commissioning of HTO-vapour monitor calibrator
P2	Measurement of response to standardised HTO
P3	Measurement of response to standardised HT
P4	Analysis of data and preparation of report with recommendations
R5.5	**Establish calibration service for positron-in-air monitors**
P1	Visit users to identify required specification for transfer instrument and dissemination procedure
P2	Develop suitable instrument
P3	Calibrate against primary standard
P4	Trial dissemination method
P5	Introduce measurement service
R5.6	**Feasibility study of using nanotechnology for rapid radiochemical assays**
P1	Report on opportunities to use micro-fluidic systems for the rapid assay of radioactivity in samples
P2	Results from experimental trials
P3	Review of existing methods

<table>
<tr><th colspan="3">RADIOACTIVITY</th></tr>
<tr><td>R6</td><td colspan="2">Measurement Infrastructure for Nuclear Decommissioning</td></tr>
<tr><td colspan="3">User Communities:

Energy (nuclear power) and Environment (Decommissioning).</td></tr>
<tr><td colspan="2">Needs:

The accurate assay of the radioactivity content of waste materials arising from site decommissioning is of public concern and has significant economic implications. Accepted best practice for clearance and sentencing of materials produced during decommissioning of nuclear facilities is provided by the Nuclear Industry Code of Practice on Clearance and Exemption Principles, Processes and Practices (NICoP), which also provides guidance on compliance with relevant legislation such as the Radioactive Substances Act. This project will address four current, specific needs for metrology support, and this will help users comply with the NICoP and the legislation. They are:

• Certified Reference Materials for the calibration or testing of instrumentation used to assay the radioactivity content of materials prior to disposal

• Advice on best practice in using mathematical modelling to assay the radioactivity content of materials prior to disposal

• The need for a rigorous but simple approach to estimating Minimum Detectable Activities. A new ISO standard (11929, parts 1 to 8) on estimating Minimum Detectable Activities has recently been published; however, the approach uses Bayesian statistics and interpreting the standard is proving difficult for users and regulators

• Advice on the use of surface contamination monitors used to assay the radioactivity content of materials prior to disposal</td><td><u>Potential Collaborators:</u>

• British Nuclear Group (BNG)
• Health Protection Agency (HPA)
• Nuclear Decommissioning Authority (NDA)
• Nexia Solutions
• Nukem
• United Kingdom Atomic Energy Authority (UKAEA)
• Other nuclear site operators, contractors and regulators</td></tr>
<tr><td colspan="3">Expected Impact:

This project would underpin:

• Compliance with the NICoP and the Radioactive Substances Act (supporting protection of the public and the environment)

• Metrology in a field of very high public visibility and concern

• Safety of the long term (i.e. millennia) disposal of radioactive waste

Additionally, accurate assay of the radioactivity content of waste materials enables more waste to be consigned with confidence to lower-activity waste streams, resulting in large economic benefits.

The project will support the NDA’s mission by improving standards of metrology. It will also support the DTI’s Sustainable Production and Consumption (SPC) initiative.</td></tr>
</table>

RADIOACTIVITY	
R6	**Measurement Infrastructure for Nuclear Decommissioning**
Sub-projects & Products	
R6.1	**Reference materials for nuclear decommissioning**
P1	Production and certification of the first Certified Reference Material
P2	Production and certification of the second Certified Reference Material
R6.2	**Mathematical modelling for decommissioning**
P1	NPL Good Practice Guide on the use of mathematical models to estimate the radioactivity content of waste materials
P2	Consultancy and audit service on the use of mathematical models
R6.3	**Knowledge Transfer for nuclear decommissioning**
P1	Attendance at joint industry NICoP Meetings
P2	Section of updated NICoP on use of Bayesian statistics
R6.4	**Evaluation of Surface Contamination Monitors for nuclear decommissioning**
P1	NPL Report and/or a journal paper on the characterisation of surface contamination monitors for responses to radioactivity in different materials

<table>
<tr><th colspan="2">RADIOACTIVITY</th></tr>
<tr><td>R7</td><td>Radioactivity Knowledge Transfer</td></tr>
<tr><td colspan="2">User Communities:

Healthcare, Defence & Security, Energy, Environment (including Decommissioning), Manufacturing, Radiation Processing Industry, Safety (Radiation Protection), Instrumentation and Test Laboratories.</td></tr>
<tr><td colspan="2">Needs:

Transfer of NPL knowledge in radioactivity metrology to the various user communities. In addition, policy makers and technical community influencers require support in promoting UK representation on the world stage for radioactivity metrology (e.g., providing invited presentations and contributions to IAEA publications).

The long-term maintenance of nuclear skills is a critical issue for the UK as outlined by the COGENT sector skills council in its recent analysis. There is, therefore, a continual need for the provision of authoritative advice on best practice relevant to nuclear skills, especially radioactivity metrology.

Potential Collaborators:

• Medical physics users
• Radiation protection users
• Instrument manufacturers
• Regulators
• Academics
• Other NMIs
• Nuclear site operators
• International bodies</td></tr>
<tr><td colspan="2">Expected Impact:

Minimisation of doses to patients through more accurate dispensing of radiopharmaceuticals. Better quality radioactivity measurements leading to better agreement between operators, regulators and stakeholders, and therefore greater public confidence. Propagation of good practice down to end users. Better prediction of project costs. Formation of mutual support networks. Earlier implementation of new techniques and developments in practice. Compliance with the Ionising Radiations Regulations (radiation protection of workers) and the Radioactive Substances Act (protection of the public and the environment).

Specific impact areas:

• P1 will support development of new or revised standards and guidance documents.
• P2 will support production of papers and reports that promote the whole theme rather than just the results of an individual project
• P3 will support staff in the review of papers for appropriate national and international journals, providing an important mechanism both for professional development of the scientists and the dissemination of best measurement practice
• P4 will support visits to NPL for a wide variety of users
• P5 will support external visits by NPL staff to user organisations where appropriate
• P6 will support the provision of a responsive technical enquiry service, providing guidance and advice to industry, hospitals and other users in matters related to measurement
• P7 and P8 will allow meetings to be attended and hosted which address the requirements of specific and appropriate user communities, providing a mechanism for key results of the theme to be disseminated.</td></tr>
</table>

RADIOACTIVITY	
R7	**Radioactivity Knowledge Transfer**
Sub-projects & Products	
R7.1	**Radioactivity Knowledge Transfer**
P1	Active participation in national and international committees to develop standards, etc relevant to radioactivity metrology (e.g. ICRM, AIWG, CEGW, IAEA, CCRI, VERMI etc.)
P2	Publication of general papers and reports on radioactivity metrology: those not covered by technical projects in this theme
P3	Refereeing of papers for peer-reviewed journals relevant to radioactivity metrology
P4	Visits by users to the radioactivity metrology facilities and staff at NPL for training and advice
P5	Visits by NPL staff to users for training, advice and promotion of the programme
P6	Technical enquiry service on radioactivity metrology topics (providing initial responses to each enquiry within 5 working days)
P7	Exhibit at two significant exhibitions within the 3 years, for promotion and awareness
P8	General presentations on radioactivity metrology at national and international meetings and attendance at conferences relevant to radioactivity metrology topics for networking purposes: those not covered by technical projects in this theme

A.5. Knowledge Transfer Theme

<table>
<tr><th colspan="2">KNOWLEDGE TRANSFER</th></tr>
<tr><td>K1</td><td>Programme Knowledge Transfer</td></tr>
<tr><td colspan="2">User Communities:
Healthcare, Environment (including Decommissioning), Energy, Manufacturing (including Advanced Materials), Radiation Processing, Instrumentation & Testing, Defence & Security, Safety (including Radiation Protection)</td></tr>
<tr><td colspan="2">Needs:
The activities in this project meet needs common across all user communities. The aim is to maximise impact from the knowledge generated by the programme and hence there is a need to assess the impact achieved. The results of such an assessment will be fed into the rolling formulation process and inform future priorities.

There is a need for awareness and promotional material informing the user communities of relevant results and developments produced by the programme. There is a need for such material to be delivered by e-mail, online on the website and in printed form. To distribute this information effectively, there is a need to maintain an up to date contact database.

There is a clear need for an increase in delivery of knowledge transfer through training, as training is seen as one of the most effective ways of maximising impact in the relevant user communities. Whilst there continues to be a need for conventional training courses, especially where hands-on practical sessions are required, there is a growing need for delivery of training through e-learning and other distance learning formats. These alternative means of delivery need to address the requirement for providing training to people who have limited training budgets and/or very little time to attend courses away from their place of work. A study is needed to determine the most effective delivery format to meet these needs.

There is a need to develop new knowledge transfer products that make full use of the interconnected society, in which the use of high speed broadband and mobile communications has become commonplace.

Finally, in any programme of this size, there will usually be the need for NPL to organise and host at least one major international conference or scientific meeting. At present, the only such meeting envisaged is the Advanced Metrology for Ultrasound in Medicine scientific meeting. Others may need to be added through rolling formulation in due course.</td></tr>
<tr><td colspan="2">Potential Collaborators:
• IPEM (particularly its training committee)
• IoP
• Institute of Acoustics
• Open University
• National Library for Health
• NHS Trusts
• NHS Innovations (e.g. Health Enterprises East)
• Regional Development Agencies
• Royal Society of Chemistry
• Nuclear site operators, contractors and regulators, including:
  • BNG
  • Nexia Solutions
  • Nukem
  • UKAEA
  • HPA
• British Medical Ultrasound Society
• EURAMET
• HSE
• Society for Underwater Technology</td></tr>
</table>

KNOWLEDGE TRANSFER	
K1	**Programme Knowledge Transfer**

Expected Impact:

An awareness of the relevance of the programme within the user communities and other stakeholders, together with an understanding of what outputs and knowledge generated from the programme are relevant to key people within each of the user communities.

There will be particularly strong impact on those receiving the relevant training, giving them a deeper understanding of the measurement issues, standards, codes of practice, good practice and other guidance necessary for carrying out their responsibilities with greater quality, safety and accuracy.

Specific impact areas:

K1.1 P1 will keep the healthcare user community well informed of the relevant outputs and activities.

K1.1 P2 will keep the environmental and decommissioning user communities well informed of the relevant outputs and activities.

K1.1 P4 will deliver examples of the impact the programme has on the users communities addressed.

K1.3 P1 will provide training for those involved with audiometry, particularly medical physicists.

K1.3 P2 will provide training for those involved with ultrasonics, particularly medical physicists.

K1.3 P3 will provide practical training on reference dosimetry for medical physicists involved with radiotherapy; this is recognised as being very important training for such professionals, complementary to all other training available to them.

K1.3 P4 will provide access to tutorial information on radiation dosimetry to a large number of medical physicists working in radiotherapy.

K1.3 P5 to P8 will provide training in radiochemistry and radionuclide metrology, complementary to the training courses provided by the HPA, for people in the environmental radioactivity and radiation protection communities.

K1.3 P9 will provide training on measurement issues in nuclear decommissioning for regulators.

K1.3 P10 will provide training on measurement issues in nuclear decommissioning for site operators and contractors.

K1.4 will provide more cost-effective forms of delivery for some of the training content from the courses and workshops of K1.3. Thus, it is expected that this will provide such training for a larger number of people, albeit in less depth and without the hands-on practical aspects.

K1.6 will provide a major opportunity for networking and exchange of up-to-date metrology developments and results for the medical ultrasound community and will inform the future direction of the Metrology Programme for Project A4.

Sub-projects & Products	
K1.1	**Awareness and promotional activities (newsletters, e-mail and printed material)**
P1	Health Matters newsletter (biannual)
P2	Environmental Measures newsletter (biannual)
P3	E-mail updates (e.g. events bulletins, sector/technical news feeds) (approx 6 per year)

KNOWLEDGE TRANSFER	
K1	**Programme Knowledge Transfer**
P4	Printed material – Theme overviews (4), case studies (3 per theme), handouts to promote events and training courses (3), updates to existing handouts
P5	Contact database maintained up-to-date
K1.2	**Web enabled dissemination**
P1	Reorganised web pages addressing both technical and user community audiences
P2	Online presentation archive
P3	Video/audio accompaniment to presentations given at NPL-run events
P4	Regular updates to web pages as new content is developed
K1.3	**Specific training courses and workshops**
P1	Development and provision of training course on audiometric calibration techniques
P2	Development and provision of training course on the measurement of ultrasonic exposure for diagnostic and therapeutic medical ultrasound equipment
P3	Development and provision of a more affordable practical course in reference dosimetry to be run annually with capacity for 24 students (total of 72 places) covering MV photon, electron, kV x-ray and HDR brachytherapy
P4	Provision of tutorial session on reference dosimetry adjacent to IPEM biennial radiotherapy meeting in 2008
P5	Organise, facilitate and host a training course on uncertainty estimation in radiochemistry, with special reference to γ spectrometry and liquid scintillation counting
P6	Organise, facilitate and host a training course on uncertainty estimation in γ spectrometry
P7	Organise, facilitate and host a training course on γ spectrometry techniques
P8	Organise, facilitate and host a training course on liquid scintillation techniques
P9	Training workshop on nuclear decommissioning for regulators
P10	Training workshop on nuclear decommissioning for site operators and contractors
K1.4	**Training packages for e-learning or other distance learning**
P1	Study to understand the full extent of training needs in the user communities especially healthcare, where attending face-to-face courses at NPL is unaffordable for many. The focus should be on delivery preferences to maximise take-up.

KNOWLEDGE TRANSFER	
K1	**Programme Knowledge Transfer**
P2	Development of training materials (workbooks / presentations) based on existing course materials, especially from K1.3.
P3	Three piloted training courses in new delivery format as a result of P1.
P4	E-training platform: develop existing systems used to record meetings, generate podcasts, and produce CDROM and DVDs, to develop an interactive training product, in line with recommendations from P1.
K1.5	**Impact assessment and new KT product development**
P1	Development of technical/project "blogs" or shared spaces e.g. "open lab books" where a scientist can write up project ideas and results in an open forum so that discussion can take place.
P2	Development of news feeds - automatically generated from blogs, to integrate information from different sources.
P3	Impact assessment report – NPL will conduct a survey, including face-to-face interviews, to establish the impact of the technical outputs and the efficacy of individual KT initiatives.
K1.6	**Organisation of major international meetings in the UK**
P1	Organisation and hosting of the Advanced Metrology for Ultrasound in Medicine (AMUM) scientific meeting, attracting at least 70 participants

A.6. Programme Management Theme

PROGRAMME MANAGEMENT	
M1	**Programme Management and Formulation**
User Communities: All those addressed by the programme	
Needs: This project covers the activities needed to co-ordinate, communicate, align, manage and control the programme, in order to deliver the required benefits and outcomes. The scope of this project also includes programme formulation.	*Potential Collaborators:* Not applicable
Expected impact: This project will ensure that the programme as a whole delivers appropriately to the full range of user communities, achieving the appropriate impact. Through the formulation activities, it will ensure that the programme adapts to meet changing needs and priorities of the user communities, and responds appropriately to environmental and technological changes.	
Sub-projects & Products	
M1.1	**Programme governance**
P1	Monthly progress reviews and reports (36)
P2	Quarterly progress reviews with DTI Programme Supervisor (12)
P3	Preparation of annual report and reviews by MAC-WG (3)
M1.2	**Rolling programme formulation**
P1	Updated programme documents to reflect approved changes in the scope of projects to reflect user needs
M1.3	**2010-2013 Programme formulation**
P1	Draft programme document (including summary of user consultation)
P2	Documents for public consultation
P3	Final programme documents

PROGRAMME MANAGEMENT	
M2	**Activities for compliance with radiation protection regulations**
User Communities: All those addressed by the programme	
Needs: The use of ionising radiation is heavily regulated. This project covers the activities of the scientific staff and Corporate Assurance staff to ensure that NPL complies with the relevant regulations (the Ionising Radiations Regulations and the Radioactive Substances Act).	*Potential Collaborators:* Not applicable
Expected impact: The impact of this project will be to ensure that NPL's work in this programme complies with all relevant regulations, and ensure that the highest standards of health, safety and security are maintained for the benefit of staff, customers, visitors and society at large.	
Sub-projects & Products	
M2.1	**Radioactive source inventory**
P1	Monthly updates of inventory
P2	Reports on holdings to regulatory bodies (EA, EURATOM)
P3	Annual physical inventory
P4	Leak testing of sealed radioactive sources
M2.2	**Radioactive source handling**
P1	Local Rules updated annually
P2	Updated Environment Agency licences
P3	Source movement approvals (to/from NPL site)
P4	Safety audit reports
P5	Inspections by HSE and counter-terrorism police, and actions arising
M2.3	**Radiation protection**
P1	Provision of personal dosimetry for classified persons
P2	Annual calibration of radiation protection monitors
P3	Radiation safety training for staff

Annex B. Outline of 2010-13 programme

This annex gives an outline of the Acoustics and Ionising Radiation programme for 2010-2013, as currently envisaged. It gives one table for each of the themes:

1. Acoustics Theme
2. Dosimetry Theme
3. Neutron Metrology Theme
4. Radioactivity Theme
5. Knowledge Transfer Theme
6. Programme Management Theme

For each theme, a table is provided giving the likely projects in that theme and for each project a few bullet points indicating the possible topics to be covered.

B.1 Acoustics Theme

ACOUSTICS	
A.1	**Airborne noise exposure and hearing**
Potential content: • Development and maintenance of measurement service facilities: microphone calibration and audiometric, including frequencies up to 100 kHz • Development of calibration methods and specification standards for advanced bio simulators of auditory functions • Integration of speech perception, intelligibility and quality measures in documentary standards for hearing aids and communication systems	
A.2	**Novel technologies for measurement of sound in air**
Potential content: • Application of sound intensity measurement using microsensors to the condition monitoring of machinery • Intelligent large scale wireless sensor networks for noise monitoring and control • Documentary standards for microprocessor based instrumentation and for widespread distributed noise measurement	
A.3	**Underwater acoustics for the marine environment**
Potential content: • Provision and dissemination of improved free-field standards for hydrophone • Transducer calibration based on new generation of optical calibration techniques • Development of standards for calibration of acoustic marine instrumentation • Development of concept of noise dose as exposure parameter for underwater marine life	
A.4	**Medical ultrasound applications**
Potential content: • Provision and dissemination of free-field standards for hydrophone calibration, measurement of ultrasound output power and ultrasonic field characterisation • Development of a dual sensor able to simultaneously characterise the thermal and acoustic pressure field from medical ultrasonic equipment • Development of concept of human dose, with regard to exposure to medical ultrasonic fields • Increased application of optical methods of field characterisation	

ACOUSTICS	
A.5	**Industrial ultrasound applications**

Potential content:

- Development of measurement techniques able to resolve acoustic cavitation occurring at surfaces
- Development of ultrasonic methods for characterising essential properties of nano-particles
- Development of concept of cavitation dose and cavitation unit, with regard to industrial applications of ultrasound (with Dosimetry)
- Development of single-bubble reference cavitation facility
- Development of methods for symmetric and antisymmetric Lamb wave sensor sensitivity calibration

B.2 Dosimetry Theme

DOSIMETRY	
D1	**Calorimetry for Radiotherapy**
Potential content: • Development and maintenance of primary standard calorimeters • Development of new primary standard for HDR brachytherapy • Ion beam calorimetry • New water calorimeter, with a view to eventually replacing graphite calorimeters for photon & electron primary standards • Calorimeters for routine use in the clinic	
D2	**Ionometry standards and services**
Potential content: • Development and maintenance of primary standard ionisation chambers • Further development of healthcare services • Development and maintenance of protection level service • Evaluating the quality of dosimetry measurements in medical physics departs of hospitals	
D3	**Novel dosimetry techniques**
Potential content: • Further innovation in dosimetry techniques • Further study of new dosimeters (e.g. pinpoint chambers, liquid filled ion chambers) • Further R&D on 3D dosimetry • Development of biosensors • Modelling to support the community	
D4	**New healthcare applications**
Potential content: • Further R&D on dosimetry for small fields & IMRT • Further development of alanine dosimetry for radiotherapy applications • Further R&D on dosimetry for novel radiotherapy techniques • Nuclear interaction data for light ions	

DOSIMETRY	
D5	**Industrial dosimetry**
Potential content: • Further development of high dose irradiation standards & facilities, including acquisition of a new high dose ^{60}Co source • Further development of dosimeters & services for industrial dosimetry • Further development of modelling for industrial irradiation plants • Collaboration with industrial dosimetry user groups	
D6	**Facilities**
Potential content: • Development & maintenance of Clinical LinAc • Installation & commissioning of new research LinAc • Development & maintenance of other underpinning facilities • Calibration and maintenance of ancillary equipment	
D7	**Dosimetry Knowledge Transfer**
Potential content: • Representation on relevant standards & professional institution committees • General dosimetry papers & presentations • Other general dosimetry KT (e.g. technical enquiry service, visits to NPL)	

B.3 Neutron Metrology Theme

NEUTRON METROLOGY	
N1	**Primary Neutron Standards**

Potential content:

- Development and maintenance of radionuclide- and accelerator-based standards.
- Development and maintenance of the Van de Graaff and Low Scatter facilities.
- Provision of standards in the presently inaccessible energy region from 6 to 13 MeV
- Extension of thermal irradiation facilities to higher intensities.
- Utilisation of time-of-flight facilities.
- Development of new primary standard instruments based on proton recoil detection.
- Investigation of neutron metrology needs for novel accelerators (e.g. those based on high power lasers).

N2	**Development and Innovation in Neutron Metrology**

Potential content:

- Demonstration of equivalence of standards with other national laboratories.
- Development and maintenance of neutron spectrometry capability.
- Extension of spectrometry systems to cover higher energies.
- Extension of neutron dosimetry capabilities in the cosmic ray area and the healthcare sector.
- Development of novel dosemeters, e.g. using polymer-based semiconductors and/or digital signal processing to separate neutrons and gammas.
- A study of the fundamentals of neutron dosimetry including investigation of: appropriate quantities for providing risk estimates, the effects of mixed LET radiation fields, and dose deposition on nanometre scales.
- Development of a means of measuring the direction dependence of neutron fields in order to derive reference personal dose equivalent values.
- Improvements in performance of real-time electronic personal dosemeters.

N3	**Neutron Theme Knowledge Transfer**

Potential content:

- Annual meeting of the neutron user community.
- Representation on relevant standards committees
- Production of Good Practice Guides to help the neutron user community in areas where there are particular problems in practical neutron metrology
- General neutron metrology papers & presentations
- Other general neutron metrology KT (e.g. technical enquiry service, visits to NPL)

B.4 Radioactivity Theme

RADIOACTIVITY	
R1	**Primary Measurement Standards and Systems**
Potential content: • Compliance with the Mutual Recognition Arrangement • Nuclear decay data evaluations • Continued provision and development of primary standards	
R2	**Infrastructure for Secondary Measurement Standards of Radioactivity**
Potential content: • Maintain operation, and extend calibration of NPL secondary standard ionisation chambers • Maintain operation, and extend calibration of NPL secondary standard γ-ray spectrometers, including realisation of Compton suppressed γ-ray spectrometer • Maintain operation, and extend calibration of NPL secondary standard α-particle spectrometers • Maintain operation, and extend calibration of NPL secondary standard liquid scintillation counters • Maintain and enhance NPL source preparation capabilities • Maintain and enhance NPL radiochemistry facilities • Maintain and extend scope of NPL UKAS accreditation to ISO 17025 for testing and calibration, ISO Guide 34 for reference materials and ISO Guide 43 (part 1) for proficiency testing	
R3	**Measurement infrastructure for Nuclear Medicine**
Potential content: • Nuclear medicine developments • Nuclear medicine Knowledge Transfer	
R4	**Infrastructure for Environmental Radioactivity Standards**
Potential content: • Continued provision of solid standards for calibration of γ spectrometers • Continued provision of low-level standards for environmental applications • Realisation of primary standards for environmental applications • Development of non-aqueous reference materials for radioactivity monitoring • Continued organisation of annual Environmental Radioactivity Proficiency Tests • Continued organisation of relevant user forums	

RADIOACTIVITY	
R5	**Infrastructure for Radiation Protection**
Potential content: • Provision of photon emitting large area reference source standard • Radiation Protection Knowledge Transfer • Response to radiation protection user community requirements – services, standards, techniques. • Continued comparison of real world measurement procedures with secondary standard quality measurements	
R6	**Infrastructure for Nuclear Decommissioning**
Potential content: • Reference materials for nuclear decommissioning • Mathematical modelling for decommissioning • Knowledge Transfer for nuclear decommissioning • Response to nuclear decommissioning user community requirements – services, standards, techniques.	
R7	**Radioactivity Theme Knowledge Transfer**
Potential content: • Representation on relevant standards & professional institution committees • General radioactivity papers & presentations • Other general radioactivity KT (e.g. technical enquiry service, visits to NPL)	

B.5 Knowledge Transfer Theme

KNOWLEDGE TRANSFER	
K1	**Programme Knowledge Transfer**
Potential content: • Awareness and promotional activities (newsletters, e-mail and printed material) • Web enabled dissemination • Specific training courses and workshops • Training packages for e-learning or other distance learning • Impact assessment • New KT product development • Organisation of major international meetings in the UK	

B.6 Programme Management Theme

PROGRAMME MANAGEMENT	
M1	**Programme Management and Formulation**
Potential content: • Programme governance • Rolling programme formulation • 2013-2016 Programme formulation	
M2	**Activities for compliance with radiation protection regulations**
Potential content: • Radioactive source inventory • Radioactive source handling • Radiation protection	