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National Measurement Office Acoustics and Ionising Radiation Strategy

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Approved on behalf of the Managing Director, NPL
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Executive Summary

This report summarises the Acoustics & Ionising Radiation Programme Strategy. The main driver for the programme is Quality of Life. Much of the programme is therefore concerned with developing the standards and infrastructure to meet society's changing needs and regulatory requirements. Rapid technological developments are also driving measurement needs – new instrumentation for acoustical measurement (based on micro-electro-mechanical systems) and radioactivity (micro-fluidic devices) are just two examples. External economic changes such as those in the energy sector (for example, the nuclear new build, measurement of cavitation and decommissioning nuclear sites) also bring new challenges to metrology.

This document sets out the strategic priorities of the programme. The Programme is delivered by National Physical Laboratory, and has a value of £8.5M p.a., which is 14% of the total National Measurement Office Budget. The programme is divided into four technical themes (Acoustics, Radiation Dosimetry, Radioactivity and Neutron metrology) plus Knowledge Transfer and Management.

The Strategic measurement priorities are:

Healthcare – Therapeutics
Improving cure rates and quality of life for UK citizens
Healthcare – Diagnostics
Medical diagnostic techniques for accurate and earlier diagnosis of disease e.g. in nuclear medicine, ultrasound and X-ray
Healthcare - Personal Safety
Protection of the public and radiation workers from ionising radiation
Environmental Sustainability - Pollution
Decommissioning of nuclear power facilities, management of radioactive discharges and nuclear waste.
Protection of the public and marine environment from anthropogenic noise exposure, using for example MEMS
Security - National Security
Prevent and reduce significant security threats, national emergencies and improve to personal security e.g. microfluidics
Energy Gen & Transmission
Maintain and develop capabilities for new energy sources and for existing and new nuclear power facilities.
Advanced Manufacturing
The optimised application of industrial processes and non-destructive monitoring techniques e.g. measurement of cavitation
Underpinning Metrology
Enabling the measurement of acoustics and ionising radiation quantities at the accuracy required by society and regulation

This document outlines ten roadmaps to address these priorities: 1 Sound-in-Air, 2 Sound-in-Water, 3 Ultrasonics for Medical Applications, 4 Ultrasonics for Industrial Applications, 5 Radiotherapy, 6 Chemical/Industrial Dosimetry, 7 Neutrons, 8 Radioactivity Primary and Secondary Standards, 9 Radioactivity related Environmental, Decommissioning and Radiation Protection activities and 10 Radioactivity related Health activities.

Contents

2. Introduction

This Programme is a National Measurement Office Knowledge Base Programme, which underpins measurements of Acoustics and Ionising Radiation in the UK.

The programme holds the national primary standards of Acoustic Pressure (Pa), Acoustic Power (W), Activity (Bq), Air Kerma (Gy), Absorbed Dose (Gy), Neutron emission rate (s^{-1}), fluence (m^{-2}) and dose equivalent quantities (Sv).

It is delivered by National Physical Laboratory, and has a value of £8.5M per annum, which is 14% of the total NMO Budget.

This programme has established expertise and facilities at NPL that are recognised as centres of excellence for measurements of acoustics, radiation dosimetry, neutron metrology and radioactivity, both within the UK and internationally. This includes the following major facilities: Acoustic free field and reverberation rooms; underwater free-field test facilities, consisting of both laboratory tank and open-water sites; Acoustic Pressure Vessel; Research LinAc; new Clinical LinAc; seven other radiation facilities; Radiochemical laboratories; Primary standard for neutron emission rate (Manganese bath), 3.5 MV proton/deuteron Van de Graaff accelerator and a low scatter neutron building.

This document sets out strategic priorities for the Programme, and the requirements for the future development of the NMO to address them, to ensure that the UK NMO remains world leading in appropriate technical areas, to support a competitive UK economy and to meet UK social challenges.

3. Objectives

The mission of the NMO Acoustics and Ionising Radiation Programme

The aim of the Acoustics and Ionising Radiation Programme is to enable all users in the UK to carry out measurements for acoustics, 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 programme seeks 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 aims of the programme are:

- To underpin the requirements for stable and accurate measurements of Acoustics and Ionising Radiation to support regulations for, and to provide a sound basis for cost-effective and reliable measurements.

- To support Acoustics and Ionising Radiation measurements in the healthcare and environmental sectors intended to improve quality of life throughout the UK.

- To enhance innovation and industrial competitiveness, by improving measurements in Acoustics and Ionising Radiation.

- To provide leadership amongst the UK communities in the application of leading-edge science and technology, thereby maximising the economic value added to the UK.

- To transfer the outputs of the programme in terms of knowledge and technology to UK users, including business, SMEs, regulators and trade bodies.

- To support trade and the comparability of UK measurements by participation in international comparisons and the development of an infrastructure for the global acceptance of measurement results.

4. Strategic Measurement Priorities

The Programme will deliver the mission and aims by addressing eight challenge-driven Strategic Measurement Priorities that are set out in an Overview Roadmap included in Annex 1. Roadmaps are also contained within that Annex of this document.

The AIR Working Group reviewed the scope and content of this document on - 1 October 2008.

1. Healthcare – Therapeutics

For example improving cure rates and quality of life for UK citizens

Every year over 200,000 people are diagnosed with cancer in the UK, and are treated with radiotherapy, chemotherapy and surgery. Radiotherapy treatment is given to about half of all patients, with intent to cure the cancer or to alleviate suffering. The radiation may be given in the form of external beam radiotherapy using high-energy electrons or X-rays, or it may come from radioactive sources placed inside the patient (nuclear medicine or brachytherapy). About 30,000 patients per year receive treatment from high activity radionuclides. For radiotherapy to be effective, it is essential that the correct amount of radiation (absorbed dose) be delivered to the patient. Too small a dose, and one or more cancerous cells may survive, leading to recurrence of the disease. Too large a dose, and the healthy tissue surrounding the tumour may be destroyed. Optimal treatment of, for example, some head and neck tumours, requires that the dose delivered should be within only a few percent of that prescribed.

Every treatment is monitored with instruments whose calibration can be traced back, via accurate secondary standard dosemeters, to the primary standard instruments held at NPL. These standards measure absorbed dose or air kerma directly from first principles, and are subject to regular comparisons with other national standards worldwide. Reference instruments are calibrated against these primary standards in order to allow the determination of absorbed dose by following the relevant Codes of Practice recommended, in the UK, by the Institute of Physics and Engineering in Medicine. Accurate dosimetry is essential to maintain and improve radiotherapy and ultimately to improve cancer cure rates and quality of life.

Cancer therapy is critically dependent on measurement standards for radiation dosimetry. 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. Awareness of the need for accurate dosimetry in Targeted Radionuclide Therapy is developing.

The Department of Health in December 2007 reaffirmed its commitment with the release of the Cancer Reform Strategy. It aims to improve cancer prevention, speed up the diagnosis and treatment of cancer, reduce inequalities, improve the experience of people living with and beyond cancer, ensure care is delivered in the most appropriate settings and ensure patients can access effective new treatments quickly.

Therapeutic uses of ultrasound are widespread, in particular the use of low power physiotherapy for the treatment of chronic and acute soft-tissue injuries. The NHS delivers approximately 1 million ultrasound therapy treatments per year and NPL provides primary and secondary calibration services for such therapy systems themselves, and for radiation force balances which are used to determine that devices are operating within specification, thus underpinning treatment safety and efficacy. A growing area of ultrasound therapeutics is high intensity focussed ultrasound (HIFU), in which strongly focussed ultrasound fields are used to ablate tumours: the National Institute for Clinical Excellence (NICE) has recently approved the use of HIFU for treating prostate cancer. An accurate knowledge of acoustic pressures and powers generated and consequent tissue heating is thus crucial for the safe and effective use of HIFU equipment.

About 2 million people in the UK have hearing aids, but only 1.4 million use them regularly. There are at least another 3 million people who do not have hearing aids but experience significant hearing difficulties in everyday life, and are likely to benefit from their use. These benefits are well documented and a recent survey showed 70% of 580 hearing impaired people reported a significant improvement in enjoyment of everyday life after they were fitted with *digital* hearing aids. The next scientific challenge is maximising the effectiveness of digital hearing aids by not only having procedure in place for their objective testing, but also the means to relate that to the benefits that the user is able to gain by the use of the hearing aid.

2. Healthcare – Diagnostics

Medical diagnostic techniques for accurate and earlier diagnosis of disease e.g. in nuclear medicine, ultrasound and X-ray

Within the UK over 40 million diagnostic X-ray examinations take place and approximately 450,000 patients receive radionuclides for diagnostic purposes each year. In diagnostic procedures, the radiation dose received by the patient is an unwanted side effect and always to be minimised, subject to acceptable image quality being achieved. There is considerable evidence that the doses received by patients for a given examination can vary considerably from clinic to clinic, however the Ionising Radiation (Medical Exposure) Regulations, IR(ME)R, introduced in May 2000, require a dose reference level to be set for each procedure in every clinic and a demonstration of consistent dosimetry.

As part of the infrastructure for compliance with these regulations NPL set up a calibration service for diagnostic X-ray dosemeters. This enables NPL to offer a calibration service suited to the requirements of the medical community and uses "practical peak potential" to define the kV, helping to reduce the doses received by patients across the UK.

The use of radionuclides in medicine, for diagnostic imaging or for therapy 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.

The safe and successful use of radionuclides for medical diagnosis depends critically on accurate measurement of the activity administered to the patient. In order that radiation doses to everybody concerned are kept to levels which are as low as reasonably practicable whilst still ensuring that diagnosis is effective, it is important that the activity of the administrations are known to a reasonable degree of accuracy. It is important too that those activity measurements can be made quickly and be shown to be traceable to national and international measurement standards. The instrument of choice for these measurements is a radionuclide calibrator, the main component of which is an ionisation chamber. All such devices in UK hospitals are calibrated using reference materials or other standards from NPL, which in turn have been calibrated against NPL's primary standards of activity. Ionisation chambers provide extremely reliable, efficient and economic measurement standards to the medical community.

Acoustics work supports measurements of hearing for protection of the health and wellbeing of workers and the public. It is needed for reduction of noise in the environment, industry and government conformance with regulations (including EU directives). Hearing loss has been a prescribed occupational disease eligible for compensation by the Department of Social Security (DSS) since 1974. Audiometric measurements to detect hearing loss in an objective and standardised manner including universal neonatal screening, are therefore critical.

Ultrasound accounts for around 20% of diagnostic scans carried out, and is the fastest growing imaging modality. To maintain the excellent safety record that ultrasound imaging has demonstrated manufacturers of scanner systems must demonstrate that the acoustic output of their systems complies with international specification standards. This is achieved by using calibrated broadband hydrophones, and it is estimated that over 90% of hydrophones in use worldwide are traceable to primary standards at NPL. The UK is also one of the worlds major manufacturers of foetal heart rate monitors, which have more stringent acoustic output limits, and NPL provides manufacturers with system design, prototype and production device testing, using unique field characterisation facilities.

Deafness is the second most common disabilities in the society generally, affecting an estimated 9 million people, about one in seven of the population of the UK in total. Since hearing loss increases sharply with age, this is set to grow as the proportion of older people rises. The basis for prescribing and fitting a hearing aid effectively (digital or otherwise) is the measurement of hearing thresholds using pure tone audiometry for initial diagnosis. For this purpose over 1,000 audiometers are in use in

around 200 ENT departments in England and Wales. Many of these departments run hearing aid clinics, providing about ½ million hearing aids annually at a cost of approximately £25m (excluding staff costs). Also private sector provision accounts for about 80,000 hearing aids annually from some 600 dispensers.

While pure tone audiometry has traditionally been the basis for hearing measurement, other assessment methods are now finding a place along side this in routine clinical practice. These 'objective audiometry' methods rely on responses to an auditory stimulus elicited without a conscious action by the patient. Such methods include evoked response audiometry (ERA) that detects brain activity correlated with an acoustic stimulus, and otoacoustic emission (OAE) methods that detect acoustic signals emitted by from the ear as a by-product of a correctly functioning hearing mechanism. These methods set new requirements for calibration and traceability.

3. Healthcare - Personal Safety

Protection of the public and workers from ionising radiation and noise

Ionising radiation has many applications, ranging from nuclear medicine to the nuclear power industry. NPL supports radiation protection of the general public and workers through the provision of appropriate standards.

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.

The national statutory requirement for the monitoring of ionising radiation in the workplace and the regular testing of appropriate monitoring equipment has applied equally to the specialised areas of alpha-, beta-, photon- and neutron radiations. This statutory obligation was strengthened with the establishment of the Health and Safety Commission and the Health and Safety Executive and the publication of the 1999 Ionising Radiations Regulations and Code of Practice 'The protection of persons against ionising radiation arising from any work activity'.

Employers must comply with these 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. 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.

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. These developments are impossible without facilities to test their properties.

Although scientists have been measuring cosmic radiation since early last century, it is only recently that the implications of the increased radiation levels at aircraft altitudes have been considered important. This stems from changes in radiation

protection legislation, which now regards workers whose exposure to natural radiation is increased as a direct consequence of their work in much the same way as 'traditional' radiation workers, such as those employed by the nuclear industry. This same legislation also for the first time sets limits on levels of radiation as a result of exposure in the home, primarily from Radon gas.

Current regulations and Codes of Practice require that radiation-monitoring instruments are regularly tested and calibrated to a known accuracy in relation to national standards. In general, this equipment will be suitable for either the assessment of the radiation dose received by the individual in the course of their work (individual monitoring) or the routine assessment of radiation levels in working environments (area monitoring).

Neutron measurements must be performed around hospital LinAcs for protection of staff and patients, requiring very specialist neutron measurement expertise. LinAcs used for radiotherapy generate adventitious neutrons, which contribute to staff and patient doses, which have to be monitored. Similarly, air travel results in enhanced 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.

Acoustics work supports occupational and environmental health, including the impact of noise emitted by machinery in the workplace, and of other sources such as aircraft and industrial noise, and the measurement and protection of hearing.
Hearing loss has been a prescribed occupational disease eligible for compensation by the Department of Social Security (DSS) since 1974. Occupational noise exposure is controlled under the new Physical Agents (Noise) Directive published in the Official Journal of the European Union in 2003 and implemented in the UK in April 2006. An exposure limit value (taking account of any hearing protection) of 87 dB(A) is fixed whilst upper and lower exposure action values (irrespective of protection) are 85 dB(A) and 80 dB(A) respectively. Noise levels of at least 85 dB(A) are thought to be present at more than 80,000 workplaces throughout Britain, with an estimated 845,000 workers exposed.The introduction of the new legislation has required employers to increase their level of health surveillance and risk assessment .to identify employees that may be susceptible to noise induced hearing loss from noise levels as low as 80 dB(A). Employers also need to put the systems in place for providing wider audiometric testing and recording/reviewing results.

4. Environmental Sustainability - Pollution

Decommissioning of nuclear power facilities; management of radioactive discharges and nuclear waste
Protection of the public and marine environment from anthropogenic noise exposure, using for example MEMS

The measurement of radioactivity in the environment is a regulatory requirement around sites where significant amounts of radioactive material are used or stored. NPL provides the standards, reference materials and laboratory proficiency testing exercises needed to support measurements of environmental samples by analysis laboratories.

The UK has a historical legacy of radioactive materials on its nuclear sites; the government has established the Nuclear Decommissioning Authority to clear the sites, a process which will take several decades. NPL provides the measurement infrastructure needed to support the nuclear industry in its efforts to decommission nuclear sites safely. Accurate and traceable measurement of the radioactivity content of waste materials is vital to ensure they are consigned to the correct waste stream.

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. There is a need to develop standards to support environmental monitoring, including primary standards for gaseous discharges of radioactivity.

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.

Acoustics work supports offshore marine activities, where acoustic systems are key in underpinning technology for oil and gas operations, oceanographic research, and defence applications, and where assessments are required of the environmental impact of man-made noise.

Airborne noise is recognised by statute to represent both a cause of nuisance and a hazard to hearing. In particular, environmental noise, caused by traffic, industrial and recreational activities is considered to be a significant local environmental problem, and complaints are increasing. There is an extensive body of regulations in place in the UK to control noise and to limit its emission many of which enforce EC Directives. There has been considerable interest in the EU to assigning monetary values to the adverse effects of noise. The DETR has reviewed studies of external costs of noise and has concluded the costs of road and air traffic noise in the home are:

- £15-£30 per decibel per household per year (covering 4 studies)
- 0.02 –2.27% GDP (covering 15 studies).

Noise exposure throughout Europe was reviewed in the EC Green Paper on Future Noise Policy (1996), and resulted in a proposed framework for action to substantially reduce environmental noise. Up to 170 million citizens of the EU were said to be living in areas where the noise levels were such as to cause serious annoyance during daytime. It is estimated that 20 % of the EU population are adversely affected by noise which is widely considered to be unacceptable. Between 5% and 15% of the EU population suffer serious noise induced sleep disturbance.

As a result Directive 2002/49/EC Assessment and Management of Environmental Noise has led to considerable activity, primarily focussed on the production of strategic noise maps for all major "agglomerations", where so far in the UK, £13 m has been allocated. These strategic activities place additional burdens on UK Local Authorities required to produce noise maps. In constructing the maps there are questions about quality control of prediction software. When the completed maps enter into services as decision making tools there are likely to be validatory demands prior to reduction and preservation Action Plans. The Commission estimate the cost of implementation of the proposal as 30 to 40 million euro annually.

Also the Mayor's London Ambient Noise Strategy 'Sounder City' (2004) identified noise as a major environmental concern, and labeled it as 'the forgotten pollutant'.

Alongside strategic activities, local authorities take responsibility for the control of environmental noise, particularly in the areas of environmental health, planning and traffic noise from highways. They receive tens of thousands of complaints each year concerning noise, many of which are confirmed as statutory nuisances following investigation. Powers to deal with environmental noise are provided under the Environmental Protection Act 1990, Noise & Statutory Nuisance Act, and the Noise Act 1996, and for all of these traceable measurements play an important evidential role.

However, the research community has also recognised the need to develop new methods to determine the exposure of the population, especially in areas where noise levels are not so high as to be a risk to health (cardiovascular effects, hearing damage etc.), but have more subtle long-term effects on the well-being of the population, such as the decrease of cognitive abilities in children and annoyance leading to increased levels of stress. New techniques and indicators to map and quantify *perceived* noise are key to cost-effective actions planning oriented to improving general well-being.

New approaches to measurement, such as Micro-Electro-Mechanical Systems (MEMS) aim to provide a low cost (mass producible) sensor for use in distributed measuring systems. There are many possible application areas e.g. noise mapping, soundscape characterisation, personal noise exposure monitoring, robust sensors for mobile (personal/in-vehicle) use, small devices for low perturbation applications, and small devices for low-visibility (external urban) applications.
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. The effects can be physical (leading to death or hearing loss), or behavioural (affecting breeding or migration). The affected species range from protected marine mammals to fish species which are important for commercial fishing. Regulation is now providing a driving

force in this area, for example from the EU Habitats' Directive 92/43/EC, and from EC Directive 2001/42/EC. In the UK, amendments to the Conservation (Natural Habitats &c.) Regulations 1994 (i.e. the Habitats Regulations, HR) and the new Offshore Marine Conservation (Natural Habitats, &c.) Regulations 2007 (the Offshore Marine Regulations, OMR) came into force on 21 August 2007. Both Regulations have revised the definition of disturbance to include underwater noise. An Environmental Impact Assessment is now routinely required before offshore activities which may generate underwater acoustic noise can commence, and monitoring is required during the activity. Although regulation is now beginning to be introduced, there is still a long way to go before the underpinning metrology and standardisation are fully established, and there is a significant role for NPL within the framework of the NMO.

The DEFRA draft Marine Bill, introduced in April 2008, recognises the importance of delivering a development of marine and coastal environment which is *sustainable*. The UK has one of the world's richest marine environments. As an island nation we are responsible for a sea area over three times larger than our land area with about 20,000 km of coastline (roughly equivalent to half way round the world). This resource supports activities ranging from fishing, aggregate extraction, oil and gas extraction and tourism. Within marine technology, acoustics remains the prime modality for sub-sea imaging, communication and navigation. Additionally, underwater acoustics continues to play a vital role in oceanographic science, with applications 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).

5. Security - National Security

Prevent and reduce significant security threats, national emergencies and improve to personal security e.g. microfluidics

Defense 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. Current priorities include mine detection (both during and after conflicts) in shallow coastal waters, highly challenging environments due to reverberation and high bubble content. Within Homeland Security, the protection of bridges and ports from the threat of terrorism is of increasing priority.

Neutron facilities are used for instrument calibration 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. A current priority is that of detecting mines in shallow coastal waters, both during and after conflicts.

It is proposed to review the literature on microfluidic technology. Alpha emitting and low-energy beta emitting radionuclides are difficult to detect directly in samples. Analysis usually requires lengthy chemical separations (typically a few hours) to extract the radionuclides of interest in a form suitable for assay. There is a need for very rapid analytical techniques for use following (for example) the explosion of a radiological bomb. This need may be met by microfluidic devices.

6. Energy Gen & Transmission

Maintain and develop capabilities for new energy sources and for existing and new nuclear power facilities.

The ability to measure ionising radiation is important to operators of nuclear power stations, fuel fabricators, re-processors and waste storage and disposal facilities. These are regulated by the Nuclear Installations Inspectorate, for compliance with the Atomic Energy Act and with the Ionising Radiations Regulations. Discharges and the movement of radioactivity from sites are the responsibility of the two Environment Agencies, EA and SEPA.

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. The problems they encounter cover X-ray, gamma, and neutron dose rate, surface contamination, discharges to air and water and bulk contamination.

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.

With strong growth in world energy demand, an average growth of 8% in sub-sea oil wells is predicted over the next five years. Underwater acoustics is an essential enabling technology, playing a vital role in applications such as geophysical surveying, positioning, navigation, echo sounding and communications.

Offshore renewable energy installations are likely to be the most intensive engineering interventions in the UK's coastal waters in the next decade. They have the potential to significantly contribute to the reduction of greenhouse gas emissions and consequently mitigate the impacts of climate change. This year the UK will overtake Denmark as the country with the highest operating offshore wind capacity in the world at over 400 MW, and the UK's Renewables Obligation, revised in the 2007 Energy White Paper, sets the challenging target of providing renewable sources for 15% of UK total energy use by 2020 (equivalent to between 25 GW and 33 GW). However, noise arising from the construction and, to a lesser extent, operation, of marine renewables may have adverse effects on marine life and presents considerable metrological challenges for the measurement of noise and assessment of its impact.

Many energy supply installations, including nuclear, rely on acoustic emission monitoring to assess the structural integrity of the generation plant and the

underpinning infrastructure. For the oil and gas industry, this extends to assuring the safety of the offshore platforms and monitoring of the gas supply lines. Cavitation in pumps is also a concern in this area, along with the water supply industry, leading to reduced efficiency and the eventual failure of critical supply pumps. In addition to this, acoustic emission is increasingly used to continuously monitor blade integrity of wind-turbines currently operating across the UK. The increasing use of these monitoring techniques for in-situ assessment has increased the demand for understanding the quantitative nature of the measurements and the requirement for traceability.

The Government released in January 2008 A White Paper on Nuclear Power Meeting the Energy Challenge. It contained a 'preliminary view is that it is in the public interest to give the private sector the option of investing in new nuclear power stations'.

7. Advanced Manufacturing

The optimised application of industrial processes and non-destructive monitoring techniques e.g. measurement of cavitation

The UK has the most active underwater acoustic manufacturing industry in Europe with over 30 companies involved in manufacturing transducers, hydrophones and systems for sonar, positioning, navigation, surveying, communication, weapons and monitoring marine life. NPL provides traceable calibrations and access to unique national facilities to enable the accurate measurement of system performance that is crucial for ensuring unambiguous specification and acceptance testing, an important consideration when many of the companies need access to overseas markets.

The aerospace industry routinely use non-destructive testing methods such as acoustic emission monitoring during scheduled maintenance which informs both expected life span of an airframe, but also feeds back into the design and testing programmes. Within the aerospace industry, acoustic emission monitoring is also used for the fatigue testing on prototype and final manufactured components. In addition to this, the UK has a large manufacturing and supply industry that provides the measurement equipment and acoustic emission sensors necessary for such tests. NPL is working on the provision of measurement services which will support the acoustic emission and end user industries within the UK.

Noise emission measurements are now a common requirement for UK industry to demonstrate compliance with EC Directives. Within the Medical Ultrasound area, the US Food and Drug Administration requires manufacturers to comply with acoustic output limits for specific clinical applications.

Within the area of industrial ultrasonics, high-power applications of sound include cleaning, materials processing and sonochemistry. The 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.

Ionising radiation is used extensively in the polymer industry to initiate polymerisation and cause effects such as cross-linking and degradation – a related

area is the testing of electronic components for radiation hardness as required in the aerospace industry, requiring specialist dosimetry techniques.

Ionising radiation is used in the radiation processing industry, to produce beneficial physical, chemical or biological effects on an industrial scale. Typical examples are sterilization of medical devices; modification of polymers, curing adhesives and resins; enhancement of gemstones; wire and cable jacket curing; tyre manufacture; and the treatment of waste. Foodstuffs can also be irradiated to extend shelf life or reduce the numbers of harmful bacteria.

The biggest industrial use of ionising radiation is in the modification of the properties of polymers. When ionising radiation passes through a material, energy is deposited which can either initiate polymerisation, or cause cross-linking to harden the polymer and increase its melting point.

The other major use of ionising radiation is the sterilization of medical devices. Approximately 50% of the single use medical devices (syringes, scalpels etc) in the UK are sterilized by ionising radiation. By delivering precisely measured doses of radiation, it is possible to ensure that any microorganisms on the devices are destroyed. Because the radiation easily penetrates the plastic or paper packaging, the device can be sterilized after it has been packaged and it will then remain sterile until the package is opened.

Accurate measurement of radiation dose is critical to the sterilization process, in order that the radiation dose delivered is sufficiently high to ensure sterilization, but not so high that the medical device or its packaging is itself damaged. We are able to offer consultation and advice on irradiations of this type, and can perform irradiations using cobalt-60, electron beams or higher-energy photon beams as well as offering calibration services for dosimetry systems (through the mailed alanine dosimeter service), traceable directly to the primary standard of absorbed dose held at NPL. We also offer consultation and advice on calibrations, and we also have significant experience in Monte Carlo modelling of industrial irradiations.

8. Underpinning Metrology

Enabling the measurement of acoustics and ionising radiation quantities at the accuracy required by society and regulation

Within acoustical metrology, there is a need to move to a new generation of primary standards. The aim is to provide sufficient headroom between the accuracy of primary standards and routine calibrations, to move away from primary standards that rely on the performance of specific standard transducers (as is the case in the reciprocity methods), and to provide greater accuracy for the most demanding measurements. The new generation of standards will be based on radically different physical principles using optical techniques to realise the acoustic pascal via the measurement of particle velocity. In water, this will be done using heterodyne interferometry to measure the free-field acoustic particle velocity using a thin optically-reflective but acoustically-transparent membrane. In air, laser Doppler anemometry will be used to measure the acoustic particle velocity in an acoustic free-field chamber. The ultimate traceability for these methods will be to the metre via the frequency of the laser light, instead of to the amp and the ohm for the current primary standards.

Calorimetric ionising radiation absorbed dose standards enabled the introduction of services for direct calibration in terms of absorbed dose to water in both photon and electron beams at therapy-level dose rates. NPL has comprehensive expertise in the design, modelling and operation of calorimeters and aims to develop the world's first absorbed dose primary standard for proton/light ion radiotherapy beams. Additionally, a new primary standard therapy-level absorbed dose calorimeter for electron and photon beams is under construction, as well as a new calorimeter to measure absorbed dose from HDR brachytherapy sources. Through its research, NPL aims to remain a world-leading NMI in graphite calorimetry.

NPL provides national resources for Acoustics and Ionising Radiation measurement. It provides traceability to the SI by maintaining and developing standards and measurement methods, linking to international metrology, and providing measurement services and advice to users. More information follows in the Section on Support for the SI below.

The apportionment of the available Programme budget across these priorities can be found in Annex 2 in the form of a pie chart.

5. Documentary standards, regulations and Directives

The Programme will identify documentary standards, regulations and Directives, which depend upon measurements underpinned by the Programme. The Programme will provide advice on best measurement practice to those implementing these standards and regulations, and to those developing or creating new standards and regulations.

The Programme will also ensure that the UK NMO meets the requirements of standards and regulations.

6. International dimension

The outputs of this Programme, particularly national measurement standards, will be coordinated and recognised internationally. This requires participation in the work of the following committees:

- ISO
- IEC
- OIML
- CCRI
- CCAUV
- IAEA
- Euramet
- ESTRO

There is an increasing coordination of the provision of the National Measurement Offices of different countries, particularly in Europe; to reduce duplication and increase cooperate on measurement research.

There are two project funded under European Metrology Research Programme (EMRP) under Theme TP2 Health

1. J07 External Beam Cancer Therapy and
2. J06 Increasing cancer treatment efficacy using 3D brachytherapy

The following are examples of international collaborators

- Industrial Acoustics Co., USA
- PTB, Germany
- LNHB, France
- IRSN, France
- JASA, Japan
- JAERI, Japan
- McGill University, Montreal, Canada
- Siebersdorf, Austria
- METAS, Switzerland
- HAARI, China
- Technical University of Madrid
- Slovak Office of Standards, Metrology and Testing
- Riso, Denmark
- IRMM, Belgum
- GE Medical, USA

7. Support for SI

The programme holds the national primary standards of Acoustic Pressure (Pa), Acoustic Power (W), Activity (Bq), Air Kerma (Gy), Absorbed Dose (Gy), Neutron emission rate (s^{-1}), fluence (m^{-2}) and dose equivalent quantities (Sv).

This Programme effectively realises and maintains the SI Derived units for: Becquerel, Gray and Sievert.

The Programme will provide the UK with traceability to of these quantities and units through calibration and measurement services. Where appropriate these calibrations and measurement services will be offered for international review under the requirements of the CIPM Mutual Recognition Agreement, and the Calibration and Measurement Capability (CMC) recorded in the BIPM MRA Database.

There are 117 CMCs registered for Radioactivity, 42 for Neutrons, 36 for Dosimetry and 42 for Acoustics.

8. Impact

The outputs of the Programme are of six main types. The following table is a proposal for setting targets the precise numbers will have to be set after careful consideration.

Output type	Exploitation Route	Take-up target per annum
Measurement standards	Measurement service	Measurement service revenue
Measurement best practice, skills	Best practice guides Secondments Documentary standards / regulations Training course Studentships MfI Programme NPL helpdesk enquiries	Downloads Number Number Number trained Number Financial value of MfI projects Evaluated at Portfolio level
Intellectual Property	Patent and licence	Number of patents, licences
New science	Publication	Number of publications
New UK capability	R&D and consultancy contracts	R&D revenue from third parties
Network developed	Use to promote other outputs and to support formulation	Level of participation in NMO Club and similar events

Case studies will be prepared regularly to provide examples of how the take-up of outputs from the Programme is delivering impact.

Targets are not set for the achievement of impact by individual Programme, but will be evaluated for the whole NMO Programme portfolio.

9. Alignment with other NMO Programmes and wider Government priorities

Particular Government priorities addressed by this programme are Public Service Agreement Targets (2007 Comprehensive Spending Review):

1. Raise the productivity of the UK economy
2. Improve the skills of the population, on the way to ensuring a world-class skills base by 2020
4. Promote world-class science and innovation in the UK
6. Deliver the conditions for business success in the UK
7. Improve the economic performance of all English regions
12. Improve the health and wellbeing of children and young people
13. Improve children and young people´s safety
17. Tackle poverty and promote greater independence and wellbeing in later life
18. Promote better health and wellbeing for all
19. Ensure better care for all
26. Reduce the risk to the UK and its interests overseas from international terrorism
27. Lead the global effort to avoid dangerous climate change
28. Secure a healthy natural environment for today and the future
30. Reduce the impact of conflict through enhanced UK and international efforts

The Programme supports the following DIUS Departmental Strategic Objectives (from DIUS 2008-09 business plan at a glance: investing in our future. Version 01/05/08):-

DSO 1: Accelerate the commercial exploitation of creativity and knowledge, through innovation and research, to create wealth, grow the economy, build successful businesses and improve quality of life

A project under pinning the Departmental strategy is "Production of a Strategic Plan for the National Measurement Office (NMO) science programmes."

DSO 2: Improve the skills of the population throughout their working lives to create a workforce capable of sustaining economic competitiveness, and enable individuals to thrive in the knowledge economy

DSO 4: Pursue global excellence in research and knowledge, promote the benefits of science and society, and deliver science, technology, engineering and mathematics skills in line with employer demand

DSO 5: Strengthen the capacity, quality and reputation of the further and higher education systems and institutions to support national economic and social needs

DSO 6: Encourage better use of science in Government, foster public service innovation, and support other Government objectives which depend on DIUS expertise and remit

DIUS sponsors the Technology Strategy Board (TSB) and Research Councils. The programme supports the following TSB key application areas:-

Environmental sustainability
Energy generation and supply
Healthcare
Transport
Built environment

and the following key technology area;-

Advanced materials.

The Programme also addresses the following Research Councils priorities

As a country, we are facing unprecedented challenges to our quality of life, environment and security. Meeting these challenges requires new, innovative ways of thinking. Novel, multidisciplinary approaches are needed to help solve the global challenges of the next 10 to 20 years. Below are the cross council priorities.

Energy. The Research Councils' Energy Programme brings together energy-related research and training across the Councils to address the vital international issues of climate change and security of energy supply.

Living With Environmental Change (LWEC). LWEC is an interdisciplinary research and policy partnership programme to increase resilience to - and reduce costs of - environmental change, addressing the associated pressures on natural resources, ecosystem services, economic growth and social progress.

Global Threats to Security. The Global Threats to Security programme will integrate research in crime, terrorism, environmental stress and global poverty, to address causes of threats to security, their detection, and possible interventions to prevent harm.

Ageing: Life Long Health and Wellbeing. This initiative will establish new interdisciplinary research centres targeting the major determinants of health and wellbeing at every stage of life reducing dependency in later life.

The justification and implementation of these activities are described in Section 4 above and the Key drivers section in the Annex below.

10. Formulation

The requirements for the future development of the Programme will be captured continuously as those delivering the Programme meet with stakeholders. (A list of stakeholders is included in Annex 4) In addition, focused studies will be carried out to research technological, market or policy developments that are expected to impact on the priorities of the Programme in the future.

To maximise the impact of the outputs from the projects, the management of the programme includes the role of 'Impact and Formulation Leader (IFL)'. The IFL is responsible for the rolling programme formulation process, maintaining and developing links with the user communities, and recommending changes to the scope of projects in response to user needs.

The Programme Advisory Working Group will provide advice and help to prioritise the requirements identified by this continuous consultation, and also review existing projects, and the Programme Strategy and Roadmap updated as necessary. The Working Group provided a list of potential projects in Annex 2.

Each year new areas of work will be prepared for the Programme as uncommitted budget becomes available, and prioritised against the strategic measurement priorities and requirements of the Technical Themes.

11. Conclusions

The Acoustics and Ionising Radiation programme addresses many different user communities and use different technologies, but have a common focus in improving the quality of life for the general public, patients and the workforce. The Acoustics and Ionising Radiation Programme delivers a balanced portfolio of projects of high impact. The major objective of the programme is to ensure valid and traceable Acoustics and Ionising Radiation measurements in the UK and to establish the equivalence of these measurements with our trading partners.

The applications of acoustical 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. Increasingly, conventional acoustical measurement methods are inadequate to meet requirements and a new generation of instrumentation is in development, based on Micro-Electro-Mechanical Systems (MEMS) and wireless communications technology.

The work in Ionising Radiation enables the benefits of using ionising radiation in medicine and industry to be realised, while minimising the associated health risks. It seeks to achieve this through facilitating accurate radiation dosimetry and radioactivity 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 NMO work is therefore concerned with supporting the relevant regulations (such as the Ionising Radiations Regulations 1999) and Codes of Practice. However new areas of research have opened up such as those provided by the clinical LinAc and imaging system or Microfluidic devices that offer the possibility of developing portable equipment, which may be used for on-site assay of radioactivity for decommissioning.

The programme supports a wide range of government objectives and addresses UK regulatory needs in a cost effective manner.

12. Acknowledgements

Funding by the DIUS NMO Acoustical and Ionising Radiation Metrology programme 2007-2010 is gratefully acknowledged. The editor is 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 – too many staff to name individually.

The apportionment of the available Programme budget across these Themes can be found below in the form of a pie chart.

13. Annex 1: Programme Roadmaps

Introduction

During May 2008 interviews were held with senior scientists within NPL to develop roadmaps for each of the thematic areas of the Acoustics and Ionising Radiation Knowledge Base Programme. Whilst some of these roadmaps used existing iMERA[1] and MSET[2] roadmaps as a starting point, they have been extensively updated and reviewed by the AIR Working Group. The roadmaps are contained within this document. During September 2008 the strategy was further developed. The AIR Working Group reviewed the scope and content of this document on - 1 October 2008.

Background

National Measurement Office, Knowledge Base programmes contain "…projects that are predominantly geared towards the essential economic and quality of life requirements for definitive measurement standards and techniques. These projects would tend to protect and develop the NMO (editors note – The National Measurement Office [NMO] was formerly called the National Measurement System [NMS]. The newer terms are used throughout this document.) infrastructure that is at the heart of the NMO…a major finding from economic modelling is that the NMO infrastructure supports innovation at all levels…"[3]. The Acoustics and Ionising Radiation programme specifically maintains and develops the NMO facilities associated with Acoustics, Dosimetry, Radioactivity including Neutrons, along with Knowledge Transfer and Management.

[1] http://www.euromet.org/projects/imera/
[2] http://www.technology-roadmaps.co.uk/
[3] Strategic Review of the UK National Measurement Office, March 2006, page 16, section 4.2.8. (http://www.berr.gov.uk/files/file32845.pdf)

Within this document the AIR Programme is structured into six scientific Themes, which are supported by a Knowledge Transfer Theme and a Programme Management Theme.

The Roadmaps contained within the document map out, for each of the Science Themes, the underpinning science and technology priorities of the AIR Programme. In doing so they provide a schematic representation of the interrelationships between the enabling science activities of the Programme and the key needs ultimately being served.

Theme	**Theme Roadmaps**
Sound-in-Air	Sound-in-Air
Sound-in-Water	Underwater Acoustics
	Ultrasonics for Medical Applications
	Ultrasonics for Industrial Applications
Radiation Dosimetry	Radiotherapy
	Chemical/Industrial Dosimetry
Neutrons	Neutrons
Radioactivity Primary and secondary standards	Radioactivity Primary and Secondary Standards
Radioactivity Sector related work	Radioactivity related Environmental, Decommissioning and Radiation Protection activities
	Radioactivity related Health activities
Knowledge Transfer and Management	None

1. Programme Overview

NATIONAL MEASUREMENT SYSTEM

Acoustics and Ionising Radiation PROGRAMME OVERVIEW

APPLICATION AREA & PRIORITY FOCUS OF IMPACT	CHALLENGE	HOW THE NMS PROGRAMME INTENDS TO ADDRESS IT	SPECIFIC NMS IMPACT	Programme themes
Healthcare - Therapeutics	Improving cure rates and quality of life for UK citizens (disease treatment and amelioration)	Developing metrology infrastructure to support the effective use of existing and new modalities in radiotherapy (IMRT, Stereotactic, IGRT, targeted radionuclides), ultrasound (inc. HIFU) and application of digital hearing aids.	Effective application of ionising radiation and acoustics in medicine	Sound-in-Air; Sound-in-Water including ultrasound; Radiation Dosimetry; Radioactivity Primary and Secondary Stds; Radioactivity Sector related activities; Knowledge Transfer and Management
Healthcare - Diagnostics	Medical diagnostic techniques for accurate and earlier diagnosis of disease	Development of new methods of measurement, instrumentation, test protocols, standards, measurement services, quality assurance, proficiency test exercises, good practise guides (e.g. in nuclear medicine, ultrasound and X-ray)	Optimised application of medical diagnostic techniques	Sound-in-Air; Sound-in-Water including ultrasound; Radiation Dosimetry; Radioactivity Primary and Secondary Stds; Radioactivity Sector related activities; Knowledge Transfer and Management
Healthcare - Personal Safety **Underpinning Metrology - Regulation**	Protect the public and radiation workers from ionising radiation	Disseminate legally traceable personal standards that meet evolving regulator needs	Continued safe operation of industries that use ionising radiation (IRR99, IRMER)	Radiation Dosimetry; Neutrons; Radioactivity Primary and Secondary Stds; Radioactivity Sector related activities; Knowledge Transfer and Management
Environmental Sustainability - Pollution **Healthcare - Personal Safety**	Protection of the public and marine environment from anthropogenic noise	Development of methodologies (including MEMS), standards, and new instrumentation to support urban noise mapping & marine renewable energy sources (wind-farms; tidal etc.)	Better understanding and mitigation of the effects of personal and environmental noise exposure	Sound-in-Air; Sound-in-Water including ultrasound; Knowledge Transfer and Management
Environmental Sustainability - Pollution **Energy Gen & Transmission - Emissions reduction**	Decommissioning of nuclear power facilities; management of radioactive discharges and nuclear waste	Providing standards, reference materials, consultancy, tools (e.g. microfluidics), exercises and proficiency tests of UK (and CTBTO) environmental laboratories	Enable the UK to comply with international obligations and more accurate sentencing of waste	Radiation Dosimetry; Neutrons; Radioactivity Primary and Secondary Stds; Radioactivity Sector related activities; Knowledge Transfer and Management
Security - National Security **Security - Personal Security**	Prevent and reduce significant security threats, national emergencies and improve to personal security.	Characterising sonar systems under ocean-like conditions. Developing new generation of measurement techniques. Enabling countries to move to civil uses of nuclear technology by training, consultancy and measurement expertise.	Reduce risks from nuclear weapons and enhanced marine defence.	Sound-in-Water including ultrasound; Neutrons; Radioactivity Primary and Secondary Stds; Radioactivity Sector related activities; Knowledge Transfer and Management
Energy Gen & Transmission - Production	Maintain and develop capabilities for existing and new nuclear power facilities. Establish new energy sources.	Validation and adapting current NPL facilities to perform reactor instrumentation tests. Measurements in support of the off-shore oil and gas industry.	Maintaining a science base to support national nuclear energy options and hydrocarbon exploration.	Sound-in-Air; Sound-in-Water including ultrasound; Neutrons; Radioactivity Primary and Secondary Stds; Radioactivity Sector related activities; Knowledge Transfer and Management
Advanced Manuf. - Process Control **Advanced Manuf. - Instrumentation**	The optimised application of industrial processes and non-destructive monitoring techniques	Developing and dissemination of standards to meet the requirements of the radiation processing industry. Development of methodologies, standards, and new instrumentation for acoustic emission and hydrodynamic cavitation	Affordable control of infection rates. Optimised application of ultrasound in detection and processing	Sound-in-Water including ultrasound; Radiation Dosimetry; Knowledge Transfer and Management
Underpinning Metrology - Extension of SI **Underpinning Metrology - Traceability**	Enabling the measurement of acoustic and ionising radiation quantities at the accuracy required by society	Providing traceability to the SI by maintaining and developing standards and measurement methods, linking to international metrology, and providing measurement services and advice to users	Internationally accepted and accessible measurement standards	Sound-in-Air; Sound-in-Water including ultrasound; Radiation Dosimetry; Neutrons; Radioactivity Primary and Secondary Stds; Radioactivity Sector related activities; Knowledge Transfer and Management

Programme Themes						
Sound-in-Air (yellow)	Sound-in-Water including ultrasound (red)	Radiation Dosimetry (blue)	Neutrons (magenta)	Radioactivity Primary and Secondary Stds (orange)	Radioactivity Sector related activities (purple)	Knowledge Transfer and Management (green)

2. Key drivers for the Programme

The key drivers for the Acoustics and Ionising Radiation Programme, based on extensive consultation of the user communities during the programme formulation process, are summarised below.

Drivers for defence and security

Instrument calibration in the defence and security sectors requires neutron expertise and facilities to develop security devices such as portable monitors etc.

The installation of **radioactivity** monitors at points of entry to the UK ('Project Cyclamen') highlights the need for reference materials that demonstrate that the monitors are working. There is also 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. A current priority is that of detecting mines in shallow coastal waters, both during and after conflicts. Within Homeland Security, the protection of bridges and ports from the threat of terrorism is of increasing priority.

Drivers for energy (generation and conservation)

With strong growth in world energy demand, **Acoustics** is an essential enabling technology for the offshore oil and gas industry, playing a vital role in applications such as geophysical surveying, positioning, navigation, echo sounding and communications. The UK's Renewables Obligation, revised in the 2007 Energy White Paper, sets the challenging target of providing renewable sources for 15% of UK total energy use by 2020 (equivalent to between 25 GW and 33 GW). Offshore renewable energy installations are likely to be the most intensive engineering interventions in the UK's coastal waters in the next decade. However, noise arising from the construction and, to a lesser extent, operation, of marine renewables may have adverse effects on marine life and presents considerable metrological challenges for the measurement of noise and assessment of its impact.

The ability to measure **ionising radiation** is important to operators of nuclear power stations, fuel fabricators, re-processors, waste storage and disposal facilities. These are regulated by the Nuclear Installations Inspectorate for compliance with the Atomic Energy Act and with the Ionising Radiations Regulations. Discharges and the movement of radioactivity from sites are the responsibility of the two Environment Agencies, EA and SEPA.
Oil exploration uses a variety of well logging tools that employ radioactive sources. Naturally Occurring Radioactive Material is also encountered both at the extraction stage and post combustion. The problems they encounter cover **X-ray, gamma, and neutron dose rate**, surface contamination, discharges to air and water and bulk contamination.

Drivers for protection of the environment (including Decommissioning)

Over the next few decades, the UK faces the problem of **decommissioning** and remediation of its legacy nuclear sites. Accurate and traceable measurement of the **radioactivity** content of waste materials is needed to ensure that waste streams are consigned for appropriate storage and disposal.

Measurements of **neutrons** are important for the nuclear industry in support of normal operation, **decommissioning**, fuel transport and waste assay. The UK's recent policy commitment to new nuclear build will further enhance this requirement.

Environmental regulation with regard to **noise** will bring further emphasis upon noise measurement as part of EIA requirements. There is an extensive body of regulations in place in the UK to control noise and to limit its emission many of which enforce EC Directives. The study of new techniques and indicators to characterize the perception of sound in air will be the key to cost-effective action plans to tackle environmental noise outdoor and indoor.

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 a network of about 100 laboratories monitors compliance with this policy. There is a need to develop standards to support environmental monitoring, including primary standards for **gaseous and liquid 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. Amendments to the Conservation (Natural Habitats &c.) Regulations 1994 (i.e. the Habitats Regulations, HR) and the new Offshore Marine Conservation (Natural Habitats, &c.) Regulations 2007 (the Offshore Marine Regulations, OMR) came into force on 21 August 2007, with noise now classed as a disturbance. Routinely, an Environmental Impact Assessment is required before activities which may generate **underwater acoustic noise** commence, and monitoring is required during the activity. Although regulation is beginning to be introduced, the underpinning metrology and standardisation are still not fully established.

The DEFRA draft Marine Bill, introduced in April 2008, recognises the importance of delivering a development of marine and coastal environment which is sustainable. Marine resources support activities ranging from fishing, aggregate extraction, oil and gas extraction and tourism. Within marine technology, acoustics remains the prime modality for imaging, communication and navigation. Additionally, **underwater acoustics** continues to play an important role in oceanographic science, with applications 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).

Drivers for healthcare

Cancer therapy, a core component of UK health strategy, is critically dependent on measurement standards for **radiation dosimetry**: external beam **radiotherapy** demands greater measurement accuracy than any other application. 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. Awareness of the need for accurate dosimetry in **Targeted Radionuclide Therapy** is developing.

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.

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 which have to be monitored. Similarly, air travel results in enhanced 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.

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 or HIFU. An accurate knowledge of the **acoustic pressures and powers** generated, and consequent tissue heating, is crucial for this the safe and effective use of the equipment. 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. **Audiometric measurements** to detect hearing loss in an objective and standardised manner are therefore critical.

Drivers for manufacturing (including advanced materials)

Noise emission measurements are now a common requirement for UK industry to demonstrate compliance with EC Directives.
The highly active UK manufacturing industry for **underwater acoustic** systems and transducers (most active in Europe) maintains the demand for traceable calibrations and access to unique national facilities. Unambiguous specification and acceptance testing is an important consideration when many of the companies need access to overseas markets.
Within the **Medical Ultrasound** area, the US Food and Drug Administration and European Medical Devices Directive require ultrasound device manufacturers to comply with **acoustic output limits** for specific clinical applications, which can only be demonstrated through the use of calibrated hydrophones/

Ionising radiation is used extensively in the polymer industry to initiate polymerisation and cause effects such as cross-linking and degradation – a related area is the testing of electronic components for **radiation hardness** as required in the aerospace industry, requiring specialist dosimetry techniques.

Within the area of industrial **ultrasonics**, high-power applications of sound include cleaning, materials processing and sonochemistry. The 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. This is of particular application in manufacturing sectors such as pharmaceuticals and biofuels,

Drivers for the radiation processing Industry

The **medical device**, **pharmaceutical** and **food irradiation** industries are all subject to stringent national and international regulation and there is a general requirement that dose measurements are traceable to appropriate national or international standards.

Drivers for safety at work (including Radiation Protection)

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. 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 under the new Physical Agents (Noise) Directive published in the Official Journal of the European Union in 2003 and implemented in the UK in April 2006, An exposure limit value (taking account of any hearing protection) of 87 dB(A) is fixed whilst upper and lower exposure action values (irrespective of protection) are 85 dB(A) and 80 dB(A) respectively.

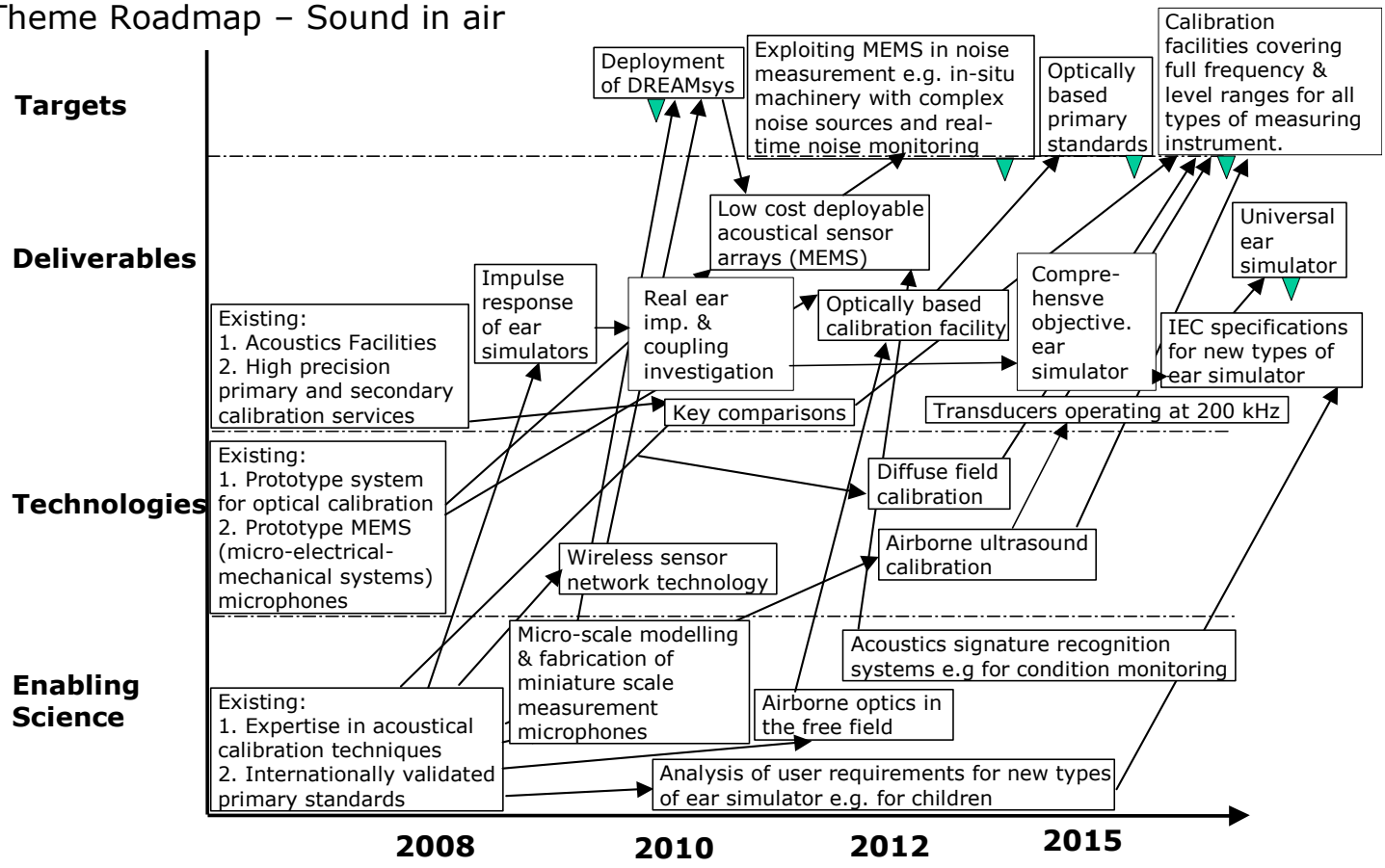
Drivers for the instrumentation and testing industry

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.

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.

3. Sound-in-Air

Theme Roadmap – Sound in air



Drivers or Challenges

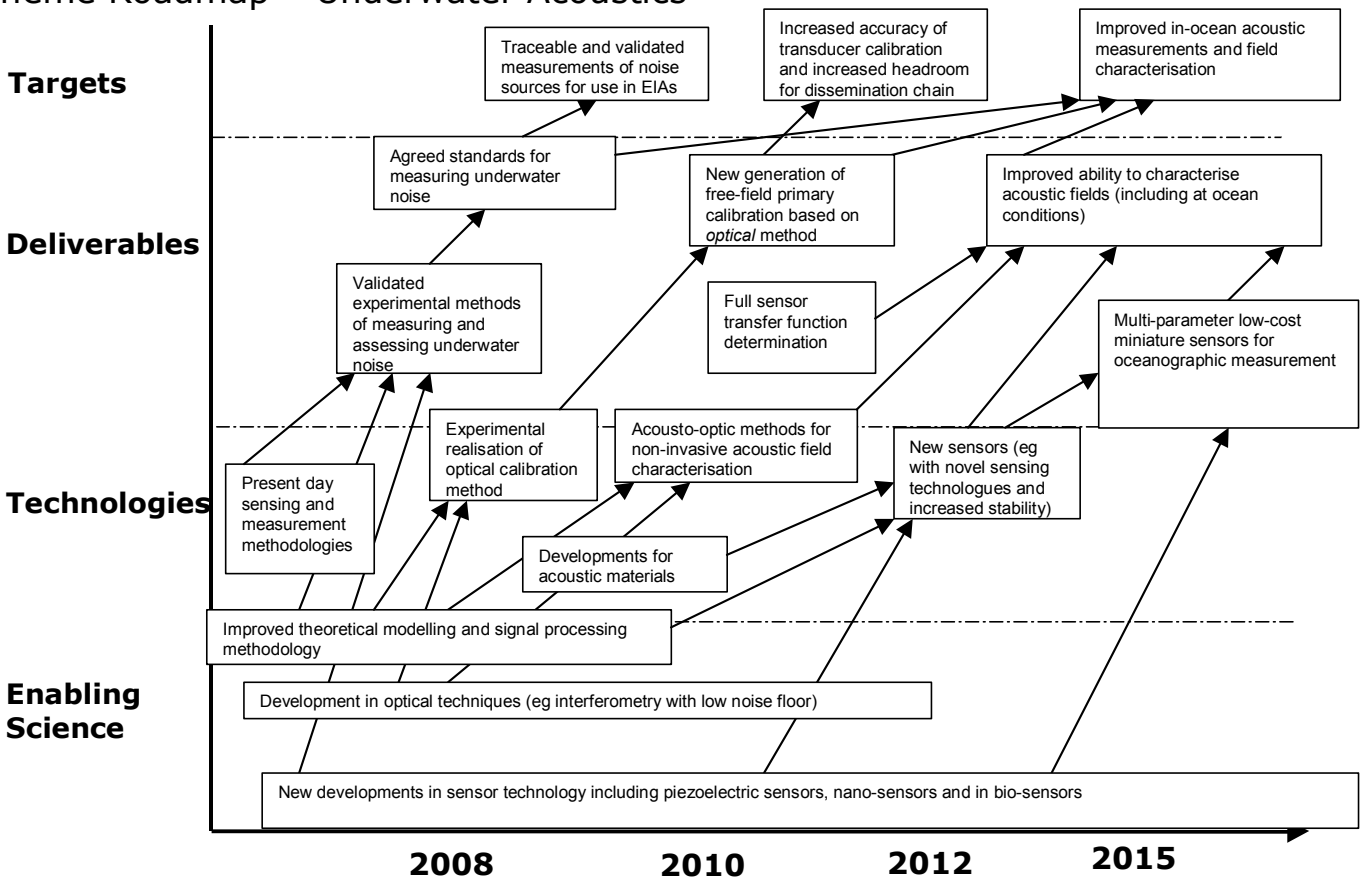
Prevention of hazardous or annoying noise levels in the workplace, the home and in the environment. Compliance with noise regulations and evaluation of human responses.

AIR Working Group – Additional Suggestions - October 2008

- Soundscapes
- Standards for beam forming, holography, calibration of field arrays
  - Standards for phase response will be available at end of this programme
  - Further capability requires development of new types of calibration facilities utilising existing measurement standards
- Source location methods
  - Likely to involve standard test environments
- Standards for structure-borne vibration and prediction
  - Work on vibration devolved to PTB many years ago
  - PTB hold primary standards for the UK
  - Currently NPL has no infrastructure or expertise in vibration

4. Underwater Acoustics

Theme Roadmap – Underwater Acoustics

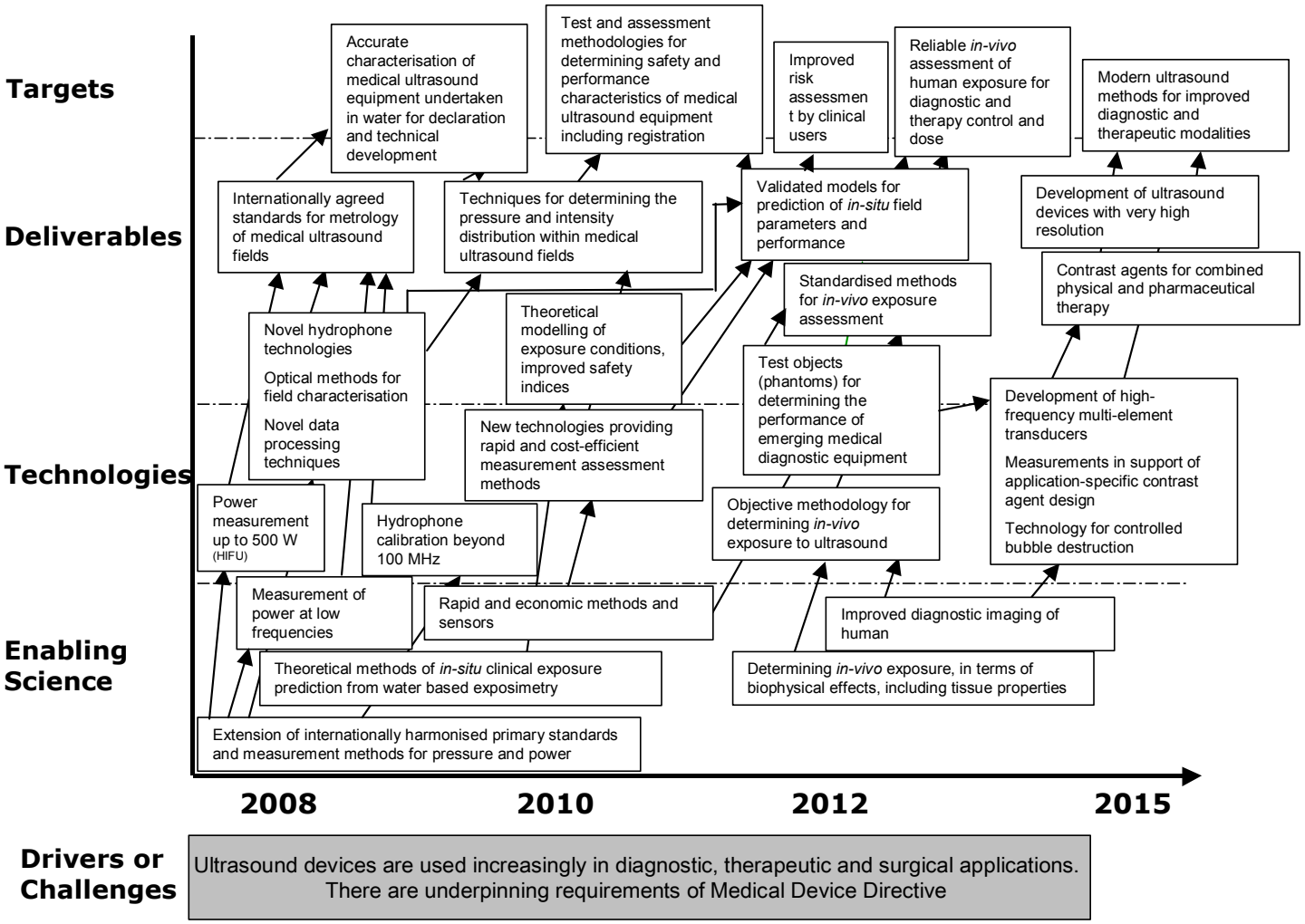


Drivers or Challenges

Increasing environmental concerns for, man-made underwater noise, validated environmental impact assessments, accuracy for most demanding industrial requirements, and measurements in real ocean conditions

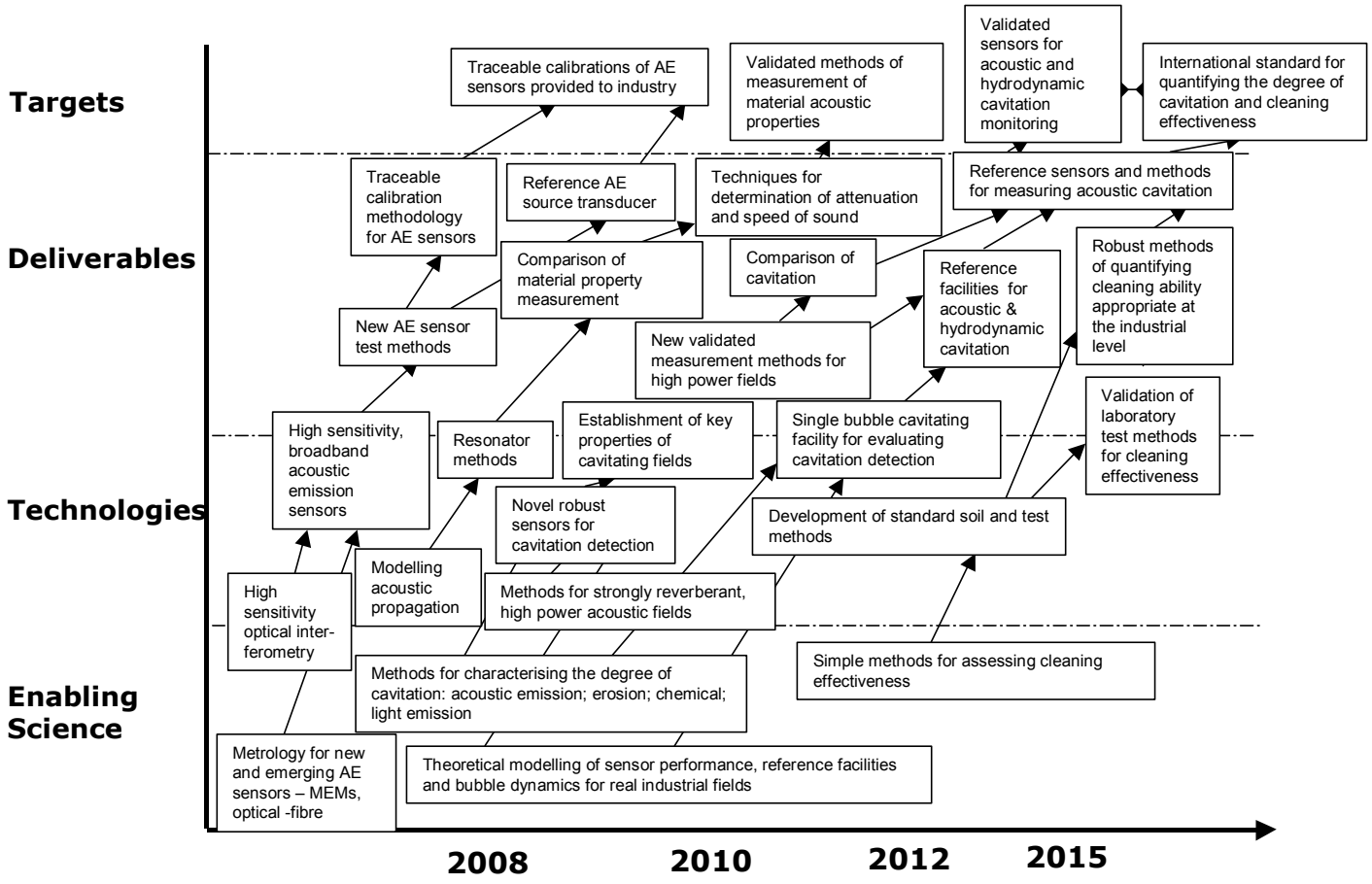
5. Ultrasonics for Medical Applications

Metrology for medical applications of ultrasound



6. Ultrasonics for Industrial Applications

Metrology for industrial applications of ultrasound

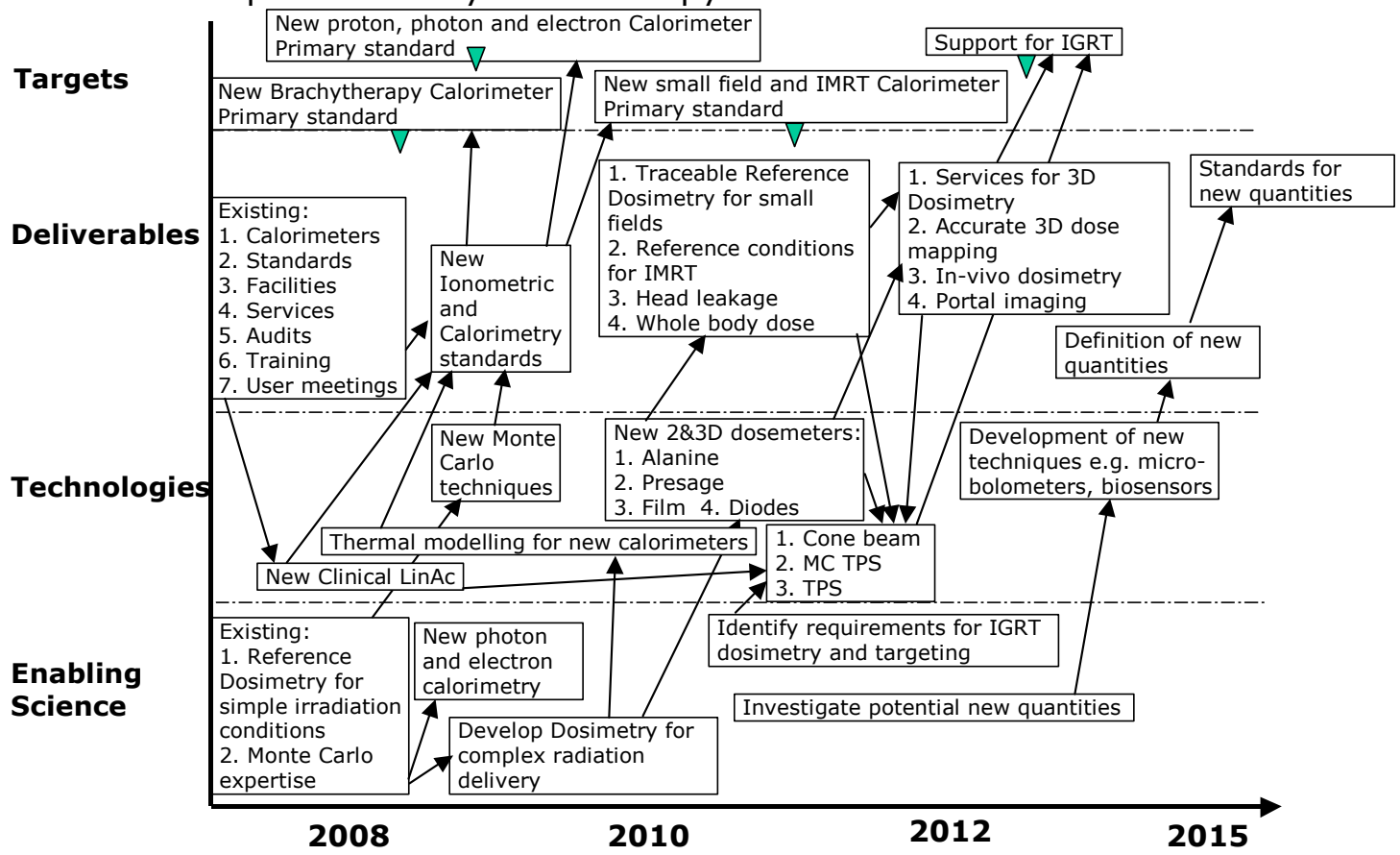


Drivers or Challenges

The following application areas are drivers: Safety-critical structures, aerospace, offshore and nuclear power-reprocessing industries, medical applications, wastewater treatment and materials characterisation.

7. Radiotherapy

Theme Roadmap – Dosimetry:Radiotherapy



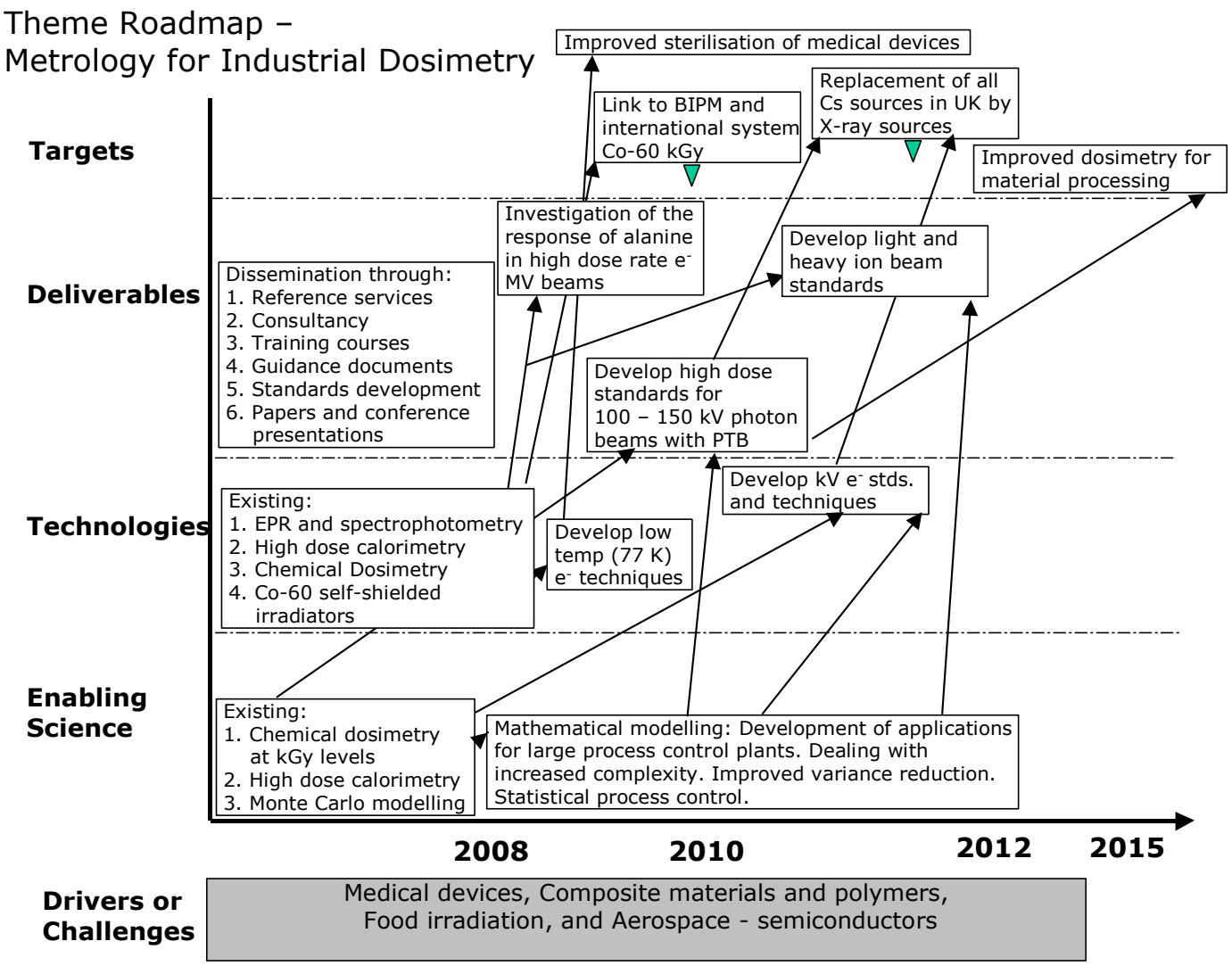
Drivers or Challenges

Cancer mortality is over 150,000 per year and increasing.
After surgery, radiotherapy is the next most effective modality for treating cancer and plays a role in over 40% of all those who are cured

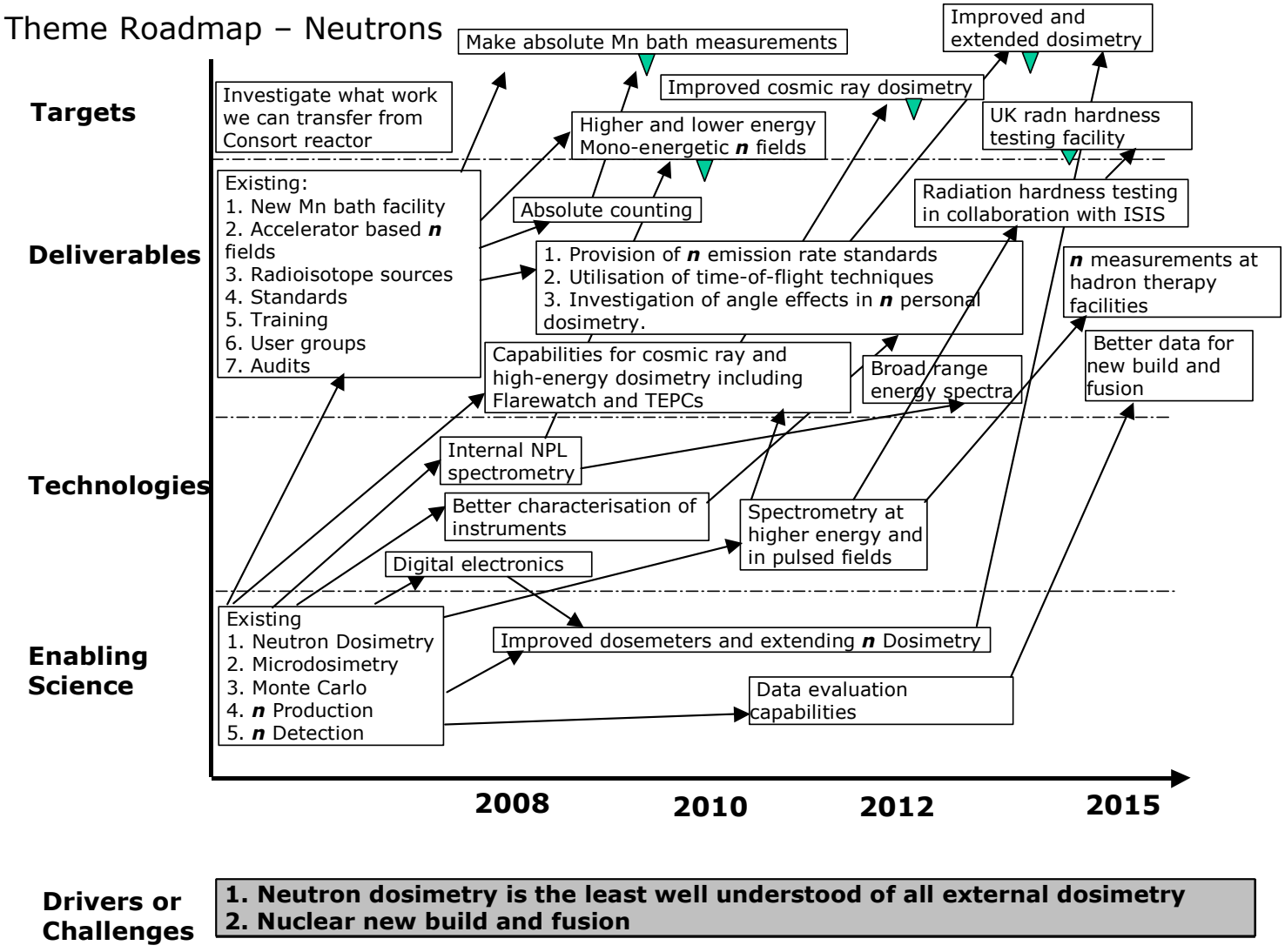
Notes

- RT is RadioTherapy
- IMRT is Intensity Modulated RT
- CT is Computer Tomography
- Cone beam is CT uses a wide rather than narrow beam (as on the new NPL Clinical LinAc)
- TPS is Treatment Planning System
- MC TPS is Monte Carlo TPS
- IGRT is Image Guided RT

8. Chemical/Industrial Dosimetry



9. Neutrons

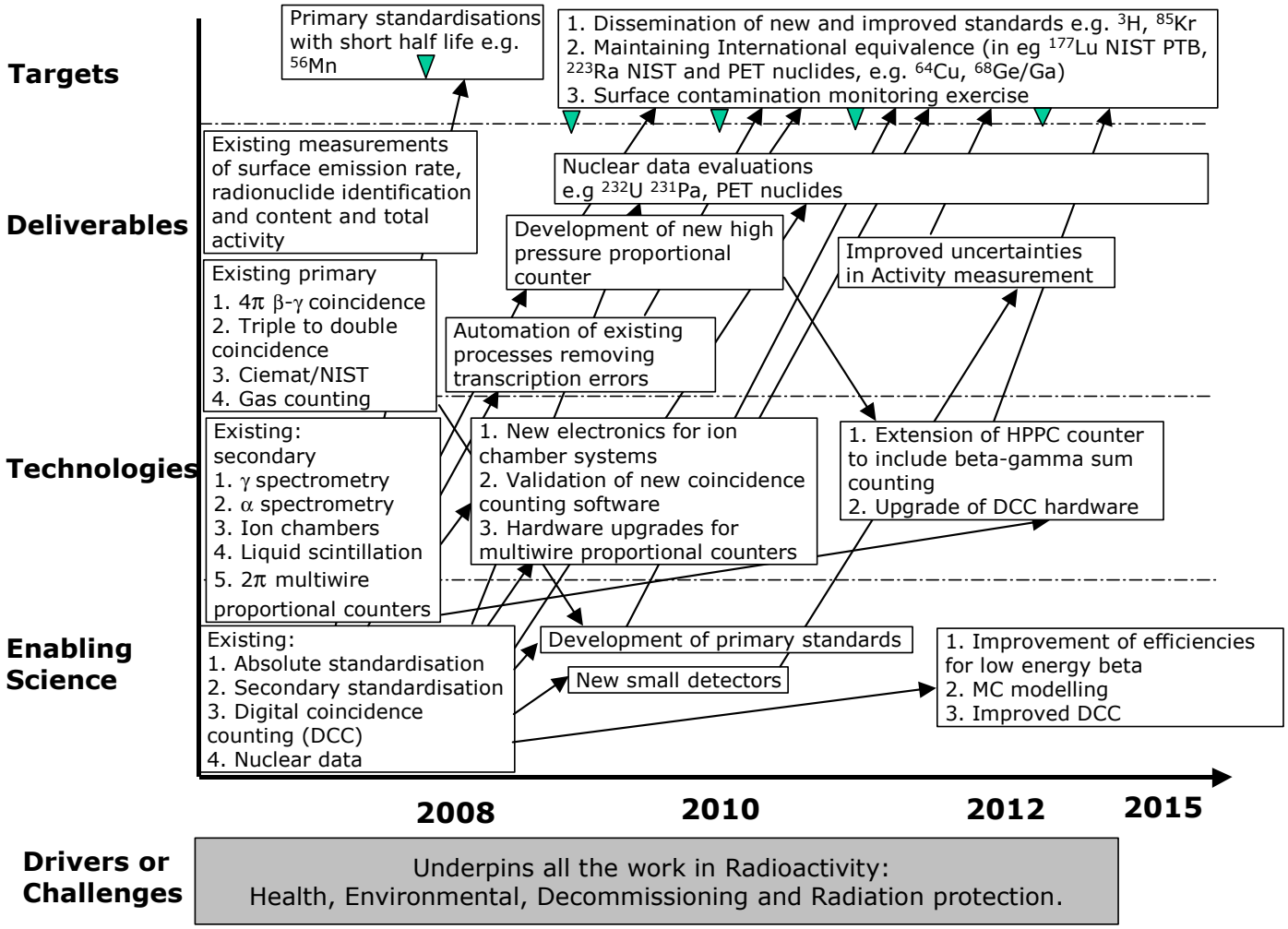


Drivers or Challenges

1. Neutron dosimetry is the least well understood of all external dosimetry
2. Nuclear new build and fusion

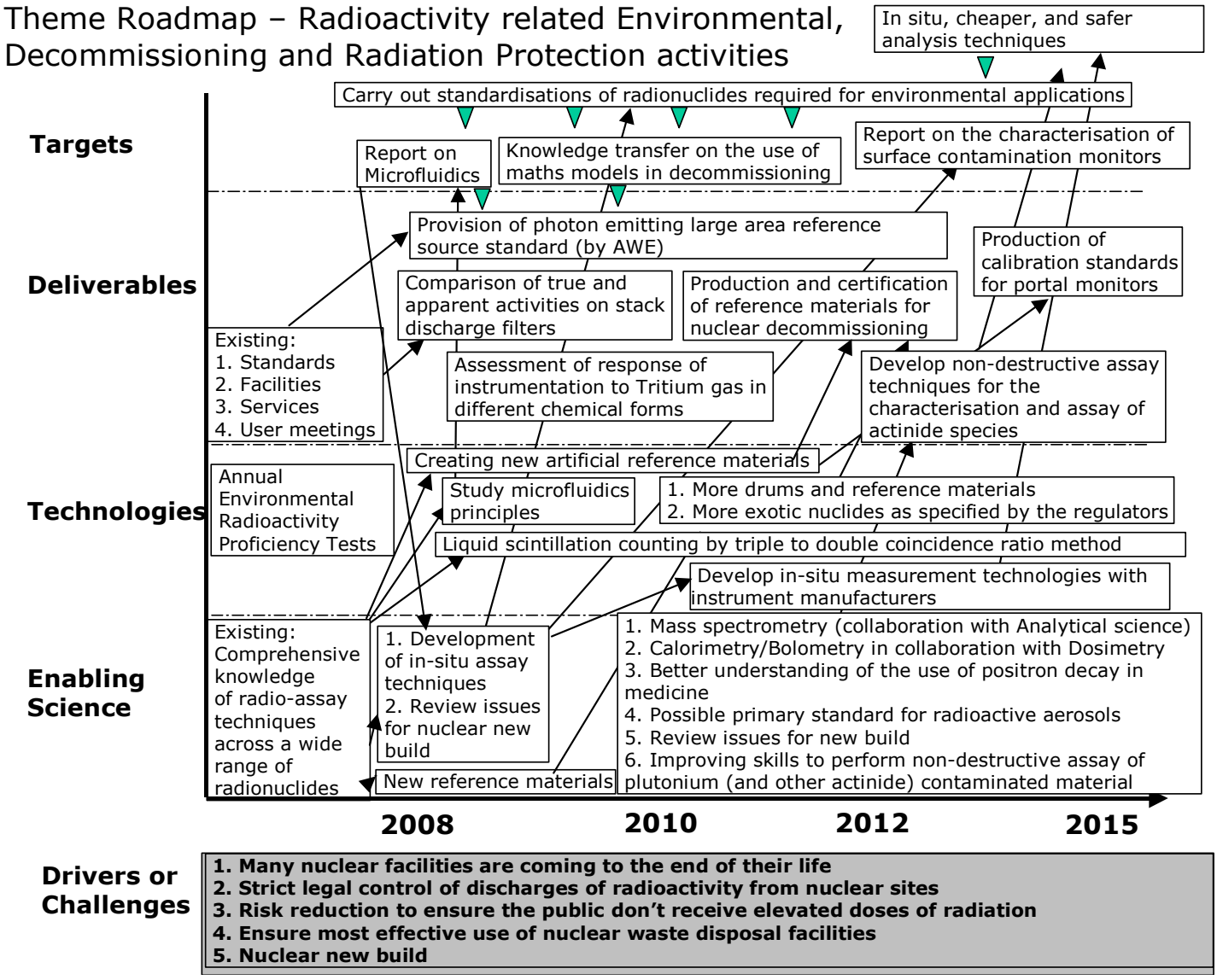
10. Radioactivity Primary and Secondary Standards

Theme Roadmap –
Radioactivity primary and secondary standards



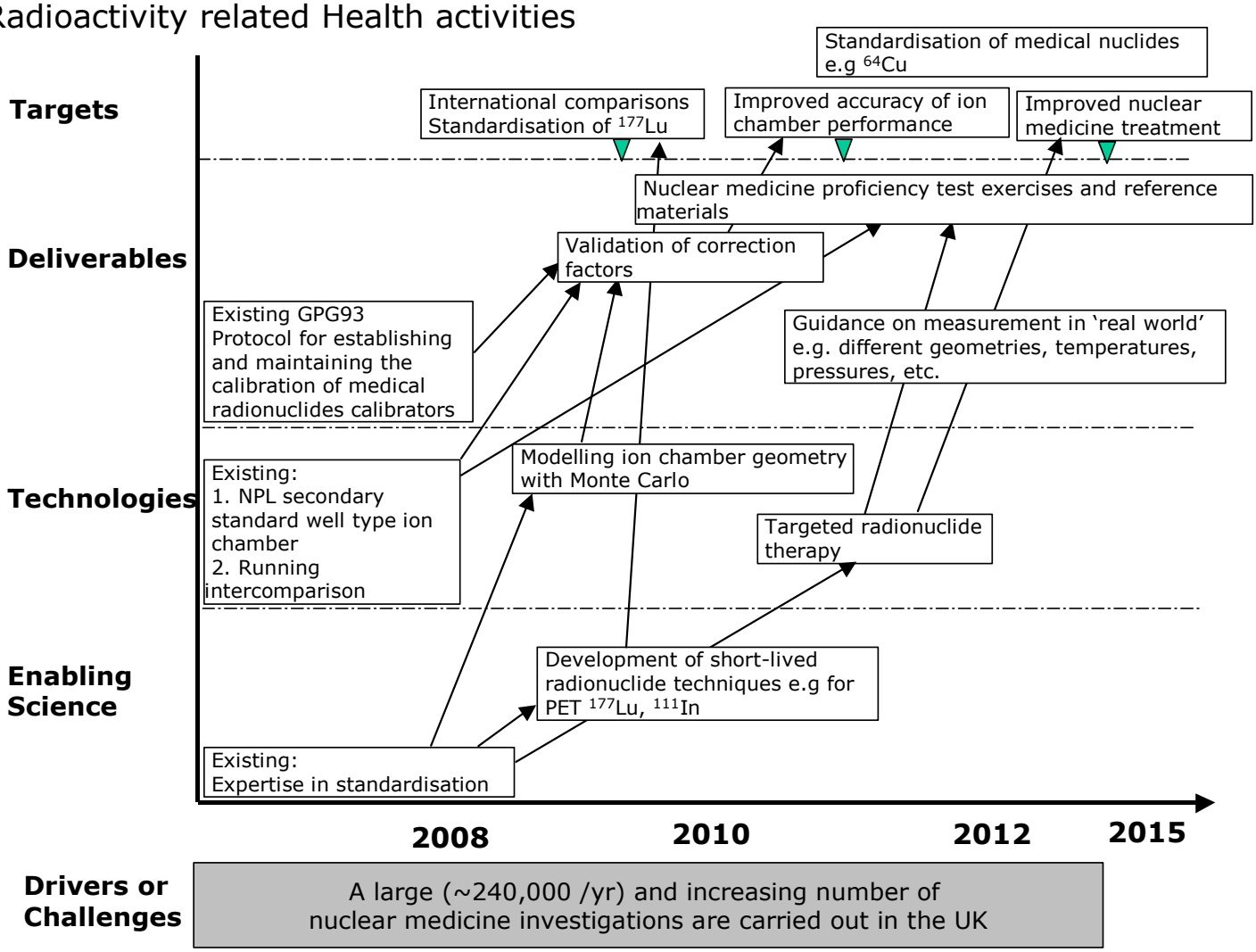
11. Radioactivity related Environmental, Decommissioning and Radiation Protection activities

Theme Roadmap – Radioactivity related Environmental, Decommissioning and Radiation Protection activities



12. Radioactivity related Health activities

Theme Roadmap –
Radioactivity related Health activities



14 Annex 2: Possible Future projects

At the AIR Working Group meeting on 1 October 2008 the following areas were identified for possible future projects:

Acoustics:

- Noise disaggregation
- Hearing aid systems – source ID, characterisation
- Environmental noise in built-up areas
- Transportation – air, etc
- Noise impact from wind farms, tidal energy technology
- Noise mapping, surveying
- Soft metrology – psychoacoustics
- Underwater noise – construction issues
- Ultrasound therapy – performance and imaging
- Structure-borne noise – vibration
- Safety and diagnostic equipment performance – imaging quality and quantification

Radiation Dosimetry:

- Good practice – leading to quality improvements, which could save on money and effort on a national scale. More efficiency.
- LinAc – giving opportunities to develop things traditionally made in hospitals.
- IMRT – micro-dosimetry of small beams
- 3D dosimetry - positional accuracy of micro-dosimetry beams
- Protons facility in 2015
- Brachytherapy – CT-based brachytherapy planning
- In vivo dosimetry verification
- Credentialing – NPL to provide rigour
- Targeted radionuclide programme – to expand
- Hadron therapy – radiation protection activity. Spectrometry at higher energies
- New Build – environmental assessment. Generic Design Assessment
- Combined dosimeter metrology
- Sterilisation issues – equipment and materials. More Quality Control
- Personal dosimetry and monitoring

Neutrons:

- Hadron therapy
- Reference field at higher energies

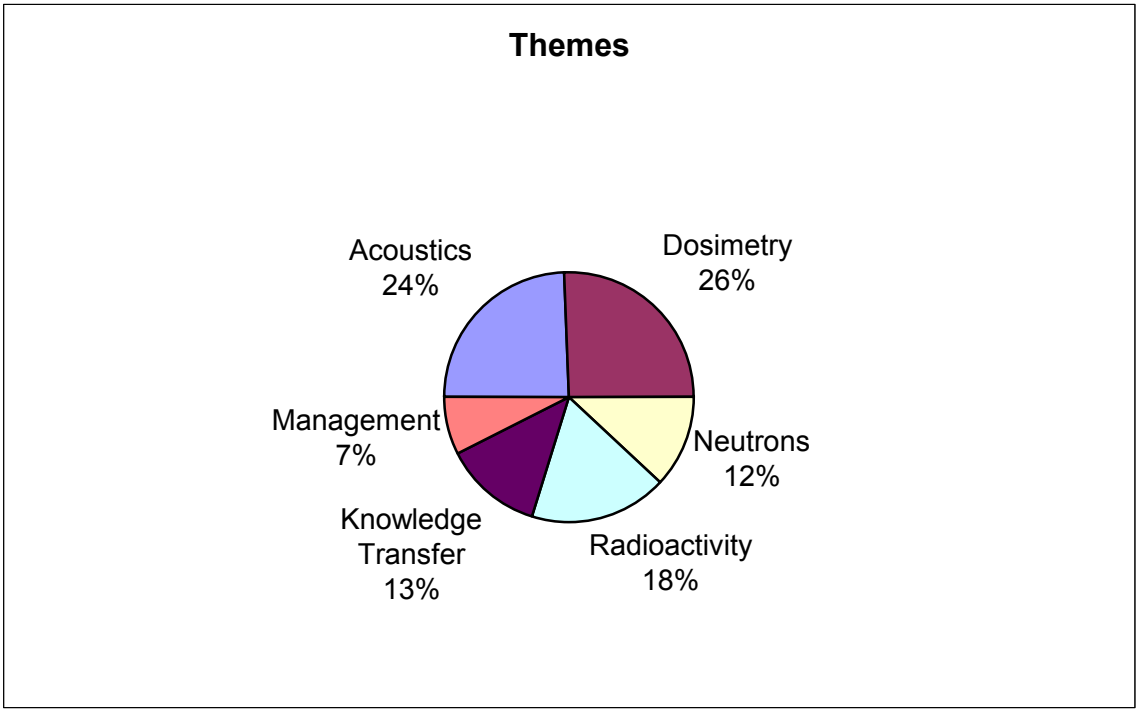
Radioactivity:

- 3D positioning – DNA interactions
- New Build – cross –section standards to provide more knowledge
- Dosimetry reactions for unfolding neutron spectra
- Decommissioning – good practice; in situ analysis. Could work with LGC and other organisations for reference materials. [This is planned, also working with IRMM]

15 Annex 3: Pie charts showing proportions of effort between strategic measurement priorities

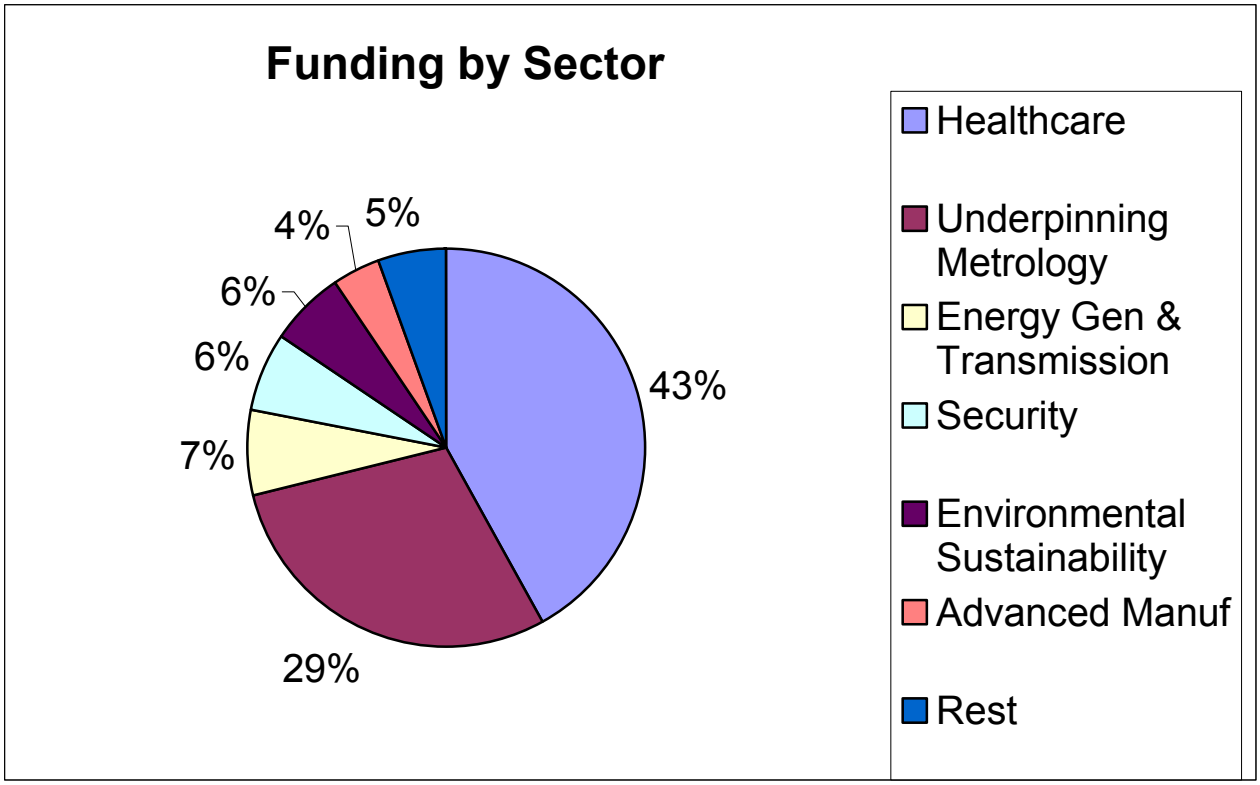
1. Acoustics and Ionising Radiation Themes

The AIR programme 2007-2010 contract value is £25,602,509. The Theme proportions were taken from the Contract Document.



2. Acoustics and Ionising Radiation Sectors

Leading Scientists estimated Application area proportions for each Project (excluding KT and Management). These were then weighted by value. All areas less than 4% are grouped as one total sector 'Rest'.



16 Annex 4: List of Stakeholders in Programme

Acoustics

Government related organisations

DIUS
NMO
SSfM
NEL
Environment Agency
UKAS
MOD
Technology Strategy Board

Committee and Institutes

IEC TC29 WG's 4, 5, 10, 13, 17, 21
IEC TC87 WGs 3, 8, 12, 13, 14, 15
ISO TC43 WG8, WG28
Consultative Committee for Acoustics Ultrasound and Vibration (CCAV)
Ultrasonics Industry Association
Institute of Acoustics
Euramet
BSI
ISO
OIML
BSA
BMUS
IPEM
AITC
British Academy of Audiology
IOP
Ultrasound Industry Association
JASA
BIR

Companies

Industrial Acoustics Co. (IAC)
Precision Acoustics
DCNS
BP
Polish Centre for Accreditation
Fraser Nash
PC Werth
AVI Ltd
HAARI, China
Drumgrange Ltd.
PCT Ltd

DSTL
QinetiQ
Acoustic Polymers Ltd
TNO
Sonic systems
Lloyd's Register of Shipping
Airbus UK
Hoare Lea
AcSoft
Campbell Associates
Bureau Veritas (formerly Casella Stanger)
Environmental Acoustics
Castle Group

Universities

Liverpool
Institute of Sound and Vibration Research, Southampton
National Oceanographic Centre, Southampton
Loughborough
Royal United, Bath
Edinburgh
Western General, Edinburgh
Churchill Hospital, Oxford
Institute of Cancer Research
Technical University of Madrid
Cardiff
Surrey
Imperial
Coventry
Newcastle

Ionising radiation

Government related organisations

DIUS
NMO
SSfM
NEL
DH
Environment Agency
UKAS
IAEA
OECD-NEA
SEPA
MOD

Committees and Institutes

ISO TC 85, 147
BSI

UKAEA
BIPM
CCRI
Euramet
ESTRO
ICRM
PTB, Germany
NIST, USA
CIRMS, USA
METAS, Switzerland
LNHB, France
Japan Atomic Energy Research Institute
Riso, Denmark
Slovak Office of Standards, Metrology and Testing
RSC Radiochemistry Group
IRMF
NSUF
LSUF
RCUF
ARMUG
MCNEG
Panel on gamma and Electron Irradiation
DDEP
CONRAD
IRSN
Richmond Borough Council
Mullard Space Science Laboratory
Selex
Siebersdorf
HPA
IRMM
IPEM
IOP
BIR
Association of British Healthcare Industries
HSE
OST
MAESTRO EU Collaboration
Society for Radiological Protection
BSI
ASTM
NHS Executive
SCA
CEWG Clearance and Exemption Working Group
XIAWG Cross-Industry Assay Working Group
CTBTO

Companies
SERCO (and subsidiaries)
Isotron plc

Reviss (UK) Ltd
Technical Services Ltd
Harwell Dosimeters
Turner and Townsend
Mitie
Coinford Construction
Southern Scientific
RCD Lockinge
CAA
Thermo Fisher Scientific
BA
Virgin Atlantic Airways
Nuvia Limited (formerly Nukem Ltd)
BAe systems
AWE
Maidstone Hospital
Guy's and St Thomas Hospital
dstl
Centronic
HMS Sultan
Canberra Instruments
GE Medical
Sellafield Sites
Nexia
British Nuclear Group
British Energy
NDA
Lab Impex Systems Ltd
Nuclitec
IBA
MBDA
Ultra Electronics
Landauer Europe
High Technology Sources

Universities

London (inc Imperial College, UCL)
Clatterbridge Centre for Oncology
McGill University, Montreal, Canada
Univ. of Surrey
Lancaster
Liverpool
Surrey

Plus many hundreds of: users of the calibration services, course students and meeting attendees.