EPSRC/STFC Review of Nuclear Physics and Nuclear Engineering

A report prepared for EPSRC and STFC by a panel chaired by Dr Sue Ion

Table of Contents

Summary

EPSRC and STFC initiated this review of nuclear physics and nuclear engineering with the following terms of reference:

- To review the scope of RCUK funded activity and training in nuclear physics and nuclear engineering in the UK
- To identify the skills and expertise with relevance to future economic impact in related application areas
- To comment on the ability of the scope and volume of the current nuclear physics and nuclear engineering activity to deliver these skills and expertise
- To identify any changes required in the scope or priorities of the nuclear physics and nuclear engineering activity in the UK
- To comment on UK competitiveness in skill and expertise provision
- To comment on any other issues relating to the provision of skills in nuclear physics and nuclear engineering

The review has revealed a number of critical interests, not all of which are the preserve of the Research Councils, but which are reflected in the recommendations made herein. Particular matters of concern were:

- the need for a coherent roadmap describing the nuclear landscape to better position the UK's research and training needs within a resurgent nuclear sector;
- the need for better links between the nuclear physics community and the nuclear engineering community, industry and funding agencies in topics with potential for future economic impact;
- the need for an urgent solution to the funding issues associated with taught Masters courses;
- the need to ensure an appropriate position for the UK in international research and development initiatives in advanced reactor system and fuel cycle development.

This report sets these matters out in detail, along with recommendations for addressing them.

Recommendations

1. It is vital that the Research Councils work closely with key departments of government – DECC, DBIS, MoD, Home Office, FCO – all of whom should have an interest in the sustainability of the skill and capability base underpinning nuclear topics across the full spectrum of issues, for the furtherance of UK policy on the international stage and in the national interest for access to highly specialised advice. The panel **recommends** that Research Councils should be proactive in discussions with the key government departments. *(p9-10)*
2. The panel concluded that the UK's needs in terms of trained personnel and scope and volume of research and development activity are dependent on the Government's intentions for new nuclear build. It is therefore clear that a high-level national strategy for nuclear is required, with a roadmap which defines how our future nuclear capability is to be achieved. The House of Commons' Innovation, Universities and Skills Select Committee's recommendation for a master roadmap for nuclear energy owned by the Office of Nuclear Development[1] is fully endorsed by the Panel. The panel **recommends** that the roadmap should consider the need for a balanced portfolio of research in nuclear engineering in the UK to serve the short-, medium-, and long-term needs of the country. *(p16*)
3. The panel **recommends** that the Research Councils should engage with the roadmapping process and relevant stakeholders, including government departments, to determine their place in the overall strategy. A managed and coherent approach to the whole landscape of nuclear engineering, science and technology is required. The relevant Research Councils should ensure that their research and training portfolio meets the needs identified in the roadmap. *(p19)*
4. The panel **recommends** that key strategic input for the Office of Nuclear Development roadmap should come from the National Nuclear Laboratory, in consultation with industry and policy makers. *(p16)*
5. The panel noted that countries with large-scale nuclear power industries such as France and the US also have relatively large pure nuclear physics research programmes. Although the panel did not identify a causal connection between the two, it **recommends** that STFC examines whether operating support for nuclear physics research at a level significantly below international OECD norms is strategically justified. *(p16)*
6. The panel noted with some concern the issue of funding for taught Masters courses in nuclear science and technology. An appropriate funding stream should be established for these courses by the Spring of 2010. The panel **recommends** that the Research Councils should work proactively with the research community to highlight the issue to relevant government departments and work towards a resolution. *(p20)*
7. In addition to recommendation 6, the panel **recommends** that the nuclear physics and nuclear engineering communities, assisted by the Research Councils, should proactively engage with industry to seek out opportunities for further funding for taught Masters courses, particularly through provision of Continued Professional Development courses. *(p21)*
8. The panel **recommends** that the Research Councils jointly and proactively engage with the nuclear physics community and other funding agencies to identify the challenges and opportunities in the areas of nuclear data, healthcare, nuclear forensics and homeland security where nuclear physics can play a key role, and capitalise on the need for technology solutions in these areas. It was recognised that blue-skies research and development spawns novel ideas and technologies, and that challenge-led research and development can bring these technologies closer to the marketplace. *(p18)*
9. The panel felt that there is greater scope for the nuclear physics community to capitalise on application areas generally. The panel therefore **recommends** that the nuclear physics and

[1] The report can be accessed at:
http://www.publications.parliament.uk/pa/cm200809/cmselect/cmdius/50/5002.htm

nuclear engineering communities seek better research links in areas with potential for future economic impact. *(p19)*

10. The panel commented on the need for a vibrant research base and a pool of trained UK nationals when considering the UK's future energy security. The panel **recommends** that the Research Councils work in concert to optimise the links between nuclear engineering, nuclear physics and industry. *(p10)*
11. There are a number of international initiatives underway, cutting across the breadth of the civil nuclear sector, in which the panel feels the UK is currently under-represented. The panel **recommends** that the UK reinvigorate its involvement in the Generation IV International Forum and other related international initiatives. *(p19)*
12. The panel considered two scenarios for the future of nuclear power in the UK and considered that it is very important for the UK to participate in generation IV reactor research. Thus, further to recommendation 11, the panel **recommends** that the Research Councils encourage research into generation IV technologies and related fuel cycle topics. *(p19)*
13. The panel **recommends** that the Research Councils continue to support nuclear engineering research and training through a combination of managed and responsive mode funding. Additionally, responsive mode applications should be actively encouraged. *(p19-20)*
14. The panel **recommends** that the Research Councils explore all possible mechanisms for continuing and increased engagement with industry to maximise the leverage of their funds. Collaboration between universities, the National Nuclear Laboratory and key industrial partners is needed to optimise the impact and effectiveness of the UK's nuclear engineering programme. *(p20)*
15. In order to facilitate recommendation 14, the panel **recommends** that the Research Councils' Energy Programme Letter of Arrangement group be expanded to include additional companies in the nuclear industry as appropriate. *(p20)*
16. Nuclear fission energy should be considered by government with the same status as other low-carbon technologies. The panel **recommends** that inclusion of nuclear fission energy in the remit of the ETI (Energy Technologies Institute) should be considered. *(p22)*
17. The panel **recommends** that the newly built laboratory of the National Nuclear Laboratory at Sellafield be fully commissioned and academic access ensured in order to allow the UK to take full advantage in reinvigorating its nuclear research and to be properly active in the field. *(p22)*
18. The panel noted that presently in the UK there are no civil research reactors for neutron research, medical radionuclide generation and for training the future generation of reactor engineers and physicists. The panel **recommends** that consideration be given as to whether the UK Government in partnership with the healthcare sector and wider nuclear industry should invest in provision of a research reactor for isotope production, materials and other research. *(p17)*
19. The panel **recommends** that the Research Councils' portfolio be examined by a suitably qualified group on a biennial or triennial basis to ensure adequate support of the correct initiatives to support a resurgent nuclear industry. *(p22)*

1 Introduction

1.1 Purpose of the Review

In 2008, a Review of UK Physics was carried out for the Research Councils UK (RCUK) Executive Group by a panel chaired by Professor Sir Bill Wakeham.[2] The purpose of the RCUK Review of Physics, also known as the Wakeham Review, was *'to specifically examine the health of the entire discipline of physics, and the priorities and challenges facing the discipline in the medium to long-term future.'*

The Wakeham Review panel heard evidence from the UK Nuclear Physics community, who had experienced changes in funding arrangements on moving from EPSRC to STFC when the latter was established in April 2007. The Wakeham Review panel noted the need for nuclear physics training in the context of decommissioning old nuclear power plants, building and commissioning new plants and waste disposal. The panel also noted the need for a nuclear physics base in providing training for related application areas and recommended that '*RCUK develop a review of the priorities in nuclear physics research to ensure they best match the needs of the UK.*'

On the same timescale, a number of reviews and studies were carried out with reference to UK skills provision in nuclear engineering and related areas. The House of Commons select committee for Innovation Universities and Skills carried out a study, *Engineering: turning ideas into reality*, which focused on nuclear engineering as a case study for examining skills provision, skills shortages and the roles of government, universities, further education colleges and industry in providing training.

Although these two areas have significant differences, there are synergies, particularly in relation to skills and training. Thus it was felt that a review of the Research Councils' support of these areas in the context of future economic impact was timely.

It is important to note that although the panel has reviewed the scope of research and training activity in nuclear physics and nuclear engineering, no comment on the quality of the research and training in these areas has been made. Reviews of research and training quality are carried out as part of International Reviews and the Research Assessment Exercise and are outside the panel's terms of reference.

It is recognised that the UK Fusion Programme has synergies with nuclear engineering, however the UK's fusion research portfolio was not considered in this review.

Furthermore, this review did not consider issues relating to nuclear weapons, but did include topics relevant to homeland security and healthcare.

1.2 Terms of Reference

The published terms of reference for the review are:

- To review the scope of RCUK funded activity and training in nuclear physics and nuclear engineering in the UK
- To identify the skills and expertise with relevance to future economic impact in related application areas
- To comment on the ability of the scope and volume of the current nuclear physics and nuclear engineering activity to deliver these skills and expertise
- To identify any changes required in the scope or priorities of the nuclear physics and nuclear engineering activity in the UK
- To comment on UK competitiveness in skill and expertise provision

[2] The report can be accessed at: http://www.rcuk.ac.uk/review/physics/default.htm

- To comment on any other issues relating to the provision of skills in nuclear physics and nuclear engineering

1.3 Review Process

EPSRC and STFC approached Dr Sue Ion to chair the review panel. The assembled panel, detailed in section 1.4 was chosen to ensure a wide coverage of the nuclear sector and includes leading figures from academia, relevant national and international industry and the Ministry of Defence.

The panel initially met through a series of teleconferences to agree the terms of reference of the review and make recommendations on the evidence required to satisfactorily meet the terms of reference. EPSRC and STFC provided detailed funding data to the panel members, as well as information on current plans and strategies in both areas. An open consultation was published on EPSRC's and STFC's websites and invitations to submit were sent to the academic community. In addition, individual submissions were invited from relevant stakeholders based on their knowledge and expertise. These included senior university management both in the UK and the US, representatives of industry and other related review panels. The review panel met to consider the evidence gathered, make recommendations and identify any further evidence requirements in July 2009. The panel finalised their main conclusions and recommendations in September 2009.

1.4 Panel Membership

Dr Sue Ion	- Independent Consultant, Chair and EPSRC Council Member
Dr Jonathan Allis	- General Electric Healthcare, represented by Professor Dewi Lewis during the meeting in July 2009
Professor Philip Beeley	- Defence Academy - College of Management and Technology
Professor Jonathan Billowes	- The University of Manchester
Professor Graham Fairhall	- National Nuclear Laboratory
Professor Sir Richard Friend FRS	- University of Cambridge
Dr Regis Matzie	- Westinghouse Electric Company
Professor James Stirling FRS	- University of Cambridge and STFC Council Member

Brief biographies of the panel members are available in Appendix A

1.5 Acknowledgements

The panel would like to thank all those who contributed to the review, either through the open consultation or through invited submissions.

2 Review of the scope of RCUK funded activity and training in nuclear physics and nuclear engineering in the UK

2.1 Nuclear Physics

The majority of nuclear physics research carried out in academic institutions in the UK is funded by STFC. Responsibility for nuclear physics funding has resided with STFC since its creation in April 2007. Prior to April 2007, nuclear physics research was funded by EPSRC through its Physics Programme. Funds for nuclear physics grant applications were allocated primarily through competition with proposals from other areas of physics supported within EPSRC's remit at responsive mode prioritisation panels, supporting investigator-led research. Some areas of research related to nuclear physics such as reactor technology and medical and security applications, still fall within the remit of EPSRC. The remit of applications to the Councils are considered on a case by case basis.

The UK nuclear physics research community currently comprises roughly 55 tenured academics, including 6 theorists, at lecturer through to professorial level, based at around ten universities and research institutions in England and Scotland. In addition to permanently contracted academics, there are around 40 post-doctoral research associates, 100 PhD students and 30 technical staff working on nuclear physics research in the UK. The UK hosts no major facilities for nuclear physics research.

The scope of the current nuclear physics programme covers the following main areas: nuclear structure, nuclear astrophysics, hadron physics, phases of strongly interacting matter and theory. STFC support, totalling approximately £10M p.a., is through a combination of exploitation funding (research activity using existing equipment and infrastructure) and project funding (typically construction of new instrumentation). STFC also supports PhD studentships and fellowships at the level of approximately £1.3M p.a. Subscriptions are also paid for the following activities: ECT* Trento (European Centre for Theoretical Studies in Nuclear Physics and related areas), NuPECC (Nuclear Physics European Collaboration Committee) and ISOLDE (running costs for the accelerator facility at CERN). At present, three major projects are funded:

- AGATA (Advanced Gamma Tracking Array, £3.8M over 4 years),
- PANDA (antiProton Annihilation at Darmstadt, £2.9M over 5 years),
- NuSTAR (Nuclear Structure, Astrophysics and Reactions, £10M over 5 years).

STFC also supports challenge-led research and development programmes for Knowledge Exchange (KE), to identify novel uses of existing skills and technologies within the STFC portfolio, and to develop technology demonstrators and industry-ready prototypes. An example of a project stemming from Nuclear Physics which has been supported through this scheme is discussed later in this report.

2.2 Nuclear Engineering

A research mapping exercise across the whole nuclear sector as part of a study sponsored by the Health and Safety Executive indicated activity in 32 universities with 231 specialists (including the 55 in Nuclear Physics identified above)[3]. The total value of the current EPSRC portfolio of nuclear engineering research and training is around £30 million, which equates to roughly £7 million over the 2009-2010 financial year. This figure excludes support for nuclear fusion through the UK Fusion Programme. The UK Fusion Programme has synergy with nuclear engineering in areas such as the research and development of fusion materials, studies of conceptual fusion power stations, remote handling technology and decommissioning. The science and engineering skills and expertise required for fusion research also have relevance to nuclear engineering. Support in this activity was reviewed in 2007 and for the next phase the Programme received £47m over two years from 1 April 2008.

[3] Roberts, JW. Available at: www.nuclearliaison.com

The current EPSRC nuclear engineering portfolio contains a range of grants from small awards through to large programmes. Both bottom-up, investigator-led research grants awarded through responsive mode funding and grants awarded through targeted calls for proposals are present. Through the Towards a Sustainable Energy Programme and more recently the Research Councils' Energy Programme the Research Councils have actively encouraged and invested in research and trained people that have helped to keep the nuclear option open. Although the majority of funding for nuclear engineering research and training comes through the Research Councils' Energy Programme, funding is also awarded through other EPSRC Programme areas. Research relating to nuclear materials is funded through the Materials, Mechanical and Medical Engineering Programme. Prior to the restructuring of EPSRC in April 2008, research in this area was funded through the Materials Programme. In addition, a small amount of funding for nuclear engineering comes through the Mathematical Sciences Programme.

In 2005, EPSRC took the lead in enabling the establishment of the 4 year, £6.1 million programme 'Keeping the Nuclear Option Open' (KNOO), developed with industry stakeholders and Government. The KNOO consortium involves 18 investigators and around 45 PDRAs and PhD students at seven UK universities. KNOO is addressing issues such as fuel cycles and fuel management, future reactor systems including generation IV technologies, waste management, storage and decommissioning and extending existing plant lifetime through materials science and technology.

EPSRC has agreed a Letter of Arrangement (LoA) with the Ministry of Defence, the Atomic Weapons Establishment, British Nuclear Fuels plc (now the National Nuclear Laboratory, NNL), British Energy plc, the Health and Safety Executive and the Nuclear Decommissioning Authority. The LoA group work together in areas of common interest in research and training to sustain critical nuclear related capabilities. The first activity under this LoA was to establish a Nuclear Engineering Doctorate Centre, which is a partnership between the University of Manchester and Imperial College London, and involving four additional universities. From October 2006, this centre recruited 10 students each year for a 4-year, industrially relevant doctoral training programme. It received further funding from the recent EPSRC call for Centres for Doctoral Training run in 2008. In addition, funding for the Nuclear Fission Research, Science and Technology Doctoral Training Centre to be led by the Universities of Sheffield and Manchester was awarded. Both centres will have their first intake of students in October 2009 and will train 50 students each over the period 2009 – 2018.

A recent report commissioned by the Technology Strategy Board and the Regional Development Agencies (RDAs) found that the UK has very strong research and development capabilities in the following areas[4]:

- Advanced reactor core modelling for both currently used and future reactor systems
- Fuel cycle modelling
- Fuel performance modelling
- Structural integrity
- Graphite technology
- Materials ageing and prediction
- Waste and effluent management
- Non-destructive examination
- Advanced construction methods
- Decontamination and decommissioning

2.3 Panel Comments

The panel identified a number of potentially critical interests not all of which are the preserve of the Research Councils. In fact it is vital that the Research Councils work closely with the relevant key departments of government – DECC, DBIS, MoD, Home Office, FCO – all of whom should have an interest in the sustainability of the skill and capability base underpinning nuclear topics across the full spectrum of issues, for the furtherance of UK policy on the international stage and in the

[4] AH Sherry, PJA Howarth, P Kearns and N Waterman. *R&D to Create Opportunities for the UK in the Worldwide Nuclear Renaissance.*

national interest for access to highly specialised advice. The panel **recommends** that the Research Councils should be proactive in discussions with the key government departments.

Although the panel did not review the quality of nuclear physics research in the UK, the panel recognise that the research carried out by the nuclear physics community has been identified as high quality, through the most recent International Review of UK Research in Physics and Astronomy in 2005[5] and the 2008 Research Assessment Exercise[6]. In a submission to the panel, the Chair of the RAE2008 Physics Sub-panel, Professor Sir John Pendry FRS noted that "…the work that was submitted to RAE2008 in nuclear physics was excellent overall with a very high fraction of the overall quality profiles at 2* and above. In common with other areas of physics there was also evidence of excellence from early career researchers." The panel also acknowledge the difficulties the nuclear physics community has faced in the transfer from EPSRC to STFC, and that the community is currently operating in a challenging financial landscape. The panel noted that the support for nuclear physics in the Universities is significantly below its international competitors.

The panel also noted some examples of activity around applied nuclear physics research and considered that there is significant potential to expand these activities where appropriate funding opportunities exist. Although the panel recognise that the community do not wish to dilute the quality of their core research efforts by branching out into other areas, it feels that the nuclear physics community has much to offer to application areas including nuclear power, medicine and homeland security. These areas and potential contributions are explored further in subsequent sections.

With regard to nuclear engineering research, the panel noted with approval the resurgence of nuclear engineering research programmes in the UK, but commented that the current portfolio of Research Council-funded research is focused heavily on waste management and decommissioning. The limited amount of research being carried out into new reactor systems is not sufficient to underpin the requirements of a resurgent nuclear sector. However, the panel supports the shift towards fuel, reactor systems and materials research apparent in the current call for research consortia from the Research Councils' Energy Programme. The panel commented on the need for a vibrant research base and a pool of trained UK nationals when considering the UK's future energy security. The panel **recommends** that the Research Councils work in concert to optimise the links between nuclear engineering, nuclear physics and industry.

The panel welcomed the recent initiatives targeted at training and skills for the nuclear industry, such as the Nuclear Engineering Doctorate and the National Skills Academy for Nuclear[7].
The panel supported the continuing development of these programmes, and felt that they would play a key role in reinvigorating the nuclear industry.

Wider recommendations associated with the breadth and volume of the portfolio in nuclear science and engineering more generally are made in subsequent sections.

---

[5] The 2005 International Review of UK Research in Physics and Astronomy was co-ordinated by the Institute of Physics on behalf of the EPSRC, PPARC and the Royal Astronomical Society, see http://www.iop.org/activity/policy/Projects/International_Review/

[6] http://www.rae.ac.uk

[7] The National Skills Academy for Nuclear was established in 2008 with a mission to 'create, develop and promote world-class skills and career pathways to support a sustainable future for the UK nuclear industry'. The Academy addresses higher-level skills as well as vocational and technical skills. The Academy has developed a range of initiatives, including the proposed Certificate of Nuclear Professionalism, which will focus on behaviours, project management and commercial skills, and will be delivered in partnership with Cranfield University and the Open University.

3 Identification of the skills and expertise with relevance to future economic impact in application areas related to nuclear physics and nuclear engineering

3.1 Research Councils Impact

The Research Councils describe economic impact as the demonstrable contribution that excellent research makes to society and the economy. Impact embraces all the extremely diverse ways in which research-related knowledge and skills benefit individuals, organisations and nations by:

- fostering global economic performance, and specifically the economic competitiveness of the United Kingdom,
- increasing the effectiveness of public services and policy, and
- enhancing quality of life, health and creative output.

Impacts from research can take many forms, become manifest at different stages in the research life-cycle and beyond, and be promoted in many different ways.

The panel recognised the importance of the provision of highly trained and knowledgeable people in nuclear topics. It was felt to be in the national interest to maintain and develop our skill and capability across the full spectrum of nuclear issues. This will enable the UK to make well-informed decisions on its future energy supply, on regulatory and safety matters, and to influence global issues associated with non-proliferation and international nuclear security. The panel felt that the research councils had a key role to play in supporting this knowledge base.

3.2 Consultation Summary and Panel Comments

As part of the consultation for this review, respondents were asked to identify the skills and expertise which are relevant to future economic impact in application areas related to nuclear physics and nuclear engineering. The open consultation responses, and those from other stakeholders, covered skills in distinct application areas including the power sector, medicine, safety and homeland security. In the power sector, the respondents considered the skills in the following areas to be relevant:

- Criticality assessment
- Fuel cycle analysis
- Fuel design and manufacture
- Radiation monitoring
- Management and disposal of radioactive waste
- Reactor physics, kinematics, thermal hydraulics (including research and development into future reactors)
- Decommissioning
- Reprocessing of spent fuel
- Control systems
- Fusion research

Respondents noted and panel members agreed that in the nuclear industry there is a requirement for a significant uplift in training provision at a number of levels and across a very broad range of topics and disciplines, including:

- Apprentice and technician level engineers with awareness of nuclear safety and quality issues;
- Graduates having gained an appreciation of nuclear issues relevant to their mainstream science and engineering degree;
- Top-end masters and doctoral level training covering specific nuclear topics;
- CPD which is particularly important in the nuclear industry and requires cooperation between industry and academic institutions

The panel agreed with the views expressed by the Royal Academy of Engineering in its input to the House of Commons Engineering Enquiry ”that there is a need for a much more coordinated approach to the provision of nuclear reactor design and operating education and training. It is not sufficient to fund MSc courses; new staff at post-doctoral level and a research culture at PhD level are also required to sustain internationally competitive research groups and a new knowledge base from which research results can ‘trickle down’ to MSc and undergraduate teaching.”

In the medical/healthcare sector, respondents felt skills required included those in:

- New detectors, advanced instrumentation and imaging techniques
- Medical techniques and medicine, operation of radiation facilities in hospitals
- Radiobiology

In terms of health and safety, respondents highlighted a need for skills in the following areas:

- Radiation protection/shielding/handling
- Health Physics
- Safety regulation, international compliance and inspectorate skills
- Remote control and operations

Many respondents commented on the generic skills required for work in these application areas. Project and risk management, financial appraisal, problem solving, team working and general research and development skills were all highlighted as necessary to ensure future success.

In addition, distinctions were made between skills which were primarily felt to be either physics- or engineering-based. Skills based in physics disciplines included:

- Measurements of nuclear decay, masses and cross section data
- Development of radiation sources, for instance wakefield accelerators
- Development of novel detectors/sensors
- Nuclear processes and reactions, properties of radiation
- The ability to contribute to international research in nuclear physics
- Code development and data analysis, modelling, statistics
- Laser techniques
- Vacuum systems

Skills based in disciplines with relevance to nuclear engineering which were highlighted included those in:

- Civil engineering
- Systems engineering
- Electronic engineering
- Mechanical engineering
- Human Factors

Respondents also felt that key skills from other disciplines, such as radiochemistry, corrosion chemistry, metallurgy and materials science and chemical engineering were required to ensure maximum future economic impact in application areas related to nuclear physics and nuclear engineering. They also felt that transfer of skills such as project management and risk assessment from other industries, for example the oil industry, is vital to ensuring future success in the nuclear industry. Many respondents noted the need for proper public engagement and education, particularly the need for contributing impartial expertise to the public debate surrounding application areas.

The panel agreed with the skills and expertise needs which had been identified through the consultation process. In all application areas, the panel felt that a vibrant, healthy research base is a key component in providing a high quality training programme and skills base.

In considering necessary skills for future nuclear power applications, the panel considered two scenarios regarding levels of nuclear new build, which are further detailed in following sections. In the first scenario, new nuclear power stations with output totalling 12 GW would be built, using existing nuclear reactor technology. No reprocessing of fuel would be carried out, waste management would concentrate on cleanup and disposal. In a scenario where new nuclear power stations with output totalling 30 GW are required, skills beyond those noted through the open consultation are required. These include:

- Fuel cycle research, including waste management
- Generation IV reactor systems
- Generation III/LWR sustainability and efficiency
- Repository issues
- Increase in homeland security and nuclear forensics

The panel considered that the necessary breadth of skills for future nuclear power applications would be highly dependent on the volume and timescale of any planned nuclear new build. Therefore, a high level strategy incorporating all relevant stakeholders is needed in order to accurately plan for future needs. The panel foresees a skills deficit associated with the teaching of nuclear topics in the coming years. Resources have been running at low levels, often with emeritus staff, in the light of low levels of student demand when nuclear was an unfavourable topic. Many of the UK's most important science and engineering departments are now seeking to include relevant modules in their undergraduate degrees. The availability of research funding for a wide range of endeavours within the overall nuclear spectrum will be important in ensuring that emergent academic groups thrive and are in a position to deliver cutting edge teaching.

The panel also received data on the destination of graduates from four nuclear-related Masters courses:

- Nuclear Technology Education Consortium MSc in Nuclear Science and Technology. This course has the capacity to train 15-20 full-time students per year alongside a similar number of part-time students from industry. The data provided to the panel covers the academic years 2005/2006 and 2006/2007.
- University of Birmingham Physics and Technology of Nuclear Reactors MSc. This course typically trains 30-40 students per year. The data provided to the panel covers the academic years 2006/2007 and 2007/2008.
- University of Liverpool Radiometrics: Instrumentation and Modelling MSc. This course typically trains 5-10 students per year. The data provided to the panel covers the academic years 2003/2004 through 2007/2008.
- University of Surrey MSc in Radiation and Environmental Protection. This course typically trains 20-25 students per year. The data provided to the panel cover the academic years 2002/03 through 2006/2007.

During the time periods covered, over 120 graduates of these courses went on to employment in the UK nuclear industry. The panel felt these courses deliver valuable training in a range of topic areas and are a very important route for the flow of trained people into industry.

The panel felt that although the numbers of students trained on the existing nuclear science and technology Masters courses are relatively low, they are very valuable to this strategically important area and expressed concern over the funding gap which has arisen. This issue is further detailed in Section 5.

4 Comment on the ability of the scope and volume of the current Nuclear Physics and Nuclear Engineering activity to deliver the necessary skills and expertise for future economic impact

The panel considered the ability of the scope and volume of the current Nuclear Physics and Nuclear Engineering activity to deliver the necessary skills and expertise for future economic impact in three major areas: nuclear power, medicine and homeland security.

Nuclear Fission Industry
Government has indicated a move towards new nuclear build motivated by carbon emission reduction targets and the need for a secure energy supply. Government has also indicated a desire for the UK to be a major player and significant influence in matters associated with the non-proliferation and international nuclear security agenda. The panel considered two scenarios for the future of nuclear power in the UK. The first represented the 'minimal' scenario in which the UK maintains its current generating capacity in the nuclear power sector – approximately 12 GW of power, using existing technology. In this scenario the present waste management techniques would be used, and advanced fuel cycles and fuel reprocessing would not feature.

The second represented a much higher but still realistic new build scenario given the Government's CO_2 reduction targets to 2050 and energy security issues. In this case one would expect the UK's nuclear generation capacity to be in the region of 30 GW, which would need to be in place by ~2030 in order to meet the carbon reduction targets for 2050.

Scenario 1
In this scenario, the UK would require eight to ten new reactors of an existing design to be constructed, operated and maintained. The panel's discussions were informed by the recent report from Cogent, the Skills Sector Council[8] on the current civil nuclear workforce, which was based on this 'replacement capacity' scenario for new build, and placed in the context of the existing legacy of the UK's current fleet of reactors. The report concluded that the present workforce, assuming recruitment levels of 500-1000 every year to 2025, would be sufficient to meet the UK's need. The majority of the recruitment would be required at apprentice and graduate level. The report noted that the major challenge will be balancing the workforce between short-term expansion in decommissioning, medium term contraction in energy production, and long-term expansion in new-build commissioning and operation. The age profile of the civil nuclear workforce meant that retirement was the main driver of recruitment requirement. This scenario would see a modest and slow decline in the operating workforce predicted out to 2025. The panel considered that this indicated that no skills crisis was expected in the minimal new-build scenario. It was, however, important that the UK maintained a well-trained workforce (as opposed to buying in expertise from overseas) in order to achieve energy security.

The panel considered the probable research and development requirements in this scenario. It was noted that a steady flow of graduates into the nuclear fission industry would still be required. It was therefore considered important that the UK maintains its teaching capacity in universities in nuclear-related areas – encompassing many disciplines such as physics, chemistry, engineering and materials. This was considered key to ensuring that the supply-chain to industry of the brightest and most able graduates was maintained. The panel felt that the best way to maintain teaching capacity was to continue to support research and development in universities in cutting-edge areas such as Generation IV technology and advanced fuel cycles. It was felt that a vibrant research base was justified and indeed necessary to maintain the UK's capacity in nuclear power across all sectors of the nuclear industry. Considering that the national base of trained personnel will be required over a number of decades for operation, safety and maintenance, it was felt to be wise to invest long-term in research and development, looking to the next generation of reactor technology.

---
[8] *Power People: The Civil Nuclear Workforce 2009-2025*, published August 2009. The report can be accessed via: http://www.cogent-ssc.com/research/Publications/NuclearReportPowerPeople.pdf

- In the minimal new build scenario, the panel felt that the current level of the Research Council nuclear-related portfolio was adequate to meet the needs of the nuclear industry, however the UK would not be a world leader in nuclear technology and skills provision.
- A steady flow of graduates into the nuclear industry will be required if the UK is to achieve energy security.
- It was considered that even in this scenario, investment in generation IV technologies and advanced fuel cycles was justified.

Scenario 2

The UK Department of Energy and Climate Change recently published '*The UK Low Carbon Transition Plan'*[9]. The plan anticipates that 'by 2050 virtually all electricity will need to come from renewable sources, nuclear or fossil fuels where emissions are captured and safely stored for the long term'. Thus, the panel felt that it was conceivable that 30 GW capacity would be required from nuclear power in order to meet the Government's carbon reduction targets. This would mean building 25-35 new reactors[10] at a rate of 2-3 per year through to 2030. In this scenario the requirements on the workforce, research and development base and teaching capacity become radically different to scenario 1, in which maintaining the steady state was considered to be adequate.

The requirement for skilled, knowledgeable personnel across the whole spectrum of top-end skills in the civil nuclear industry would increase significantly. The panel considered that a major increase in nuclear engineering research and development would certainly be required in the following areas: sustainable fuel cycles, generation IV reactor systems, efficiency and sustainability in current generation III designs, waste management, homeland security, nuclear forensics and radiological engineering. The present level of nuclear engineering research and development activity in the UK would be wholly insufficient both in terms of scope and volume. It was noted that, whilst a portion of the research and development would be performed by industry, that the intellectual challenges presented in many of the aforementioned areas would demand a significant increase in university-based research. Partnerships between academia and industry would be key to facilitating the technological advances required. The current Research Council portfolio would therefore need to be significantly expanded, and more courses in nuclear science and technology would be required both at undergraduate and graduate level.

In a world where there is much enhanced use of nuclear energy and the UK potentially has on the order of 35 generation III+ reactors, supply of fuel (uranium availability) and long term sustainability rise to the fore as issues. It becomes much more likely that the UK will need to have recycling as an option and the ability to deploy Fast Reactor[11] technology. Additionally, it becomes imperative to properly and responsibly manage the nuclear waste, not only from an environmental perspective but also from non-proliferation considerations. High temperature gas-cooled reactor technology with the ability for multiple missions, for example heat and H_2 production as well as electricity, may also become attractive for the UK.

Whichever scenario the UK follows, the global use of nuclear energy is expected to significantly increase. In this context, the requirement for research and development into counter-terrorism

---

[9] The report can be accessed via:
http://www.decc.gov.uk/en/content/cms/publications/lc_trans_plan/lc_trans_plan.aspx

[10] Depending on choice of reactor design

[11] In a fission reactor, power is produced when an atom of fissile material (the fuel) is hit by a neutron, which then becomes unstable and breaks up, releasing energy in the process. Reactors can be classified by the speed of the neutrons, which determines the characteristics of the fuel burning process. 'Fast reactors' (i.e. using fast neutrons), can create more fuel in the form of Plutonium than they use, or maintain the Pu inventory in balance, depending on mode of operation. They can also destroy (transmute) many of the dangerous long-lived waste products, unlike in conventional reactors where these by-products would need to be treated and stored. Fast reactors therefore will play an important role in achieving sustainable, proliferation-resistant fuel cycles in the future.

technologies and nuclear forensics would increase, as well as the need for a proliferation-resistant fuel cycle and a robust, well-informed regulatory structure where the UK would wish to influence any international initiatives and can only do so if actively engaged in relevant cutting edge research and development. This means that the UK needs to be actively participating now in global efforts to develop proliferation resistant fuel cycles and to bring fast reactors and high temperature gas-cooled reactors, and their associated fuel cycles, to the point that they are realistically deployable options.

Furthermore, the nuclear sector would become a significant part of the UK economy in this scenario. The panel therefore considered that it would make good business sense to have a healthy, vibrant research base within the UK. Not only would this aid the supply-chain of skilled personnel to industry, but would also ensure that the UK retained the intellectual property (IP) generated, and that associated spin-off companies would be spawned within the UK.

Summary

The above analyses are illustrative of the dependency on the Government's intentions for new nuclear build of the UK's needs in terms of trained personnel and scope and volume of research and development activity. It is therefore clear that a high-level national strategy for nuclear is required, with a roadmap which defines how our future nuclear capability is to be achieved. This needs to be done on such a timescale as to enable industry, the higher education sector and the research councils to realign their priorities, to create the required intellectual and technological capacity. It is emphasised that the scenarios presented are illustrative only, and that a thorough, in-depth analysis of workforce and research and development needs would be required as part of the roadmapping exercise.

The panel are therefore supportive of the recommendations made in the recent House of Commons Innovation, Universities and Skills select committee report on engineering which highlighted the need for a comprehensive roadmap for nuclear, to be owned by the Office of Nuclear Development. The panel **recommends** that the roadmap should consider the need for a balanced portfolio of research in nuclear engineering in the UK to serve the short-, medium-, and long-term needs of the country. The panel **recommends** that key strategic input should come from the National Nuclear Laboratory, in consultation with industry and policy makers. The panel feel that planning the future research agenda will only be possible with a comprehensive roadmap. The Research Councils have a key part to play in developing this roadmap and the panel encourage proactive engagement with this process.

The panel emphasised the importance of a diverse research portfolio in nuclear engineering to ensure future economic impact. The current Research Council portfolio is heavily geared towards decommissioning and waste management; the volume of research into more forward-looking areas such as reactor design is currently sub-optimal.

The panel noted the evidence submitted by the nuclear physics community regarding the destination data for PhD students. Since 2003, 26 PhD graduates in nuclear physics have found employment in the nuclear sector, of which eight are in defence. Whilst it was not clear the highly specialised knowledge gained during a PhD was truly required by industry, it was recognised that the transferable skills gained, such as research skills, team-working and problem solving were highly valuable. It was noted that countries with large-scale nuclear power industries such as France and the US also have relatively large pure nuclear physics research programmes. Although the panel did not identify a causal connection between the two, it **recommends** that STFC examines whether operating support for nuclear physics research at a level significantly below international OECD norms is strategically justified.[12]

[12] The panel received evidence from the UK nuclear physics community comparing support for nuclear physics in the UK to other countries. This document drew on evidence from the OECD Global Science Forum report by the Working Group on Nuclear Physics and can be accessed at http://www.oecd.orf/sti/gsf and a 2006 survey by NuPECC (an Expert Body of the European Science Foundation) which can be accessed at http://www.nupecc.org/pub/survey2006.pdf.

However, the panel felt that the nuclear physics community has a significant contribution to make in counterterrorism, healthcare, nuclear forensics, radiation protection and environmental applications, which are discussed in more detail in the following sub-sections. Their novel detector development work through projects such as AGATA has already made an impact in these areas and the panel felt there was potential to do more. In addition, the panel noted that in the UK, research in nuclear data relevant to the nuclear industry covering both new reactors and spent fuel management has considerably decreased over the last 20 years due to a reduction in funding. This has resulted in academics moving to fundamental physics research. However, the skills of nuclear physicists in nuclear structure and fission are considered particularly important as a resource for future needs in decommissioning, waste management, new reactor design and safe reactor operation.

Healthcare

The issue of radioisotope production for medical imaging scans[13] was highlighted to the panel. It was recognised that there has always been a need for nuclear research reactors which could be used to carry out reactor materials testing, fuel fabrication experiments, reactor core design, radioisotope production, medical technologies, and fundamental neutron physics research. In the mid 1970s the International Atomic Energy Agency recorded 470 such reactors in operation, but due to aging and funding cessation it is estimated that by 2009, there are less than 240 still in operation. Presently, in the UK there are no civil research reactors for neutron research, medical radionuclide generation and for training the future generation of reactor engineers and physicists.

The nuclear medicine imaging industry is now facing a crisis situation due to the limited supply of the 6-hour half-life radionuclide ^{99m}Tc. Globally there are 35 million nuclear medicine imaging scans per year, and around 80% of which use ^{99m}Tc. Technetium is supplied to hospitals in the form of a three-day half life parent ^{99}Mo, which is produced in research reactors. Because of the demanding technical nature of producing ^{99}Mo, very few of the world's research reactors have the technical specifications, and 95% of the world's ^{99}Mo is generated in only five research reactors – and these few reactors are facing problems of ageing and disrepair. There are very few new reactors available to replace these ageing facilities.

It is noted that the UK is one of the very few nations with a commitment to future nuclear power generation but no civil research reactor capability. The panel felt that the provision of a research reactor could fulfil a very important role in research and development for future nuclear power generation, in training reactor engineers and physicists, and in helping to support the global supply chain of isotopes for medical applications. The panel **recommends** that consideration should be given as to whether the UK Government, in partnership with the healthcare sector and wider nuclear industry, should invest in provision of a research reactor that could also produce radioisotopes.

Homeland Security and Counterterrorism

The review consulted Dr Dick Lacey, the Chief Scientist in Chemical, Biological, Radiological, Nuclear and High-Yield Explosives (CBRNE), at the Home Office Scientific Development Branch (HOSDB). He noted that several nuclear techniques have been applied in the field of counter-terrorism, for the detection of explosives, chemical agents and drugs. To exploit these techniques, we need physicists, experienced nuclear instrumentation users, spectroscopists, computer programmers and for some applications radiochemists.

The panel recognised that the work of the UK nuclear physics community in blue-skies detector research and development has direct relevance to challenges in counter-terrorism and nuclear forensics.[14] Similar technologies also have relevance to medical diagnosis and imaging

[13] D M Lewis, *Eur J Med Mol Imaging*, 2009, 1371-1374, DOI: 10.1007/s00259-009-1171-4
[14] See, for example, the DISTINGUISH project - http://ns.ph.liv.ac.uk/imaging-group/projects/distinguish/index.php

techniques. The panel noted that the nuclear physics community has a track record of developing its technologies for real-world applications, and felt that the community should be encouraged to pursue these projects to expand and enhance its economic impact.

The panel **recommends** that the Research Councils should jointly and proactively engage with the nuclear physics community and other funding agencies to identify the challenges and opportunities in the areas of nuclear data, healthcare, nuclear forensics and homeland security where nuclear physics can play a key role and capitalise on them. It was recognised that blue-skies research and development spawns novel ideas and technologies, and that challenge-led research and development can bring these technologies closer to the marketplace. If funds are available, a combination of both approaches would therefore be appropriate to support these initiatives.

Case Study: Nuclear Physics leading to advances in medical imaging techniques*. A collaboration between nuclear physicists at Liverpool University and Daresbury Laboratory and the NHS, supported by STFC, is leading to significant improvements in SPECT (Single Photon Emission Computed Tomography) imaging sensitivity. The main application of this work will be in cardiac and brain imaging, and in early diagnosis of tumours. Using specialist expertise in digital electronics, semiconductor detectors and software design, originally developed for nuclear physics detectors such as AGATA, this project will deliver a clinically-evaluated demonstrator of the device. Potential commencement of sales will be in 2014, with a market value of up to £26M. In addition to medical use, the final product will also find application in other sectors such as homeland security, decommissioning and environmental monitoring.*

5 Identification of changes required in the scope or priorities of Nuclear Physics and Nuclear Engineering research and training activity in the UK

Nuclear Physics

The panel acknowledged that recent funding cuts had damaged the UK's Nuclear Physics community, and that the size of the community now meant that it was extremely vulnerable. It was recognised that financial pressures have an adverse effect on the ability of the Nuclear Physics community to realise its potential in economic impact areas. It was felt that further funding cuts could be terminal, resulting in the loss of an important skill set which would impact the delivery of Masters courses. This concurred with the view of many respondents to the open consultation who felt that within the academic community, sustained provision for PhD studentships, PDRAs and early career fellowships is required to foster research excellence, expand the UK's research expertise and positively impact the volume of the corresponding skills base. The panel considered that it was not within its remit to comment on the scope or quality of the pure research activities of the Nuclear Physics community; but recognised that other reviews, such as the 2005 International Review of UK Research in Physics and Astronomy and the 2008 Research Assessment Exercise had commented on the excellence of their endeavours. However, the panel did feel that there is greater scope for the Nuclear Physics community to capitalise on application areas. Thus, the panel **recommends** that the Nuclear Physics community should:

- seek better research links with the Nuclear Engineering community and the nuclear fission industry
- look to expand research efforts to increase contributions to the healthcare industry as well as homeland security and counterterrorism efforts.

The panel **recommends** that the Research Councils proactively engage with the community to identify the opportunities in these areas and capitalise on them.

Nuclear Engineering

In both of the scenarios described in the previous section, it was considered important that the UK participates in generation IV reactor research. A demonstrator of a sodium cooled fast reactor (one of the six possible generation IV designs) will be constructed in Europe on the timescale of ~2020-2025, and the technology is expected to be commercialised and in operation by ~2040. Thus if the UK does not reinvigorate its involvement now, it will be adrift of global efforts in research and development for next generation reactors and their associated fuel cycles. In addition the panel felt that the UK is unique in having a wealth of data and operating experience from the fleet of UK gas-cooled reactors which would benefit generation IV technologies; this should be capitalised on. This could be thought of as analogous to the UK's contribution to ITER,[15] and the panel stressed that the intellectual challenges of this research are certainly equal to those involved in designing and building the world's first fusion reactor. Indeed, there are areas of synergy between the two. The panel **recommends** that the UK should reinvigorate its involvement in the Generation IV International Forum (GIF)[16] and play a leading role in other related initiatives. A modest investment, on the order of £1M/year, would facilitate re-engagement and would have significant leverage. Furthermore, the panel **recommends** that the Research Councils should encourage research into Generation IV technology and related fuel cycle topics.

Noting that the volume and scope of research and development will be proportional to the UK's plans for future nuclear build, the panel **recommends** that the Research Councils actively engage with the Office of Nuclear Development roadmapping exercise for nuclear energy to determine their place in the overall strategy. A managed and coherent approach to the whole landscape of nuclear engineering, science and technology is required. In addition the relevant Research Councils should ensure that their research and training portfolio meets the needs identified in the roadmap, and regularly review their research portfolios and support mechanisms. The panel

[15] http://www.iter.org/default.aspx

[16] Generation IV International Forum: The GIF is a forum consisting of countries collaborating on the research and development needed for a future generation of nuclear energy systems. The GIF has created a legal and organisational framework for this cooperation, bringing together the resources of its member nations. The GIF has 13 members (Argentina, Brazil, Canada, China, Euratom, France, Japan, South Korea, Russia, South Africa, Switzerland, UK, USA), of which three are non-active members (Argentina, Brazil, UK).

recommends that the Research Councils should continue to support nuclear engineering research and training through a combination of managed and responsive mode funding. Additionally, responsive mode applications should be actively encouraged.

Greater collaboration between universities, the NNL and key industrial partners is needed to optimise the effectiveness of the UK's nuclear engineering programme. The panel therefore **recommends** that the Research Councils should explore all possible mechanisms for engagement with industry to support its initiatives, to maximise leverage. In order to facilitate this process the panel **recommends** that the Research Councils' Energy Programme Letter of Arrangement group should be expanded to include additional companies in the nuclear industry as appropriate.

Training

The panel recognised that the nuclear physics community had an important role to play in the delivery of existing Masters courses in nuclear science and technology, but noted that their specific expertise covers only a small fraction of the much broader landscape of topics and skills needed for future nuclear build. It was therefore suggested that universities take a coherent, cross-departmental approach to teaching, involving a number of different disciplines. The panel felt that the level of nuclear physics required by an individual going into the nuclear power industry was not necessarily particularly advanced. Whilst the ideal situation would be to have all MSc components taught by specialists, it was considered that much of the nuclear physics material could probably be taught by non-specialist physicists, and hence universities should not necessarily consider this to be a barrier to establishing more nuclear power related MSc courses or to inclusion of nuclear modules within a wide range of undergraduate science and engineering courses.

The panel noted with some concern the issue of funding for Masters courses, which was raised in many of the open consultation submissions. The panel understood that Research Council funding had recently been withdrawn, because taught postgraduate courses were considered to be outside their remit. However, no alternative funding source had been put in place prior to the withdrawal of Research Council funding, which happened at short notice. The outcome is likely to be that viable and highly relevant Masters courses will become rapidly unviable unless an alternative funding source is established. An appropriate funding stream should be established for taught Masters courses in nuclear science and technology. The panel **recommends** that the Research Councils should work proactively with the research community to highlight the issue to relevant government departments and work towards a resolution by the Spring of 2010. In addition, the community, assisted by the Research Councils, should proactively engage with industry to seek out opportunities for further funding, particularly through provision of Continued Professional Development courses.

Universities are encouraged to introduce more nuclear-specific modules to undergraduate courses to support the flow of graduates into nuclear related research and development work and into industry. This would apply to a wide range of disciplines, to reflect the breadth of skills and expertise required in nuclear engineering. There is anecdotal evidence of a renewed interest from students in nuclear-related courses. Institutions in the UK might look to successful university training models in other countries; it may be appropriate to mirror what is being done elsewhere. The panel notes that key university departments overseas have vibrant research and development efforts in nuclear engineering, and would expect the UK to be similarly engaged. It is therefore important that the UK research base is forward-looking and appropriately supported not only to drive nuclear technology forward, but also to maintain high-quality teaching capabilities. This will be key to enabling the UK to develop well-informed national policies. As noted in the discussion of the scenarios in the previous section, the volume of research and development will largely depend on the scale of the UK's aspirations for new nuclear build.

The panel noted the importance of Continued Professional Development (CPD), and felt that this would play a key role in maintaining and enhancing the skills of people currently working in the nuclear industry. Industry must align itself to changing national priorities, which will be achieved more swiftly by adopting a through-life approach to training, rather than relying solely on graduates emerging from university. Again, the importance of collaboration between industry and academia is emphasised.

6 UK Competitiveness in skill and expertise provision

6.1 Consultation Summary and Panel Comments

During the consultation phase of the review, respondents were asked to consider UK competitiveness in skill and expertise provision in application areas related to nuclear physics and nuclear engineering.

Many respondents highlighted the UK's previous track record in producing world leaders in both nuclear physics and nuclear engineering and particularly noted the strengths of past industry/academia partnerships. The consensus among many respondents, both national and international, was that although the UK currently has pockets of internationally leading research and development in a range of areas and a substantial knowledge base from past activities, the low volume of current activity has had a detrimental impact on the UK's competitiveness as a skills provider. Also there is a perception reinforced by international respondents that the UK is invisible through absence in any practical sense from the international initiatives like the Generation IV International Forum but also from key academic interactions such as that coordinated by the ENEN (European Nuclear Education Network) Many noted the potential of the UK to both regain its place as a leading provider of highly skilled people in the nuclear industry and become a leading provider of skilled people in radiological protection, medical applications and homeland security.

The panel endorsed these points and felt that along with the UK's current research and development strengths, there is substantial legacy knowledge and nuclear data held in the UK which puts it in a unique position.

Many of those consulted noted that the likely world-wide resurgence of the nuclear industry may limit the UK's short-term options as importing skilled people from abroad may be neither possible nor practical. The panel concurred with this view and commented that for the UK to retain security of supply in any future energy scenario which includes nuclear new build, a substantial fraction of the workforce will need to be UK nationals.

In the panel's view there is currently a window of opportunity to capitalise on what is already recognised as an internationally competitive research base, based on the UK's historic investment and residual expertise. The UK should take advantage of the possibility of joining current international initiatives where any investment we might make will be significantly leveraged. This includes but is not limited to the Generation IV International Forum. We do not believe this is adequate and steps should be taken by OND to enable UK experts and assets to contribute to the global endeavour. Full advantage should also be taken of the opportunities presented by the Sustainable Nuclear Energy Technology Platform (SNETP) launched by the European Commission in May 2009 which will set the agenda for European Community research through the Euratom framework programmes. This offers our key universities and academic groups the chance to make significant contributions in areas of existing UK strength in structural materials, materials ageing, modelling and simulation, fuel and associated fuel cycles targeted to minimise proliferation risk and minimise waste and for any Research Council investment to be significantly leveraged.

Amongst both the consultation respondents and the panel, there was strong support for the provision of training in the nuclear physics and nuclear engineering through MSc-level courses. The panel recognised that although these courses are primarily delivered by the UK nuclear physics community, they ensure a good breadth of training across physics, engineering and materials science. The consultation highlighted concern that the low volume of people trained through the current provision of courses is not enough to make a sustained international impact. The panel echoed this concern and also noted the detrimental effect of the change in funding arrangements for MSc courses through the Research Councils. However, the panel appreciate the reasons for the change in funding and do not suggest a further change in Research Council policy. In addition, the panel **recommends** that the community proactively engage with industry to seek out opportunities for further funding, particularly through provision of Continuing Professional Development courses.

7 Other issues relating to the provision of skills in Nuclear Physics and Nuclear Engineering

The panel noted that the active laboratory at the NNL in Sellafield is a state of the art facility, and has the potential to be a major asset to UK research and development for the fission industry. However, the facility has not yet been commissioned for use. Several respondents to the open consultation commented that the UK has a history of producing world-leading experts in nuclear engineering, which was developed through academic links to national facilities such as Harwell, Risley and Sellafield, but which are now either closed or extremely difficult to access. It was felt that the UK's ability to re-establish its track record would be greatly enhanced by enabling academic access to existing nuclear facilities. The panel therefore **recommends** that the NNL's laboratory should be fully commissioned as a high priority, and that suitable arrangements are made for academic access to the laboratory. This would be a key enabler in reinvigorating research for generation IV technologies and associated fuel cycles.

The panel **recommends** that a suitably qualified group examines the Research Councils portfolio on a triennial basis to ensure adequate support of the correct initiatives to facilitate the resurgence of the UK nuclear industry. It is clear that a balanced portfolio will be required to support the UK's short- medium- and long-term requirements.

The panel **recommends** that nuclear power is considered by Government with the same status as other low-carbon technologies. A starting point would be the inclusion of nuclear in the remit of the Energy Technologies Institute (ETI). The ETI was established as a Limited Liability Partnership between international industrial companies with an aim to speed up the development and demonstration of energy technologies and shorten the lead times to market. In particular, its objectives include: reducing greenhouse gas emissions, accelerating development and deployment of affordable low carbon technology solutions, increasing security of energy supply in conjunction with greenhouse gas mitigation, increasing the level and capacity of the low carbon skills pool. The panel considered that nuclear fission energy will play a major part in achieving these objectives and feel it is sensible to include nuclear fission energy in the remit of the ETI as several of the industrial board members have strong nuclear interests and may otherwise support the funding of specific nuclear projects relevant to early UK deployment.

Appendix A: Biographies of Panel Members

Dr Sue Ion, Chair

Dr Ion is a member of EPSRC Council and was President of the British Nuclear Energy Society between 2004 and 2006 and remained a member of its Executive Board until its merger with the Institution of Nuclear Engineers to form the Nuclear Institute in December 2008. She is a senior contributor in matters of national Science, Engineering and Technology Policy and is a Vice President and Member of Council of the Royal Academy of Engineering and a member of the UK Council for Science and Technology. She was a member of the Particle Physics and Astronomy Research Council from 1994-2001 and Chairman of its Audit Committee. She is a non-Executive Director on the Board of the Laboratory of the UK Health and Safety Executive.

Dr Ion was BNFL's Group Director of Technology 1992-2006. Throughout the 1990's, she directly managed BNFL's UK R+D portfolio with an annual budget of £100M, overseeing capital investment programmes in excess of £300M and major rationalisation of the Group's R+D resources. From 1997 she assumed functional accountability for the whole of the Group's Technology portfolio including Westinghouse, during a period of tremendous change for the Company and the nuclear sector generally. She chaired the Group's Technology Executive and Committees concerned with Government and Regulatory issues and remains an advisor to the Company in a consultancy capacity.

Sue Ion's background is in materials science/metallurgy. She gained a first class honours from Imperial College in 1976 and a PhD in 1979 before joining BNFL. She was appointed Visiting Professor at Imperial College in 2006 and has been a member of the Board of Governors at the University of Manchester since 2004.

She has extensive working knowledge of the nuclear fuel cycle, in particular fuel manufacture and reprocessing and recycle technologies. She represents the UK on a number of international review and oversight committees for the nuclear sector including the Generation IV International Advisory Committee, the IAEA Standing Advisory Group on Nuclear Energy and the Euratom Science and Technology Committee.

Dr Ion has held a number of non-executive directorships associated with technology-based businesses and consultancies.

Professor Philip Beeley

Professor Beeley was Head of the Nuclear Department, Defence Academy College of Management and Technology (1999-2009). Phil was educated at St Joseph's College Ipswich before graduating in 1977, with an honours degree in Chemistry from Salford University. In 1981 he completed his PhD in nuclear chemistry and physics at McGill University, Montreal, Canada and then carried out postdoctoral research in radiopharmaceuticals at the Carbohydrate Research Institute, Queen's University, Canada. In 1984 he took up a research appointment with Atomic Energy of Canada working on nuclear fuels and fission product analysis for the CANDU programme.

He was recruited by Queen's University in 1985 as a lecturer with dual appointment as Senior Operator of the SLOWPOKE - 20kW Research/Training Nuclear Reactor Facility at the Royal Military College of Canada, Kingston.

He returned to the UK in 1990, taking up the position of Senior Lecturer, Reactor Physics in the Department of Nuclear Science and Technology (DNST) at the Royal Naval College Greenwich. He was subsequently promoted to Deputy Manager of the Physics and Computing Division, DNST (1993) and Deputy Director DNST (1996). He was appointed Director and Professor of DNST, HMS Sultan, Gosport on 1 May 1999 and became Director, The Nuclear Department, HMS Sultan on 1 April 2001.

In 1993 he embarked on a MOD sponsored Executive MBA programme at the Imperial College, University of London. His thesis, submitted in 1995, was entitled, "Development of A Partnership Strategy Within the Naval Recruiting and Training Agency."

He is a past President of the Institution of Nuclear Engineers, British Nuclear Energy Society (BNES) representative on the European Nuclear Society (ENS) Board, Member for the Court of University of Surrey, Member of Associated Institutions of University of Surrey. He has just stepped down as Vice President of the European Nuclear Education Network (ENEN) and as a member of the Executive Committee of the European SNETP. Phil is a Visiting Professor at the Universities of Southampton and Manchester and takes up a new appointment at Khalifa University, Abu Dhabi, UAE from October 2009.

Professor Jonathan Billowes

Professor Billowes is Head of the Nuclear Physics Group in the School of Physics & Astronomy at the University of Manchester and Director of Education in the Dalton Nuclear Institute.

He moved to Manchester in 1986 following post-doctoral research at Oxford University and the State University of New York at Stony Brook. His research interests are in laser spectroscopy of radioactive atoms. This work is carried out the University of Jyvaskyla, Finland and at the ISOLDE facility, CERN, Geneva.

He is course director for the MSc in Nuclear Science and Technology which is run by the UK university consortium, NTEC, and serves on the Management Board of the university consortium delivering the Nuclear Engineering Doctorate programme.

Professor Dewi Lewis

Professor Lewis is Head of Physics with General Electric Healthcare R&D in the UK. He served as a member of Council for the Council for the Particle Physics and Astronomy Research Council (PPARC) from 200 to 2006 and for the Central Laboratory of the Research Councils (CCLRC) from 2006-2007; he sits on various advisory panels for STFC, EPSRC and the Medical Research Council (MRC).

He studied for a PhD in experimental positron physics at the University of Swansea and then as an Applied Science & Computing Fellow at CERN, Geneva. After his Fellowship he became Engineer in Charge of the CERN Intersecting Storage Rings before returning to the UK to work on accelerators applications in industry with Amersham International plc. His industrial experience has included being head of the Amersham Cyclotron department, business manager for cyclotron and reactor pharmaceuticals, director of the Reviss joint venture, strategy manager for the company’s operations, and he is a former chairman of the European industry association (AIPES) committee on reactors and isotopes.

He is a Fellow of the Institute of Physics and the Royal Astronomical Society and has visiting chairs at the University of Liverpool and the Cockroft Institute and advisory roles at Cardiff and Oxford Universities. His fields of interest include accelerator applications, radioisotope technology, nuclear science, software and medical imaging; he is currently active in medical imaging R&D with GE Healthcare.

Professor Graham Fairhall

Professor Fairhall joined BNFL in 1979 with a degree in chemistry and a PhD in the behaviour of liquid sodium. He has spent over 29 years working in Research and Development in the nuclear fuel cycle field for the BNFL Group of Companies and the NNL. He has led major R&D programmes for BNFL on the back end of the nuclear fuel cycle including advanced fuel cycle studies.

In 1995 he was appointed to the role Chief Technologist for Waste Immobilisation, the first appointment to senior level in BNFL based upon technical contribution. Since that time he has held a number of senior technical roles within BNFL and the NNL.

In his current role he is accountable across the National Nuclear Laboratory for the scientific and technical approach and strategy for programmes covering the breadth of the nuclear fuel cycle. He also has responsibility for the NNL's interactions with Universities, research councils and R&D collaborations with international and national National Labs and research institutes.

Professor Sir Richard Friend FRS
Richard Friend is Cavendish Professor at the University of Cambridge and a fellow of St John's College with a world-renowned reputation for his research into the physics and engineering of carbon-based semiconductors.

His work has been applied to development of polymer field effect transistors, light-emitting diodes, photovoltaic diodes, optically pumped lasing and directly printed polymer transistors. He pioneered the study of organic polymers and revolutionised the understanding of the electronic properties of molecular semiconductors. He is a co-founder of Cambridge Display Technology (CDT) and Plastic Logic. Professor Friend has over 700 publications and more than 20 patents.

Professor Friend served on the review panel for the RCUK Review of Physics and the RAE Materials sub-panel in 2008.

Dr Regis Matzie
In April 2009, Dr Matzie retired from his post as Senior Vice President and Chief Technology Officer, Westinghouse Electric Company. He was responsible for all Westinghouse research and development undertakings and advanced nuclear plant development. Previously, Dr Matzie was responsible for the development, licensing, detailed engineering, project management, and component manufacturing of new Westinghouse light water reactors. He was also the executive in charge of Westinghouse replacement steam generator projects and dry spent-fuel-canister fabrication projects. Dr Matzie became a senior vice president in 2000, when Westinghouse Electric Company purchased the nuclear businesses of ABB.

In 2006, Dr Matzie served on a committee reviewing the US Department of Energy’s Nuclear Energy Research and Development Programme.

Earlier, Dr Matzie was vice president of nuclear systems for ABB Combustion Engineering (ABB CE) Nuclear Power in Windsor, Connecticut. During his 25 years with ABB CE, Dr Matzie held technical and management positions, including vice president of nuclear engineering; vice president of nuclear systems development; director of advanced water reactor projects; manager of reactor engineering; and manager of analog plants.

Dr Matzie's career has been devoted primarily to the development of advanced nuclear systems and advanced fuel cycles, and he is the author of more than 120 technical papers and reports on these subjects. Dr Matzie completed 30 years of active and reserve service in the U.S. Navy in 1995, retiring with the rank of captain. Dr Matzie graduated from the U.S. Naval Academy, where he obtained a BS in physics, and served in the U.S. nuclear submarine program for five years. He then attended Stanford University, where he earned an MS and a PhD in nuclear engineering.

Professor James Stirling CBE FRS
James Stirling is Jacksonian Professor of Natural Philosophy and Fellow of Peterhouse in the University of Cambridge. He was previously Professor in Mathematical Sciences and Physics, Director of the Institute for Particle Physics Phenomenology and Pro-Vice-Chancellor for Research at Durham University.

He was born and grew up near Belfast, Northern Ireland, and was educated at Belfast Royal Academy. He read mathematics at Peterhouse, Cambridge University, graduating BA in 1975 and obtaining his PhD in Theoretical Particle Physics in 1979. After periods of research in the USA, Cambridge and the European Organization for Nuclear Research (CERN) in Geneva, Professor Stirling was appointed to a lectureship at Durham University in 1986. In 2000 he became the first

Director of the University's new Institute for Particle Physics Phenomenology (IPPP), which together with the Institute for Computational Cosmology forms part of the Ogden Centre for Fundamental Physics. From 2001 to 2003, Professor Stirling served as the first Chair of the PPARC Science Committee, the research council's top-level scientific advisory committee. He has also been a member of the Physics Panel in two Research Assessment Exercises (2001 and 2008) and was Deputy Chair of the 2008 panel. In 2005 he was appointed Pro-Vice-Chancellor for Research at Durham University, a post which he held for three years before moving in September 2008 to the Cavendish Laboratory at Cambridge University to take up the Jacksonian Professorship.

Professor Stirling's research area is theoretical particle physics. In a research career spanning more than 30 years, he has published more than 300 research papers, including some of the most frequently cited papers in the physical sciences. His particular research interest is particle physics phenomenology – the interface between theory and experiment – and he works closely with experimentalists at research laboratories in Europe and the United States. In recognition of his contribution to particle physics research he was elected to the Fellowship of the Royal Society in 1999. He served on the Council of the Royal Society from 2007 to 2008, and is currently a member of the Council of the Science and Technology Facilities Council (STFC). Professor Stirling was awarded a CBE in the 2006 New Years Honours list, for services to science.

Appendix B: List of Acronyms used in the Report

AGATA – Advanced Gamma Tracking Array
CPD – Continued Professional Development
DBIS – Department for Business, Innovation and Skills
DECC – Department of Energy and Climate Change
ECT* Trento – European Centre for Theoretical Studies in Nuclear Physics and Related Areas
ENEN – European Nuclear Education Network
EPSRC – Engineering and Physical Sciences Research Council
ETI – Energy Technologies Institute
FCO – Foreign and Commonwealth Office
GIF – Generation IV International Forum
KNOO – Keeping the Nuclear Option Open
LoA – Letter of Arrangement
LWR – Light Water Reactor
MOD – Ministry of Defence
NDE – Non-Destructive Evaluation
NNL – National Nuclear Laboratory
NuPECC – Nuclear Physics European Collaboration Committee
NuSTAR – Nuclear Structure, Astrophysics and Reactions
PANDA – antiProton Annihilation at Darmstadt
PPARC – Particle Physics and Astronomy Research Council
RAE – Research Assessment Exercise
RCUK – Research Councils UK
RDA – Regional Development Agency
SNETP – Sustainable Nuclear Energy Technology Platform
SPECT – Single Photon Emission Computed Tomography
STFC – Science and Technology Facilities Council