Materials R&D for Nuclear Applications: The UK's Emerging Opportunities

Materials UK Energy Review 2010

Report 6 - Materials R&D for Nuclear Applications: The UK's Emerging Opportunities

A report prepared by the Dalton Nuclear Institute, National Nuclear Laboratory and Battelle on behalf of Materials UK

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Contents

Introduction

With a market valued at around £600 billion for new nuclear build and £250 billion for decommissioning, waste treatment and disposal, the predicted resurgence in the nuclear market over the next 20 years could lead to significant opportunities for UK businesses both nationally and globally in the area of nuclear engineering and its associated technologies.

The UK has a strong historic track record in nuclear engineering, having been one of very few countries that has closed the complete fuel cycle. It has developed thermal and fast reactors, reprocessing technology, fuel manufacture, and enrichment expertise. However, it is recognised that much of this capability (with the exception of the defence sector) has been in decline over the past two decades as the UK focus has shifted away from nuclear to other power generation sources. With the advent of a global nuclear renaissance there should be significant opportunities for UK organisations to take advantage of this new market, particularly if a coordinated approach, which recognises the UK's core skills, is taken to develop the necessary supply chain and skill-base.

A report [1] was commissioned by the Technology Strategy Board in association with a number of the UK's Regional Development Agencies and Materials UK, and assessed the UK's current R&D capacity and the opportunities for UK organisations to develop and deploy innovative technologies to support the civil nuclear industry. As part of that review, MatUK commissioned specific work on the UK's R&D capacity and priorities for Nuclear Materials.

This report summarises the findings of that part of the review and presents the UK's Nuclear Materials R&D capacity and priorities going forward over the next 5-10 years. The report provides more detailed information, additional data and recommendations to the report produced by MatUK in 2007 [2] and makes recommendations for where public sector intervention is most appropriate.

The review is the sixth in a series of reviews commissioned by Materials UK and has been compiled in consultation with many of the major organisations involved in the nuclear supply chain in the UK and their input is acknowledged.

1.0 Scope of Study

The review looks at the opportunities for UK organisations to develop and deploy innovative technologies to support the civil nuclear industry against the following criteria:

1. **Is there a UK capacity to develop and exploit the technology and become a leading global player?**
2. **Does the technology have potential for impact in the right time frame?**
3. **Is there a clear role for public sector intervention and support that adds value above and beyond that of private investment?**

The UK materials capability is critical for underpinning the following five strategic national nuclear goals over the short- (within 5 years), medium- (5 to 20 years) and long-term (beyond 20 years) in the following areas:

- Plant-life extension of existing Magnox, AGR and PWR power stations
- New nuclear build of PWR power stations
- Safe and reliable operation of new Gen III PWR power stations
- Development of Gen IV and fusion reactor systems
- Decommissioning, management, interim storage and geological disposal of nuclear waste

Experience has been obtained over the last 60 years in the UK in managing the complete life cycle of civil nuclear reactors. This has demonstrated that an essential requirement for maintaining a fleet of operating reactors, for assessing and commissioning new plant designs, and for developing appropriate waste management strategies, is that in-depth knowledge, understanding and supporting materials data are used effectively to predict the evolution of materials properties throughout and beyond plant life. The UK materials community – including the skills, technology and infrastructure – should support this essential requirement.

A recent analysis of opportunities across technology-, infrastructure- and knowledge based markets [1] has indicated that in the field of materials technology there is a global market opportunity for exploitation across the nuclear sector.

Particular areas highlighted include condition monitoring and non-destructive examination, structural integrity and lifetime prediction, high-value manufacturing, advanced fuel manufacture and fuel cycles, and advanced simulation and modelling.

This report focuses primarily on opportunities afforded by the new UK nuclear build agenda in respect of the ‘nuclear island’. In particular, in supporting operation of new build plant through life; i.e. the focus is therefore on the design, fabrication, commissioning, and operation of new nuclear plant. Indeed, the UK’s Nuclear Installations Inspectorate (NII) is currently assessing the safety and acceptability of two new nuclear reactor designs under their Generic Design Assessment (GDA) process. These are the AP1000 PWR (Westinghouse) and the European pressurised water reactor (EPR) (EDF/Areva). Whilst opportunities exist, e.g. in the development of life-prediction approaches based on materials degradation processes, the report does not focus on plant life extension of AGR reactors or the continued operation of the Sizewell ‘B’ PWR; neither does it address opportunities associated with decommissioning, waste management and geological disposal, or fusion technology.

The report presents the following:

- UK’s Materials Capacity
- a UK Materials Roadmap
- opportunities for public sector intervention,
- spill-over benefits of the high priority opportunities.

2.0 UK Materials Capacity

This section addresses the question, *"Is there a UK (materials) capacity to develop and exploit the technology and become a leading global player?"*

It aims to capture specific elements of the UK materials capacity that could be exploited for public sector intervention with respect to the new nuclear build agenda.

Two aspects of the capacity are discussed: firstly, the materials supply chain for manufacturing and fabricating key structural components for the next generation of nuclear power stations, and secondly the capability for exploiting advanced materials technology. This discussion makes use of core competencies required to address the technological materials challenges inherent in new build. These core competencies were identified in the Materials UK assessment of the priority research needs in nuclear energy materials [2], and include the capacity to determine in-service changes in material microstructure and properties, the ability to predict the behaviour of materials over a range of scale lengths using theoretical modelling, and access to both proxy and neutron irradiation facilities to develop underpinning materials data for model validation and safety case development.

2.1 Materials supply chain

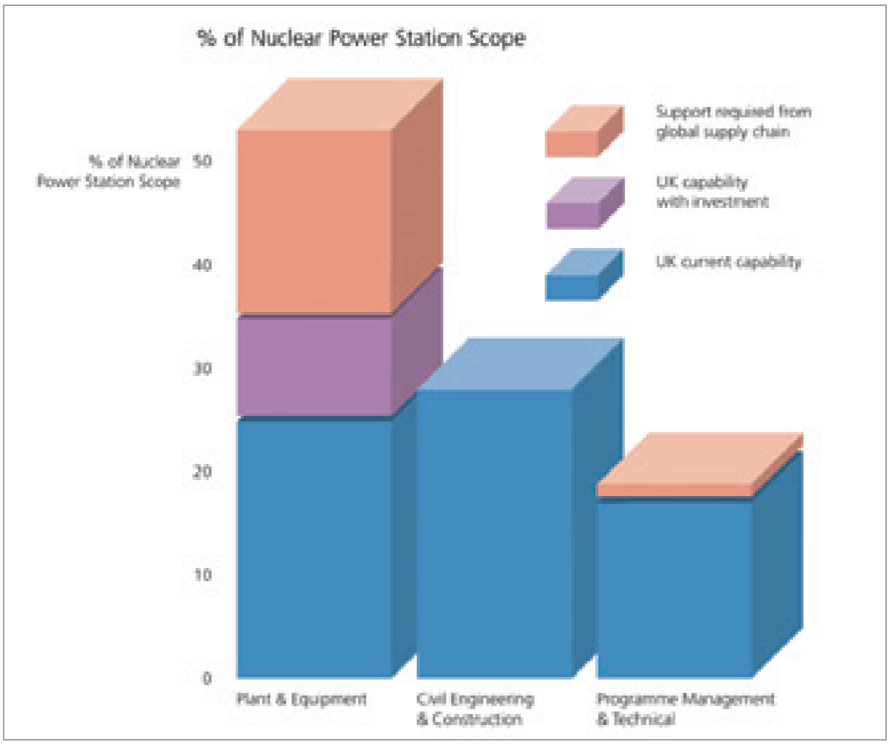
Materials UK have undertaken a mapping of the materials supply chain in relation to the UK's power generation sector [3]. Chapter 3 of this reference provides a focus on nuclear energy. In addition there has been a Nuclear Industry Association (NIA) study on the UK capability to deliver a new nuclear build programme [4,5]. This section highlights the major points from these reviews on the importance of the materials supply chain to new build and highlights the strengths and weaknesses of the UK materials capability for the manufacture and fabrication of components.

The NIA study did not focus on materials specifically but did consider the area of 'Plant and Equipment' which is of most relevance to the materials supply chain (other areas being 'civil engineering and construction', and 'programme management and technical').

The report indicates that 'Plant and Equipment' typically comprise approximately 55% of a nuclear power plant build. The NIA reports indicate that current UK industry capability to support approximately half of the 'Plant & Equipment' necessary for new nuclear power plant build. With investment, they considered that this might be expanded to approximately 70% of the required capability, Figure 1. This points to the potentially important role investment in the materials supply chain could play in exploiting the opportunities that are arising from new build.

When the Sizewell B PWR power station was built in the early 1990s most components, apart from the heavy section forging, could be fabricated in the UK. Since that time, whilst there has been no further civil nuclear build in the UK, ongoing support for the nuclear fleet, plant modifications to support life extensions, new plant build at Sellafield, alongside decommissioning work has enabled the UK fabrication and manufacturing sector to maintain a significant capability.

Figure 1
NIA analysis of UK capability to support new nuclear power plant build



2.0 UK Materials Capacity

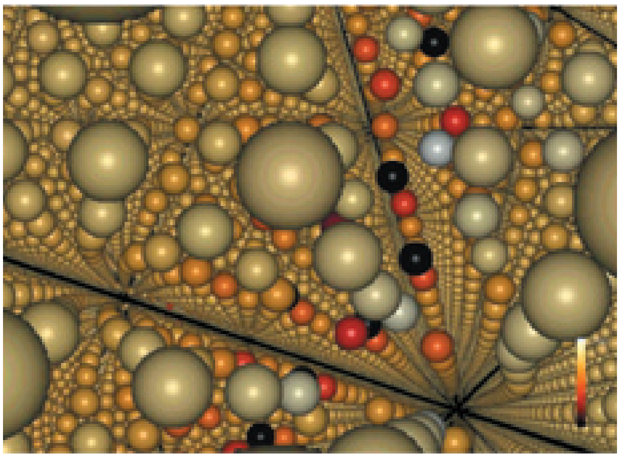
An analysis of the capability to supply the key engineering components (Table 1) for new nuclear power plant in the UK was included in the Materials UK study [2]. The analysis demonstrated that aside from the large forgings, the UK has capability to provide most other key engineering components. It is to be noted that there are supporting organisations in the UK such as specialist steel makers, e.g. CORUS, or R&D organisations focusing on specific aspects of fabrication and joining, e.g. TWI, who enhance the ability of the UK supply chain to supply advanced material solutions.

Reference 3 also included a SWOT analysis of the UK materials and manufacturing input to the civil nuclear industry. This analysis emphasises that opportunities for UK business lie in the ability to respond to the new nuclear build agenda by investing to: (a) reinstate facilities and skills and (b) increase the scope and capacity of existing manufacturing plant to support the UK and worldwide renaissance in new nuclear build, including, for example, large-scale forgings and nuclear fuel.

In summary, UK companies are (potentially) able to supply a large proportion of the key components for new nuclear build. This is important from an invertor's perspective as it demonstrates that there may be clear benefits from public intervention. For example, an important focus might be from stimulating the use of improved manufacturing techniques for nuclear plant, including welding and joining, surface technology and modularisation. This is particularly important for the Reactor Pressure Vessel (RPV), reactor integrated head package, RPV internals, steam generators, pressuriser and primary circuit pipework.

Table 1 Key engineering components

Key engineering components
Containment Building
Reactor Pressure Vessel (RPV)
Reactor Pressure Vessel Head
Reactor Pressure Vessel Internals
Steam Generators
Pressuriser
Pumps and Valves
Generic Fabricated Metal Components (inc. forgings, pipework)
Other Components
Fuel



An illustration of the power and utility of modern materials modelling methods. This shows a computational simulation of about a million atoms of iron in a distorted configuration of the crystal lattice such as can be produced by bombardment by neutrons. Such distortions are ultimately responsible for creep, swelling, etc. The forces between the atoms have been calculated by a new approach that takes into account the magnetism of iron at the atomic level. The colouring of the atoms reflects the strength of their magnetic moments.

2.2 Advanced Materials Technology

In 2007, the nuclear materials R&D capacity was reviewed in the UK [2] by Materials UK. The major conclusions were that:

- Nuclear fission related R&D in the UK has declined steadily over the past 20 years or so and, since the 1980s, public investment in nuclear fission R&D has dropped by more than 95% and the industrial R&D skill base has decreased by more than 90%.
- The UK maintains leading materials expertise across both the academic and industrial sectors, with key initiatives such as The Dalton Nuclear Institute (The University of Manchester) the EPSRC's "Keeping the Nuclear Option Open" (KNOO), The National Nuclear Laboratory (NNL), the Dalton Cumbrian Facility on Westlakes Science and Technology Park, and Nuclear Fusion activities associated with the International Thermonuclear Experimental Reactor (ITER) concentrating UK efforts.
- It will take significant effort to build up the required resources (skills) within the timescale for licensing and contract awards; within a period which is likely to be no longer than 5 years.

Capacity relates to both the expertise required to support the advanced materials technology and the infrastructure necessary to develop it.

Firstly, with respect to infrastructure; since the review was published in 2007, a number of new nuclear research academic initiatives have been established that have significantly strengthened the UK infrastructure for advanced research into high temperature materials, modelling of materials performance, fuels technology, radiation damage, and graphite technology. The creation of the Nuclear Advanced Manufacturing Research Centre (NAMRC) as a partnership between the Universities of Sheffield and Manchester will have a major impact on the UK manufacturing supply chain for new nuclear build.

2.0 UK Materials Capacity

Further it should be stressed that there are UK strengths in a number of the core competencies and facilities that were identified in [2] as key to meeting the challenges inherent in new build.

These strengths include:
(i) experimental techniques for characterising microstructural changes and their influence on bulk physical, mechanical, and corrosion properties during service,
(ii) modelling techniques that enable simulation of materials behaviour across a range of scale lengths, and
(iii) facilities that allow the examination of activated or contaminated materials.
(iv) Capability in advanced manufacture.

However, as pointed out in [2] there is the increasing need for proxy irradiation facilities, including ion beams, to provide model validation data, and assured access to irradiation facilities in materials test reactors where there are limitations in UK capability. This need is being addressed, in part, within the Government's Energy Coast Masterplan [6] including the establishment of the UK National Nuclear Laboratory with state-of-the-art 'hot cells' for the testing and examination of irradiated materials and through a partnership between the Nuclear Decommissioning Authority and The University of Manchester in the development of the Dalton Cumbrian Facility which will house new research facilities for radiation science research.

Secondly, with respect to expertise, the UK has significant skills in various elements of advanced materials production, near service condition testing, materials characterisation (both at the start of, through life, and end of life) and predictive modelling and assessment.

Since the Materials UK review there have been a number of initiatives, particularly within the academic sector, aimed at developing higher level skills in the nuclear materials area via:

- Existing materials courses being broadened to implicitly include a nuclear component
- New "with nuclear" degrees being introduced at undergraduate level,
- Masters level training in nuclear subjects

Further, higher level skills in nuclear materials are being developed through post graduate research programmes including the materials work package in the EPSRC Keeping the Nuclear Option Open programme, materials research within the EPSRC Nuclear Engineering Doctorate programme, EPSRC Doctoral Training Colleges in Fission (Manchester and Sheffield), Advanced Metallic Materials (Sheffield and Manchester) and Materials modelling (Imperial College London). The NAMRC will address the training and skills development in the nuclear manufacturing sector.

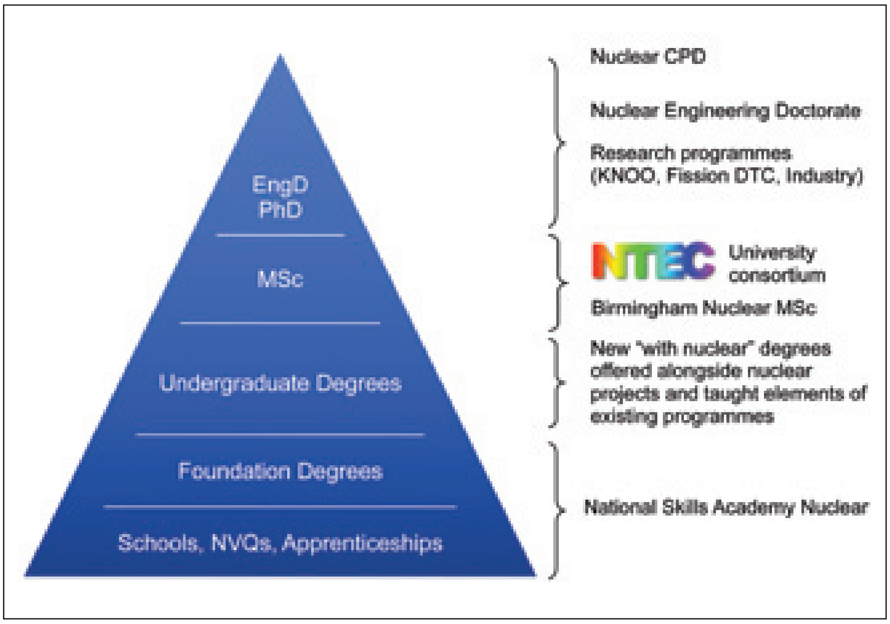
In addition the National Skills Academy for Nuclear (NSAN) aims to supply many nuclear training products and services, including for example programmes for secondary schools, accreditations for industry and particularly nuclear top up modules for trade apprenticeships.

These initiatives may be viewed within the context of a 'skills pyramid' as shown in Figure 2.

Overall in the UK we estimate that there are currently ~ 40 undergraduates specialising in courses directly related to nuclear materials, 175-200 people involved in M.Sc or Ph.D courses/projects or acting as post-doctoral research assistants. There is a research income of £6-7M per annum associated with the latter. We also note that four or five years ago these numbers would have been dramatically smaller, however, the level of activity still remains low with respect to the declared and perceived requirements across utilities, manufacturers and the supply chain.

We have emphasised above the growing skill base in the UK for nuclear materials arising from the increased training opportunities.

Figure 2 Nuclear skills pyramid



2.0 UK Materials Capacity

However, the non-prescriptive regulatory regime in the UK, where the plant operator has to demonstrate the safety of the plant rather than comply with externally imposed design/operating codes, imposes significant requirements on the level of expertise in all elements of the supply chain.

In particular, there needs to be suitably knowledgeable and experienced people available as many of the current experts are approaching retirement age. This emphasises the need for not only training a new generation of experts but taking steps to ensure the expertise of current experts is captured for subsequent generations.

It is noted that contractors and Small and Medium Enterprises (SMEs) are reacting positively to new nuclear renaissance in UK and worldwide. Some larger organisations have already increased recruitment in the materials area, e.g. Serco Technical and Assurance Services, whilst others have set clear business objectives to increase expertise in nuclear field (including materials), e.g. Rolls-Royce, NNL, and there is evidence that companies are considering recruitment and retention strategies carefully, e.g. BAE Systems .

In summary there is an increasing UK capacity for advanced materials technology with specific areas of real materials expertise that can be exploited. However, this increasing capacity follows a period of decline. Thus, in terms of capability for advanced materials technology, public sector funding may be used to stimulate new industrial organisations entering the supply chain through appropriately directed Knowledge Transfer Partnerships.

2.3 Interim summary

In response to Question 1 the position reviewed in this section has demonstrated that there is a UK materials capacity to develop and exploit the technology and become a leading global player. Specific areas which are suitable for public intervention include:

- Stimulating the use of improved manufacturing techniques for nuclear plant, including welding and joining, surface technology and modularisation.
- Stimulate new industrial organisations entering the supply chain through appropriately directed Knowledge Transfer Partnerships.
- Stimulating technologies/ methodologies for capturing expert knowledge

These areas are further developed in Section 4.

Cut-away view of an intermediate level waste container

High level waste containers. *[Courtesy of Nexia Solutions].*

3.0 Impact of Advanced Materials Technology

This section provides a response to question, *"Does the (materials) technology have potential for impact in the right time frame?"*

This section aims to identify priorities for new build materials in light of UK and International experience. It should be noted that there are strong synergies between the research needs in developing materials for application in fission reactors and for application in fusion reactors. Although the reactor concepts are different, there is a wide range of commonalities in the materials issues. For example, there is strong overlap in the classes of material employed and in the effects responsible for the material and component in-service performance. Further, the research methods (both experimental and theoretical) are similar for a broad range of issues. In fusion technology specific additional problems arise in the case of plasma facing components, due to the damage caused by the impacts of high-energy ions.

3.1 New build materials technology priorities

There is no UK analysis that focussed on specifically developing a roadmap for materials technology development associated with new build. The overall materials research priorities identified in the Materials UK assessment of the priority research needs in nuclear energy materials [2] addressed the full nuclear fuel cycle, and were summarised as follows:

- Mechanisms of in-service and in-repository corrosion and degradation of materials,
- Predicting the behaviour of welded structures subjected to high temperatures and complex loadings,
- Predicting irradiation damage effects in fission and fusion materials, and
- Developments of new and improved methods for non-destructive monitoring and evaluation of materials in service.

Specific research opportunities and challenges associated with the full nuclear lifecycle were identified. Those associated with the new nuclear build technology are summarised in Table 2. It is also considered important that research associated with improved manufacturing technology should emerge as a new research priority in the light of the new build agenda.

Materials technology is being developed worldwide to support the management of ageing Light Water Reactor (LWR) plant and the build of a new generation of nuclear plant. Many of these national LWR programmes have also highlighted the importance of the research needs identified in [2] and given above. Of particular note are the following programmes:

In the USA, there is a focus on the development of a scientific basis for understanding materials degradation processes, providing the materials data and the assessment methods to enable long-term performance of materials to be predicted. Specific degradation mechanisms being addressed include irradiation effects on microstructure (late blooming phases), properties including environmentally-assisted cracking, fatigue and fracture.

Materials technology developments in Japan address six degradation mechanisms in relation to LWR materials degradation: (i) neutron irradiation embrittlement of the RPV, (ii) stress corrosion cracking including IGSCC, PWSCC and IASCC, (iii) fatigue, (iv) thinning of piping by flow-accelerated corrosion and erosion, (v) insulation degradation of electrical cables, (vi) degradation of concrete properties for strength and shielding.

Within Europe, the joint EDF-EPRI-TEPCO Materials Ageing Institute was recently launched to develop materials technology in relation to nuclear plant. Areas of current focus include: (i) Understanding and modelling of physical phenomena, including thermal ageing, irradiation, physical modelling of corrosion, prediction of chemical and radiochemical behaviour, (ii) Research related to specific materials, including concrete, polymers and new materials.

3.0 Impact of Advanced Materials Technology

It is clear that there is an international consensus of the degradation mechanisms that require investigation. Further, it is apparent that, internationally, it is recognised that it is necessary to undertake collaborative industrial and research programmes to support the licensing and managing of the long-term, safe and economical operation of current and future nuclear power (LWR) plants. However, such programmes should also include condition and surveillance monitoring of key components. Within this there is also the need for advanced NDE techniques and the development of advanced tools for the assessment of realistic defects in aging components under plant loading conditions.

Thus to address the advanced materials technology requirements for new build we need to consider:

1 Materials degradation, structural integrity and life prediction including:

a. Understanding mechanisms of material corrosion in-service, including behaviour within nuclear power reactors.

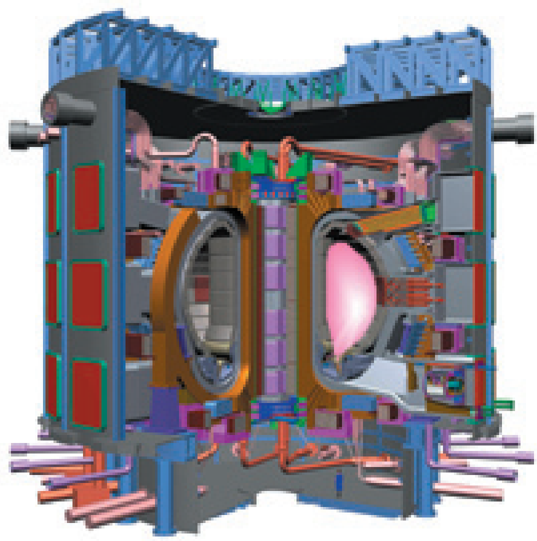
b. Understanding and predicting radiation effects on materials, including microstructural, microchemical, and environmental aspects that influence dimensional stability, mechanical performance, fracture properties and electrochemical behaviour.

2 Condition monitoring and preventative maintenance to enhance safe life and reduce downtime alongside establishing new and improved techniques for the applied metrology of material state and non-destructive monitoring of nuclear plant, systems, and components. Such condition monitoring includes improved surveillance schemes to monitor the in-service properties of specific components such as the reactor pressure vessel.

3 Developing new component and fuel manufacturing capability including materials, processing and joining technologies.

	Behaviour at high temperature	**Irradiation damage**
Main materials of interest	• Austenitic and ferritic steels. • High nickel alloys. • Zirconium alloys	• Austenitic and ferritic steels. • Zirconium alloys
Main problems	• Thermal cycling. • Joining and interface technology.	• Irradiation creep. • Swelling. Irradiation enhanced segregation. • Crack propagation and • embrittlement. • Irradiation assisted corrosion and environmental degradation. • Joining and interface technology.
Key methods for solution of problems	• Modelling and its validation. • Advanced materials characterisation. • Advanced measurement and testing techniques. • Advanced plant monitoring techniques.	• Modelling and its validation. • Advanced materials characterisation. • Proxy irradiation (e.g. ion beams). • Advanced measurement and testing techniques. • Advanced plant monitoring techniques.
Most promising immediate opportunities	• Modelling validated by microscopic characterisation, plant service data and long-term experiments. • Exploit research synergies for fission, fusion and fossil-fuel plant materials.	• Modelling validated by microscopic characterisation, proxy irradiations, plant service data and long-term experiments. • Exploit research synergies for fission, fusion and fossil-fuel plant materials.
Key gaps in capabilities	• Lack of irradiation facilities.	• Lack of irradiation facilities.
Components	• Primary and secondary circuit in PWRs.	

Table 2 Research opportunities and challenges for new nuclear build



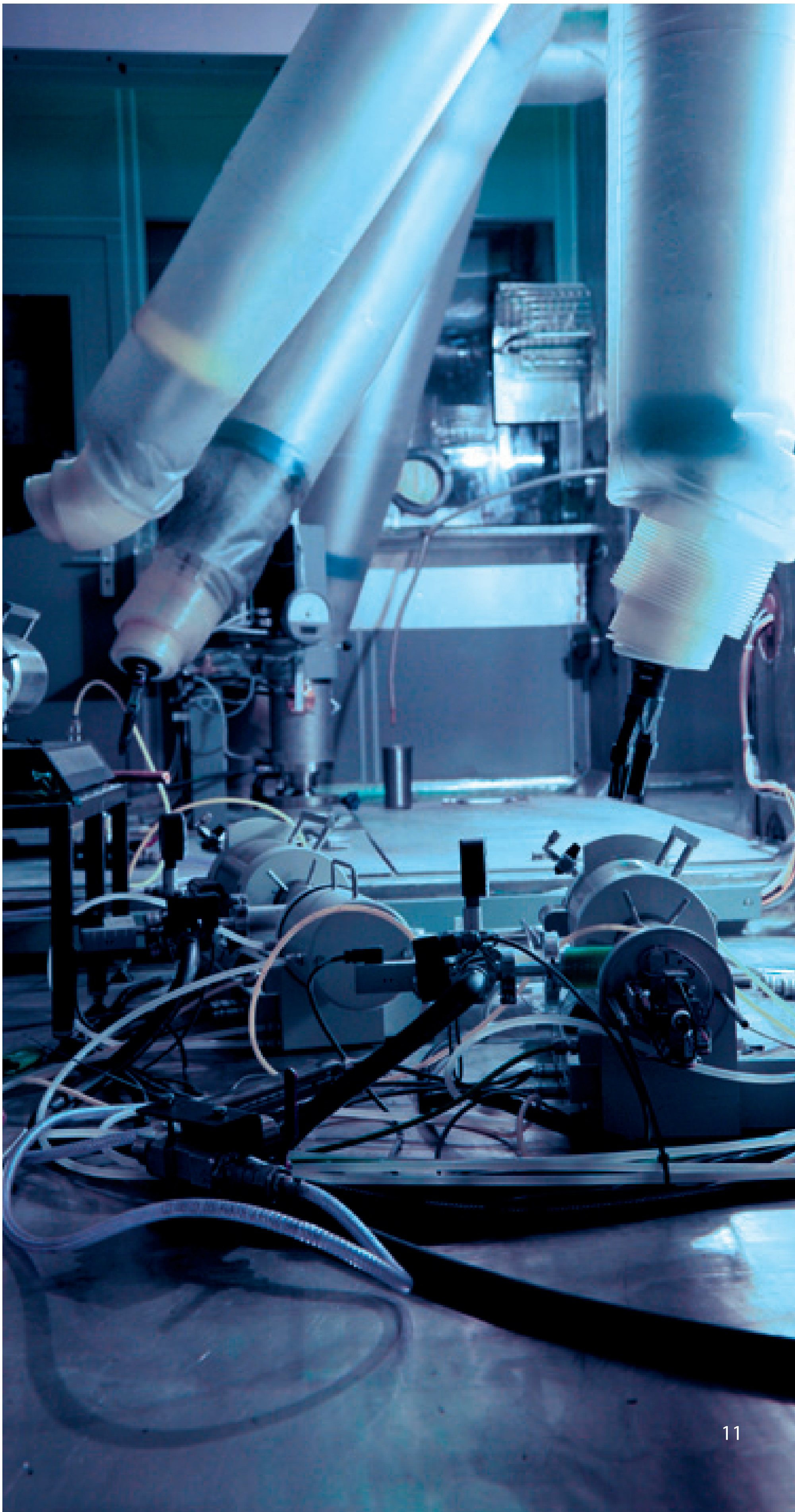
A cutaway drawing of the core of a 600 Megawatt fusion device, ITER, which is beginning construction in France. The partners in ITER are Europe, Japan, China, India, Russia, Korea and USA. Although fusion and fission power plants are different in many respects, there is a large overlap in the classes of materials they employ, the effects that limit the lifetime of materials, and the research methods used to gain the understanding needed to optimise materials performance.

3.2 Interim summary

In response to Question 2, there is strong evidence that materials technology development has the potential for impact in the right time frame, including supporting the licensing and managing the long-term, safe and economical operation of current and future nuclear power plants.

Further, there is a clear consensus amongst the international community regarding the key materials technology challenges associated with new nuclear build. More specifically, there are opportunities to maximise the impact of materials technology through a structured and proactive approach to international collaboration.

Finally, advanced manufacturing research and development for new nuclear build provides the opportunity to introduce 'step change' processes that will enable the UK supply chain to reduce costs and timescales while maintaining the quality of nuclear components for new nuclear build in the UK and overseas.



Interior of a remote handling cave.
[Courtesy of Nexia Solutions]

4.0 Opportunities for Funding Interventions

This section explores specific opportunities for public sector intervention in relation to materials technology in support of the new nuclear build agenda in the UK. Firstly, particular areas for public sector intervention are summarised in relation to infrastructure-based and technology-based opportunities. Secondly, potential mechanisms for intervention are explored.

4.1 Areas for public sector intervention

Infrastructure-based opportunities

Section 1 of this report identified the opportunity to stimulate the use of improved manufacturing techniques for nuclear plant, including welding and joining, surface technology and modularisation. Given the new nuclear build agenda, it is recognised that the UK manufacturing capability will be strengthened through the formation of a UK Nuclear Advanced Manufacturing Research Centre to address high value manufacturing by the supply chain [1]. The Nuclear Industry Association (NIA) map indicates the distribution of the UK capacity to engage in such an initiative, Figure 3. In addition, a recent review of the nuclear capability within UK universities has been published by Dr John Roberts and indicates that indicates over 200 academics with nuclear research interests in over 30 universities across the UK. A number of the academic institutions listed in that review could contribute significantly to such an initiative.

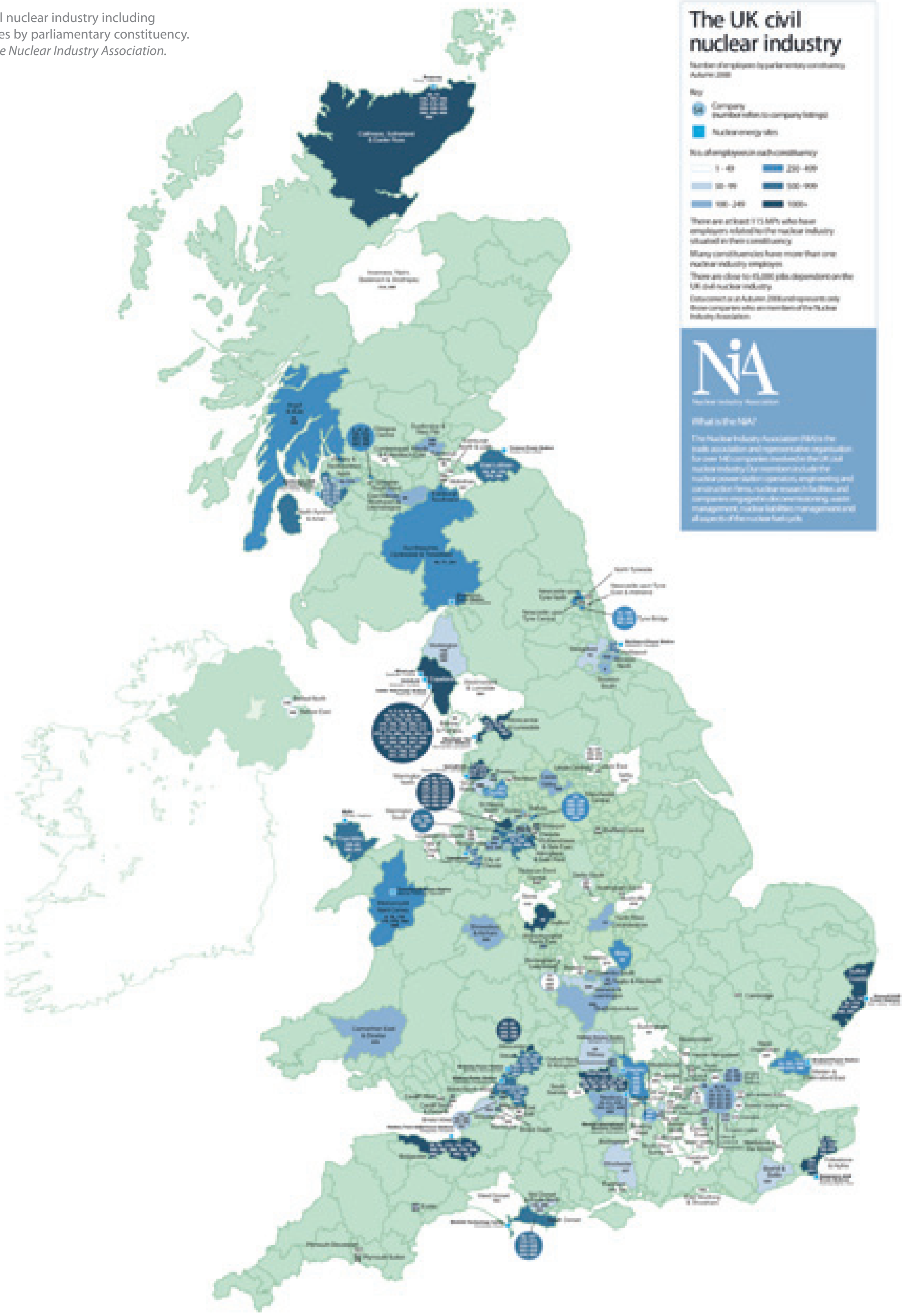
Key aspects to be addressed by an initiative like this would include:

- Production Readiness: proving of current methods
- Process Improvement: cost reduction through cell demonstration
- Process Qualification: proving of current methods
- Non-destructive testing: demonstration, Development, and Qualification
- Advanced Materials, cutting, joining and surface technology

Unique aspects of a centre to support new nuclear build in the UK include the ability to handle large structural components, thick welds and associated inspection, cladding and nuclear-specific materials.

Photo courtesy of Dalton Nuclear Institute

Figure 3 The UK civil nuclear industry including number of employees by parliamentary constituency.
Picture courtesy of the Nuclear Industry Association.



Note, the above diagram is illustrative and there are a significant number of other organisations and universities that can support new nuclear build that may not be represented on the NIA map.

4.0 Opportunities for Funding Interventions

Technology-based opportunities

Section 2 of this report identified the increasing UK capacity for advanced materials technology with specific areas of real materials expertise that can be exploited. Areas of specific opportunity were summarised in Section 3 as relating to: (i) materials degradation, structural integrity and life prediction, and (ii) condition monitoring of nuclear plant.

Within these two areas specific opportunities exist for public sector intervention that builds on current materials research and development programmes in the UK including:

- Improved understanding and prediction of materials degradation
  - Build on research undertaken within the EPSRC Keeping the Nuclear Option Open programme to use proxy irradiation techniques as a means to develop corrosion sensors for irradiated material.
  - Establish use of new corrosion-resistant materials through minor alloying additions such as platinum group metals.
  - Build tools for the application of advanced assessment methods to extend linear elastic fracture mechanics-based approaches to predictive models based on materials degradation methods, e.g. automated approaches for creating finite element models of three-dimensional crack tips, post-processors to derive model parameters and predictive capabilities.
- Improved fabrication techniques
  - The development of improved modelling and measurement approaches for residual stress characterisation and weld improvement, including improved constitutive models and supporting data for weld simulation using advanced three-dimensional finite element analysis and measuring approaches such as the contour method and deep hole drilling.

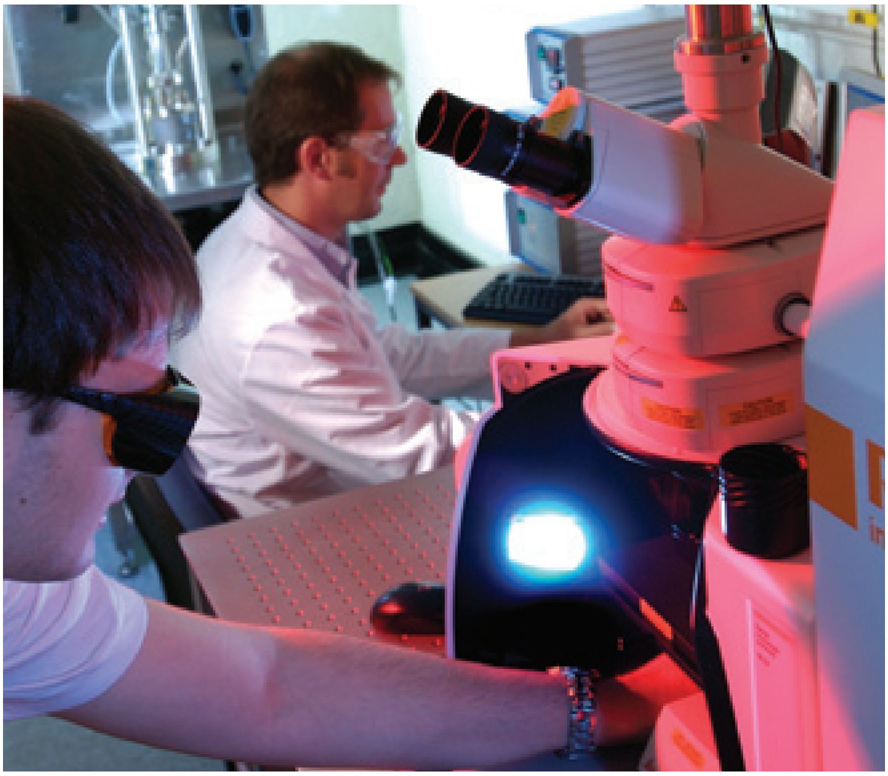


Photo courtesy of Dalton Nuclear Institute

  - The development of new surface technology for nuclear components including laser and water-jet peening, electropolishing, and combinations thereof.
- Improved structural integrity approaches
  - Build on research and development within the R6 development programme to strengthen the assessment of subcritical crack growth (see above), the influence of residual stress effects on fracture and load history effects.
- Improved non-destructive examination
  - Build on research undertaken within the EPSRC Keeping the Nuclear Option Open which aims to physically connect ultrasonic generators and receivers to the component via a solid, but flexible, ‘waveguide’, thus removing sensitive equipment away from ‘hot’ areas of interest, where the high temperatures and radiation field are detrimental to the equipment.

Within these areas it is recognised that there is strong international consensus regarding the priority themes for materials technology development and as a consequence a structured and proactive approach to international collaboration would maximise the impact of materials technology. In particular, collaboration with the joint EDF-EPRI-TEPCO Materials Ageing Institute would strengthen the impact of investment relating to the understanding and prediction of material degradation.

4.2 Support mechanisms

Knowledge Transfer Partnerships (KTP)

Knowledge Transfer Partnerships are a tried and tested method of enabling companies to obtain knowledge, technology or skills which they consider to be of strategic competitive importance, from the further/higher education sector or from a research and technology organisation. The knowledge sought is embedded into the company through a project or projects undertaken by a good quality individual recruited for the purpose to work in the company.

It is recognised that KTPs are a particularly useful vehicle to enable SMEs with a relevant skills base (possibly derived from involvement in non-nuclear industries) to enter the nuclear supply chain. This report has highlighted the potential for advanced fabrication techniques to make an impact within the timescales relevant to TSB/RDA intervention. In particular KTPs should be established in areas such as the following:

- Develop and apply best practice for welding plant components and for fabricating new plants. This includes applying robust computer simulation tools for weld modelling including supporting material property data and validation.
- Apply surface technology, including peening (glass bead, laser, and water jet), electropolishing, etc., to develop corrosion and wear resistant components.
- Development of new approaches for large component fabrication including hot hydrostatic pressing.
- Apply advanced non-destructive testing include ultrasonic waveguides and phased arrays, eddy current methods for pipe wastage, and development of methods for the measurement of residual stress and fatigue damage.
- Collaborative Research and Development Programmes (CRD).

Public sector collaborative research and development programmes are designed “to assist the industrial and research communities to work together on R&D projects in strategically important areas of science, engineering and technology - from which successful new products, processes and services can emerge.”

It would be beneficial for the public sector to stimulate CRDs in the one or more of the following advanced materials technology areas:

1. Neutron irradiation effects on microstructure and properties,
2. Environmentally-assisted degradation in nuclear plant components including corrosion-fatigue, PWSCC and IASCC,
3. Non-destructive examination of nuclear plant components

In addition, it is recognised that the UK Research Centre in Non-Destructive Evaluation (RC-NDE) leads the research and development in the area identified under number 3 in the list above, and can provide a significant contribution in this area.

Stimulating increased collaboration: Knowledge Transfer Network (KTN)

A Knowledge Transfer Network is a “single over-arching national network in a specific field of technology or business application which brings together people from businesses, universities, research, finance and technology organisations to stimulate innovation through knowledge transfer”.

The objective of a Knowledge Transfer Network is to improve the UK's innovation performance by increasing the breadth and depth or the knowledge transfer of technology into UK-based businesses and by accelerating the rate at which this process occurs. The Network must, throughout its lifetime, actively contribute and remain aligned to the goals of the Technology Strategy Board.

As part of our recommendation in the main report relating to the establishment of a Nuclear Special Interest Group within the Energy Generation & Supply KTN, it would be beneficial for the TSB to consider supporting the international collaboration in the field of advanced materials technology in relation to new nuclear build. As noted in Section 3.1 of this report, there is a clear consensus amongst the international community regarding the key materials technology challenges associated with new nuclear build. There are clear opportunities to maximise the impact of materials technology through a structured and proactive approach to international collaboration. In particular, it is recommended that a proactive approach be taken to international collaboration including the Euratom Framework programmes, links with the EDF-EPRI-TEPCO Materials Ageing Institute, and other international players including INL, EPRI and JAEA. In such a network there are also clear benefits from stimulating technologies/ methodologies for capturing expert knowledge.

4.3 Interim summary

This section has provided further detail regarding the opportunities for public sector intervention in the materials field including infrastructure- and technology-based opportunities, and has summarised the mechanisms that could be exploited for intervention. It is recognised that there are specific opportunities relating to advanced manufacturing research to support the new nuclear build agenda, and in the understanding and predicting of materials degradation, fabrication and joining, structural integrity and condition monitoring areas that build on recent research supported by the EPSRC and other funding bodies. Specific mechanisms for support have been identified including KTPs, CRDs and KTNs which would enable considerable benefit to be taken from international developments in this area.

5.0 Spill-over Benefits

It is recognised that there are significant 'spin-in' and 'spin-out' benefits from public sector investment in the materials technology- and infrastructure-based opportunities highlighted in the previous section.

Within the nuclear industry this includes the strong synergies that exist between the civil PWR programme and the UK Naval Propulsion Programme in areas including materials and chemistry as well as structural integrity of current and future propulsion plant.

Within the power industry this includes particular benefits associated with component fabrication and materials degradation related to the secondary steam-raising plant and the electricity-generating components, including steam turbines. For example Report 2 on Materials UK assessment of the priority research needs for materials used in fossil fuelled plant [7] emphasised the need for research in many of the themes identified above, e.g. surface protection coatings, and advanced NDE techniques. Similarly, the report on materials for Alternative Energy Technologies [8] identified as a priority developing high strength, corrosion resistant heat exchanger alloys and coatings for biomass and waste systems.

To judge the benefits to other industrial sectors we refer to the Technology Strategy Boards materials strategy [9]. More specifically, the TSB has developed a strategy which outlines ways in which the materials sector can continue to innovate and grow. Three priority areas, based on an analysis of common market sector drivers, have been identified as channels for technology inspired activities; these are described as Energy, Sustainability and High value Markets. Further, in this strategy the need is recognised "for continued investment in underpinning and emerging generic materials technology development, and exciting thrust areas have been identified which are anticipated to have a major impact in the key challenge areas" . These thrust areas are listed in Table 3 in terms of their relevance to the three priority areas.

It can be seen that several of the thrust areas have been identified in this report as being key to materials for new nuclear build; for example, materials to withstand more aggressive environments, surface engineering and coating technologies, joining technologies, and predictive modelling through the full life cycle, including lifetime prediction. Given this synergy it appears that developing advanced materials and components for application in new build plant should have benefits to other sectors that require high performance materials that operate in harsh environments.

Table 3
Technology thrusts in each of the key challenge areas.

	Energy	Sustainability	High Value Markets
Lightweight materials and structures, including composites and hybrids	●	▲	◆
Materials to withstand more aggressive environments (eg high temperature, corrosive, erosive)	●	▲	◆
Electronic and optical functional materials	●		◆
Smart and multifunctional materials, devices and structures	●	▲	◆
Surface engineering and coating technologies	●	▲	◆
Particulate engineering: near net-shape manufacturing	●	▲	
Fibre and textile-based technologies	●		◆
Bioresorbable, bioactive and biocompatible materials			◆
Natural and bio-based materials		▲	◆
Joining technologies	●	▲	◆
Materials for portable power sources (batteries/fuel cells)	●		◆
Nanomaterials	●	▲	◆
Materials with reduced environmental impact through life		▲	
Materials designed for reuse/recycle/remanufacture		▲	
NDE/SHM/condition monitoring	●	▲	◆
Predictive modelling through the full life cycle, including lifetime prediction	●	▲	◆

6.0 Summary and Recommendations

A summary of the findings of this report in relation to three key questions it set out to address; namely:

1. **Is there a UK capacity to develop and exploit the technology and become a leading global player?**
2. **Does the technology have potential for impact in the right time frame?**
3. **Is there a clear role for public sector intervention and support that adds value above and beyond that of private investment?**

Further, we provide recommendations for consideration by the public sector in relation to priority areas and mechanisms for intervention.

1 In summary there is an increasing UK capacity for advanced materials technology with specific areas of real materials expertise that can be exploited. However, this increasing capacity follows a period of decline. Thus, in terms of capability for advanced materials technology, public sector funding may be used to stimulate new industrial organisations entering the supply chain through appropriately directed Knowledge Transfer Partnerships. Out of the analysis undertaken there are specific areas which are suitable for public intervention. These include:

- Stimulating the use of improved manufacturing techniques for nuclear plant, including welding and joining, surface technology and modularisation through the formation of an Advanced Manufacturing Research Centre for Nuclear.
- Stimulate new industrial organisations entering the supply chain through appropriately directed Knowledge Transfer Partnerships.
- Stimulating technologies/ methodologies for capturing expert knowledge

2 There is strong evidence that materials technology development has the potential for impact in the right time frame, including supporting the licensing and managing of the long-term, safe and economical operation of current and future nuclear power plants.

Further, there is a clear consensus amongst the international community regarding the key materials technology challenges associated with new nuclear build. More specifically, there are opportunities to maximise the impact of materials technology through a structured and proactive approach to international collaboration.

Analysing these materials challenges has indicated the following priority opportunities in relation to new nuclear build on a 5-year timescale:

- Technology-based opportunities:
  - Materials degradation, structural integrity and lifetime prediction including water chemistry and doping to reduce corrosion and advanced materials
  - Condition monitoring and preventative maintenance to underwrite safe life and reduce downtime
  - NDE/NDT to accelerate new build programme reduce in-service inspection times.
- Infrastructure-based opportunities:
  - Advanced Manufacturing Research Centre(s) for Nuclear to address high value manufacturing by the supply chain.
  - Advanced fuel manufacturing processes including more efficient fuel and fuel recycling.

3 It is recognised that there are specific opportunities relating to advanced manufacturing research to support the new nuclear build agenda, and in the understanding and predicting materials degradation, fabrication and joining, structural integrity and condition monitoring areas that build on recent research supported by the EPSRC and other funding bodies. Specific mechanisms for support have been identified including KTPs, CRDs and KTNs.

There are opportunities to maximise the impact of materials technology through a structured and proactive approach to international collaboration, including links to the EDF-EPRI-TEPCO Materials Ageing Institute, and other international players including INL, EPRI and JAEA.

There are significant spill-over benefits from investment in these opportunities to both Naval Propulsion Programmes and to other Power Generation industries.

Photo courtesy of Dalton Nuclear Institute

6.0 Summary and Recommendations

Recommendations

Based on this review of nuclear materials R&D and manufacturing opportunities associated with the new nuclear build programme, alongside a study of the UK materials capacity, the following recommendations are made to the funding agencies:

1. Co-invest with industry in advanced materials technology for the new nuclear build programme and, in particular, create a centre of excellence which brings together the expertise of the UK in industry and the universities in the minimisation, detection and prediction of materials degradation to be deployed in the new nuclear reactors and thereby increase the lifetime, efficiency and safety of nuclear power.

2. Co-invest with industry in the UK R&D base to take novel NDE/NDT and Condition Monitoring techniques and instruments (including residual stress measurements) from Technology Readiness Levels (TRL) 4/5 to TRL 7.

3. Co-invest in an Advanced Manufacturing Centre for the components and systems needed for the new nuclear build programme. The Centre should focus on novel manufacturing techniques for SMEs in niche areas such as hot isostatic pressing, welding and joining, and surface technologies including the application of nanotechnology to nuclear engineering.

4. Examine ways of building up the manufacturing capabilities of the UK for advanced fuel production with higher burn up capability and lower waste generation.

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