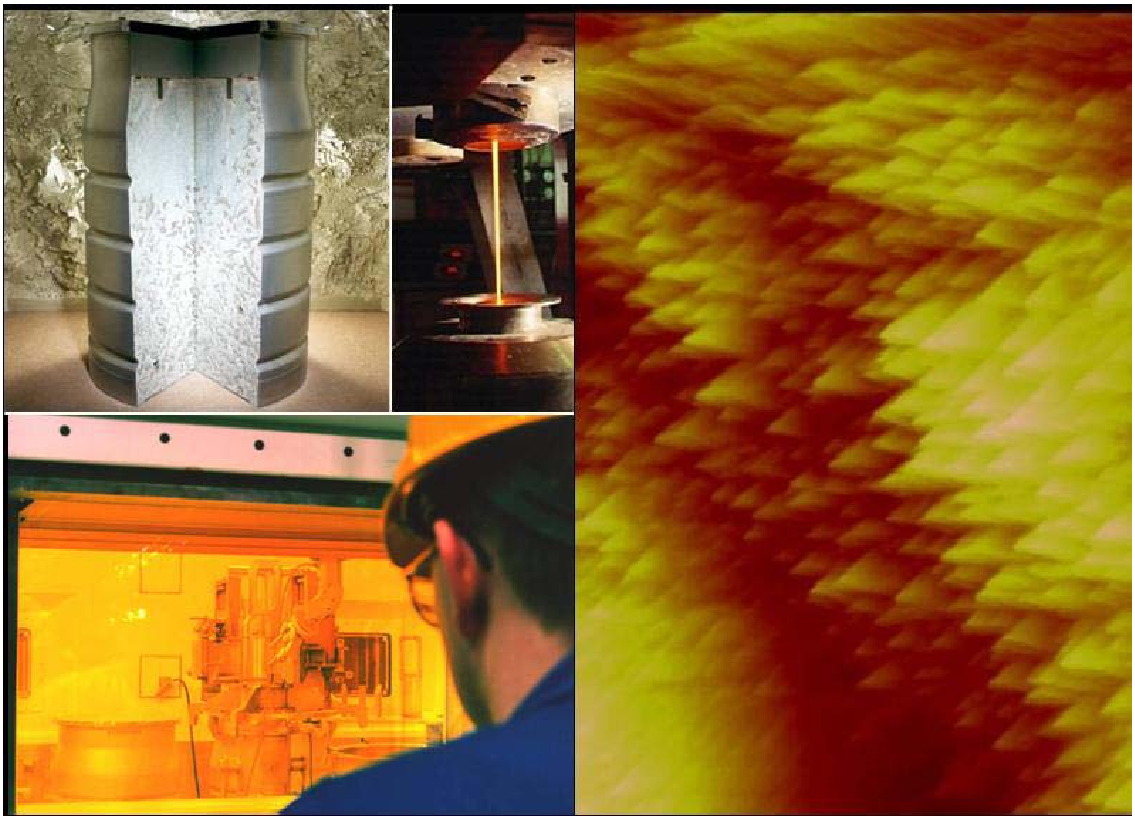
Materials for Nuclear Waste Management

January 18th 2006
Royal Society of Chemistry



RSC Environment, Sustainability and Energy Forum and Materials Chemistry Forum

Executive Summary

The UK needs a long term option for both its existing nuclear waste and any future waste created by new nuclear power plants.

In order to package nuclear waste in a form suitable for long-term management it is vital that the exact nature of the geological repository where they are to be stored is known. The Government must act swiftly and make a decision once the recommendations from the Committee for Radioactive Waste Management (CoRWM) are reported in July 2006.

Research is needed into wasteform design and stability. There is particularly a need for research into immobilising unconventional nuclear wastes, including substantial quantities of plutonium and graphite; there is no current long-term management option for a number of radioactive materials.

There is no managed funding programme in the UK that specifically addresses nuclear waste; currently researchers must bid into competitive programmes where nuclear waste research may be disadvantaged as it does not always fit the criteria of selection panels. In addition, working with radioactive materials is costly. A ring fenced funding programme for nuclear waste management is needed.

The UK has a shortfall of facilities at which experiments and characterisation of radioactive material can be carried out. This is hindering progress on nuclear waste management and means the UK has a weak hand in EU and international collaborative projects as we have little to offer.

There are now too few scientists with skills in nuclear waste management in the UK. How many scientists have left the nuclear industry is not known as there is no skills register. To ensure there is a supply of appropriately skilled scientists in the future there is a need for courses at undergraduate level and funding for research at postgraduate level.

Nuclear waste researchers and the nuclear industry must look to other sectors for collaboration on dual use technology and relevant know-how.

The issues of public acceptance of nuclear waste repositories must be considered by nuclear scientists and engineers who must put forward the case for safe, long term storage.

Recommendations

Funding bodies

- It must be a key priority of the Nuclear Decommissioning Authority (NDA) to provide the facilities needed to support UK civil research into nuclear waste management.
- A managed funding programme (either directly from the NDA or through the research councils) is needed to ensure that key research can be carried out into nuclear waste. In particular, there are specific research challenges associated with unconventional nuclear waste that require significant effort to overcome. Any research programme must be aligned to the ultimate long-term management option for nuclear waste as recommended by CoRWM.

Skills and education

- There are too few chemists with skills in nuclear waste management in the UK, in particular:
    - There is a need to construct a central skills register to determine the range of skilled workers inside and outside of the nuclear industry.
    - There is a need to train more undergraduates in radiochemistry and nuclear waste management to ensure there is a sustainable supply of skilled future chemists.
    - There is a need to provide funding and facilities to encourage and retain both UK and international scientists in nuclear waste research.

Government bodies

- It is vital that the Government acts quickly upon the recommendations of CoRWM regarding long-term nuclear waste management.
- Lessons must be learned from geological disposal consultation processes carried out in other countries (such as Finland and Sweden). The UK needs an open and transparent process where local stakeholders are fully engaged and the public is fully informed.

Learned societies

- Safe long-term nuclear waste management will require the efforts of multi-disciplinary teams of scientists. It is critical that the learned and professional societies collaborate to bring researchers together to tackle the challenges faced. It is recommended that the RSC along with other learned and professional societies collaborate on future workshops and conferences focussing on nuclear waste management.

Introduction

The workshop – Materials for Nuclear Waste Management – was organised by the Royal Society of Chemistry in collaboration with the University of Manchester Dalton Nuclear Institute and the University of Sheffield Immobilisation Science Laboratory and Radioactive Waste Immobilisation Network. Its aims were to provide a forum for researchers spanning a range of disciplines. The scope covered developments in nuclear waste management from both a national and European perspective and particularly the role of the chemical sciences. Future scenarios for waste management were explored in an interactive session to identifying key technologies, skills and potential collaborations. This workshop was attended by scientists working in the nuclear industry, as well as physical scientists, materials scientists, and engineers. This report summarises the presentations and the discussion during the breakout sessions.

The presentations

Derek Taylor - Directorate General for Energy and Transport European Commission

Radioactive Waste Management - The European political perspective

Derek Taylor stated that by 2030, the EU demand for energy will have increased by 30%. Electricity demand may rise even faster. The need for imported fuels will rise accordingly and we may be importing 80% of natural gas by 2030, from 3 suppliers (current). Increased CO_2 will arise from the use of fossil fuels, manly through transport and electricity. However, if more renewables and nuclear power were employed – together with increased energy efficiency - the “business as usual” case CO_2 emissions would be significantly reduced. Nuclear power currently accounts for 1/3 of EU electricity and has an important role in the diversity of energy supply. The cost of alternative fossil fuels is increasing and this has a knock-on to electricity price. The emissions trading scheme (ETS) also is adding to the cost of fossil fuel derived power, and is causing some coal stations to close. Under these conditions nuclear power is becoming even more cost competitive.

There are three core issues for any future energy policy must address – security of supply, costs (competitiveness) and impact on the environment. Use of nuclear energy can reduce our dependence on imported fossil fuels and the costs of nuclear generated electricity are likely to be lower than for any other fuel (and much lower than the cost of electricity from renewable forms of energy).

On the question of the environmental impact, a majority of the public do not yet realise that nuclear power plants do not emit CO_2. In addition they are concerned about the issue of radioactive waste. A key statistic is that if told that nuclear waste would be managed safely 14/15 EU countries said that they would be happy with nuclear build. It should be realised that the volumes of such waste are small and that the technologies already exist for their safe management. In terms of quantities, the EU produces 45,000 m^3 of nuclear waste each year (equal to 100mL per citizen) and the majority of this is LLW (only 500 m^3 is HLW). To put this in perspective, the EU generates 2 billion tonnes of all other forms of waste annually of which 35 million tonnes is hazardous (8kg each) and is stored in 55,000 sites.

The EU “nuclear package” deals with the safety of nuclear installations and nuclear waste through the safety and waste directives. In the safety directive each state assesses the safety of its nuclear installations and then the reports are then reviewed by the other member states. The directives have not yet been ratified and this is now unlikely to happen before 2007.

The UK has made little progress on HLW and most of it is in storage on the surface. Derek stated that the UK would likely face difficulties in getting a positive opinion from the Commission on plans to expand its nuclear programme without first identifying a long term option for nuclear waste management.

Professor Charles Curtis – Nirex and University of Manchester
Overview of the Different Types of Nuclear Waste and Different Options for their Disposal
Professor Charles Curtis stated that the aim of waste management organisations is to convert all raw wastes to a stable, immobilised condition and to package such that no further treatment should be needed throughout storage, transport to a final location, emplacement, facility closure and afterwards. And therefore that raw waste treatment and packaging must thus be to specifications which address all of these in a fully coherent way.

The UK has a large legacy of radioactive wastes and that much of the waste is old and in poor condition. UK waste is divided into three categories, high level waste (HLW), intermediate level waste (ILW) and low level waste (LLW). HLW is predominately an acidic by-product of nuclear fuel reprocessing and is currently encapsulated in vitrified glass and stored at Sellafield. ILW includes fuel casings and reactor components and is currently encapsulated in cement and stored in drums. LLW includes soil, rubble and discarded protective clothing and is currently placed in containers and stored at Drigg.

There are a number of unconventional wastes that need to be managed alongside conventional wastes and these include plutonium, uranium (both enriched and depleted), contaminated land and radioactive sources (such as those found in medical devices). Such waste types will need specific waste management methods to be developed and therefore there is a need for R&D.

A number of waste types are very long lived and Nirex believes that deep geological disposal must be the preferred basis for management of these very long-lived wastes. Professor Curtis introduced a Nirex Phased Geological Repository Concept that incorporates a long and variable period during which the wastes are retrievable and are monitored for package performance. The Committee on Radioactive Waste Management (CoRWM) is due to report recommendations regarding long term waste management July 2006.

Professor Francis Livens – University of Manchester
Facilities and Scope of Radioactive Work in the UK
Professor Francis Livens argued in his presentation that there is no avoiding doing experiments with high specific activity materials in support of radioactive waste disposal. Chemical analogies are unreliable when we require insight into mechanisms and the international scientific benchmark is now a mechanistic level of understanding. He cited examples where advanced characterisation of highly radioactive samples has been absolutely crucial in determining mechanisms of direct relevance to nuclear waste management.

The UK has limited facilities for the analysis of radioactive substances and these facilities are mainly centred on Sellafield, Springfields, Manchester and Daresbury. Funding bodies outside the nuclear industry need to be educated in the costs, timescales and practicalities of radioactive work. European and international facilities for application of advanced techniques to radioactive samples are available, often through collaboration so Professor Livens argued that if the UK is to join and be an active partner in European and international projects then it needs to be in a position to contribute something to these projects.

In summary, Professor Livens stated that the UK needs to answer two questions-

1. what infrastructure will it provide?
2. what infrastructure will it access through international collaborations?

He also suggested that infrastructure for characterising radioactive samples is essential because the UK has to carry out fundamental research into radioactive waste management. Without this, there will be no credible waste management strategy and this would prejudice any future new build.

Richard Taylor – Head of Technology – Nexia Solutions
Storage of Radioactive Wastes
Richard Taylor stated that before we can commit ourselves to a programme of nuclear waste management, we need to know what the end game is, i.e. the ultimate storage solution for the waste. Until we know this, we cannot know whether our packaging (i.e. what form the waste is currently managed in) is the correct one for the chosen long term management option. Significant reworking of waste is something that should be avoided.

Richard went on to described two categories of waste, firstly, well characterised and homogeneous waste (such as that from reprocessing fuel) and secondly, poorly characterised heterogeneous waste (such as that found in legacy storage facilities from the early days of the nuclear industry). There is a need to characterise, separate and pacify legacy waste, but it is important to ensure that it is managed in a form that is appropriate for a chosen long term waste management.

Professor Bill Lee – Imperial College
Problem Wastes, Wasteforms and Knowledge Gaps
Professor Bill Lee identified a number of problem wasteforms in his presentation, including plutonium (radiotoxic), plutonium contaminated material (radiotoxic), halides (easily biologically assimilated), graphite (high volume – 100,000 tonnes), TcO_4^- (long lived), reactive metals and ill characterised magnox sludges.

Professor Lee defined immobilisation as incorporation of waste into the structure of a host such as ceramic, cement or glass and stated that when considering immobilisation that you must consider and model the atomic level, microstructural level, packaging, near-field environment and the far-field geosphere as all these factors are important in a repository. He described that wastes can be difficult for a number of reasons including that they are radiotoxic, contain radionuclides with long half lives, contain highly mobile radionuclides, are easily assimilated in the body, are high volume, uncharacterised or have escaped into the environment.

Professor Lee reiterated Richard Taylor's point that we need to know the geological environment of a UK national repository to guide durability experiments and modelling to determine most stable wasteforms. There is also a need for Life Cycle Analysis (LCA) of all possibilities in order to make informed decisions; this is something that the NDA is looking at as part of their decommissioning programme.

The vast majority of current waste is already taken care of by immobilisation of HLW in glasses and ILW in cements. There are however some problematic wastes that have no current management route, including pertechnatate, ^{129}I, graphite and Cs-contaminated clinoptilolite filters.

There is a need for further R&D in order to manage certain past legacy wastes (including Pu) left over from past civil or military programmes and decommissioning wastes.

Future wastes such as spent fuel from current and future (e.g. Generation IV) reactors need more R&D. In particular the durability of many potential future wasteforms, including spent fuel from AGRs and Gen IV reactors in the likely repository environment, is unknown.

Professor Lee noted that the application of nanotechnology presents opportunities for improved separations technology and development of nanoparticles able to sorb escaping radionuclides in a repository environment, but much R&D is required.

Dr Neil Milestone – University of Sheffield
Nuclear Waste Immobilisation – Cementation
In his presentation Dr Milestone emphasised the need for cement based encapsulation to deal with the large volumes of ILW and LLW compared to HLW. Cementation offers a system that is well understood, easy to handle, is inexpensive and gives a stable product. However, ordinary Portland cement

(OPC), which is the best understood and most widely used cement, suffers from some drawbacks; in particular the hydration reaction is exothermic which can lead to thermal stress cracking and the cement is very alkaline (pH <13). To address this, high replacement levels of mineral admixtures are added which react with the $Ca(OH)_2$ produced from OPC hydration reducing both the heat output and the high pH). The presence of an excess of mineral admixture means that hydration does not go to completion leaving free water in pores that can be measured by ^1H NMR relaxometry.

The durability of the hardened matrix is dependent on the chemical properties and chemical reactions that occur between the cement pore water and the waste. Therefore it is important to be able to identify the specific reactions that occur within the encapsulation matrix. The work carried out by Dr Milestone has identified several issues and some of the necessary actions to address them, including:

- Iron flocs, generated for actinide recovery during fuel reprocessing, must be pre-treated with $Ca(OH)_2$ before cementation otherwise the cement does not hydrate correctly and a weak structure forms.
- Aluminium, which is present in historic wastes and associated with fuel cladding, corrodes at pH >12 with a mechanism that leads to hydrogen liberation and cement cracking. OPC is therefore not a suitable matrix for aluminium containing waste. Activated slags and calcium sulphoaluminate (CSA) cements are proposed as a potential matrix for aluminium as the pH remains below 12.
- Zeolites that are used to remove radioactive caesium and strontium during reprocessing cannot be encapsulated in OPC composites because during the cementation reactions the zeolite reacts, releasing the caesium which can be mobilised and leached. Calcium sulphoaluminate (CSA) cements are proposed as one alternative as they do not produce $Ca(OH)_2$ and caesium leaching is reduced.

Dr Milestone concluded that for non-reactive waste OPC is a suitable matrix, but for reactive wasteforms, alternative cement chemistry may be required.

Dr Greg Lumpkin – University of Cambridge
Ceramic Waste Forms
Dr Lumpkin stated that we should attack remediation with good science. The PUREX process of nuclear waste reprocessing gives rise to a number of species to tolerate and that there are many requirements for wasteforms. Ceramics are a suitable material for HLW encapsulation and there has been significant research on the materials since the 1970's. There are a number of wasteform criteria that must be met by candidate materials, including:

- High waste loadings
- Ability to tolerate impurities
- Simple & reliable processing methods
- Acceptable microstructure
- Mechanical, thermal and radiation stability
- Thermodynamic stability (kinetics)
- Durable in aqueous fluids

- Demonstration of long term effects - modeling and use of natural systems

Numerous crystalline ceramic phases that can potentially be used for HLW management. Special purpose compositions have been created for plutonium, strontium and caesium through using crystal chemical principles & advanced solid state chemistry and physics. In particular pyrochlore, zirconolite and monazite are applicable for actinide encapsulation and hollandite is suitable for caesium encapsulation.

Dr Etienne Vernaz - CEA / Nuclear Energy Division / Marcoule
Nuclear waste in France: Current and future practice
France derives 80% of its electricity from nuclear power and has built up significant knowledge relating to nuclear fuel reprocessing and nuclear waste management. Spent fuel is reprocessed in the La Hague plant in a process where 95% of the fuel is recovered meaning that only 5% is waste and must be vitrified in glass. The vitrified waste product is poured into canisters and is currently stored at the La Hague facility. The plutonium produced during reprocessing is used in Mixed Oxide Fuels (MOX) which saves about 10% of the need for natural uranium. MOX fuel is currently not reprocessed. Fuel casings (hulls) are compacted and stored in the same style of canisters as vitrified glass (in the UK hulls are encapsulated in cement and stored in drums). In the past bitumen was used to immobilise liquid effluent treatment sludge, although this is no longer practiced in the most advanced plant, UP3, in La Hague. In this plant the radioelements are now concentrated and vitrified with the fission product solution. LLW is compacted, immobilised in concrete and stored in an above ground facility at the Soulaines centre in Northern France. France also has a category of very LLW, which arose through a political decision not to design an exemption threshold below which nuclear waste could be categorised as conventional waste.

Dr Vernaz introduced the French *Bataille Act* of 1991 which relates to the disposition of long-lived high level radioactive waste and has three major thrusts:

1. Identify solutions for separation and transmutation of the long-lived radioactive elements present in the waste
2. Investigate the possibilities of reversible or irreversible placement in deep geological formations
3. Examine processes for conditioning and long-term surface or subsurface interim storage of long-lived high-level waste (LLHLW)

Significant research is being carried out on all three of these topics and an underground laboratory has been built in Bure in Northern France to gather information about a potential deep geological repository. Further work is also being carried out on the next generation of vitrification technology, including a combined system of combustion and vitrification for the reduction in volume of ILW (Shiva process).

The breakout sessions

A summary of the key points arising from discussion is described below.

The lack of facilities in the UK for radioactive research

There is a shortage of academic and industrial facilities available in the UK where radioactive materials can be handled and studied. The available facilities have been summarised as follows;

Conventional Instrumentation for Radioactive Samples

	non-Nuclear	Nuclear Sites
Atomic Force Microscopy	All available	?
X-ray Photoelectron Spectroscopy	but only for U,	Sellafield? (Berkeley)
Electron Microscopy	Th (and in	Sellafield, (Berkeley)
X-ray Analysis	Manchester	Sellafield, (Berkeley)
Secondary Ion Mass Spectrometry (depth profiles and maps)	< 0.4 Bq g^{-1})	Sellafield?
X-ray Powder Diffraction		Springfields (U), Sellafield?

The Berkeley facilities have been decommissioned

In practice, access to facilities on nuclear sites is very difficult- shipping, sample preparation, instrument time are all painful

A wide range of facilites exists at AWE but these cannot be used for material subject to EURATOM Safeguards (*i.e.* all civilian Th, U, Pu).

Synchrotron Techniques

	Daresbury	Diamond
Synchrotron X-ray Fluorescence Mapping	Limited (U, Th)	"…we do not intend to
X-ray Absorption Near Edge Spectroscopy (XANES)	U, Th, Tc	provide facilities for testing of
Extended X-ray Absorption Fine Structure (EXAFS) Spectroscopy	U, Th, Tc	radioactive samples"
Synchrotron X-ray Powder Diffraction	U, Th (Tc)	Colin Norris, Science Director, 22 Dec 2005

This information was provided by Professor Francis Livens and illustrates the limited opportunities for research using radioactive samples. The BNFL Technology Centre at Sellafield can handle radioactive substances and Universities can access its facilities but they are given low priority and the facilities are expensive. Facilities at the Berkeley Centre are now decommissioned. There are also industrial facilities for studying plutonium at the BNFL site at Risley and the UKAEA site at Winfrith, but whether these facilities are available for academic research is unknown. There is now no research reactor for materials testing in the UK as previous facilities have now been decommissioned.

If a new technology, such as a reprocessing technology was developed in the UK, there is uncertainty as to where and how the technology could be tested and demonstrated.

The lack of facilities is linked to the lack of new nuclear build in the UK. If there was a move to new build then perhaps there would be more of a ‘market’ for radioactive facilities and such facilities would be built. However this does not address the problem of legacy nuclear waste which must be dealt with regardless of the country’s position on future nuclear power.

There is also a problem with transporting active materials which can make travelling to research centres difficult and taking samples to facilities in other countries very difficult.

What research programmes are needed in the UK?
Workshop participants highlighted the following areas where research is needed:

- wasteform design – particularly for problem wasteforms such as plutonium contaminated material and ill characterised magnox sludges.
- how radiation damage affects materials properties – important for long term storage implications
- aqueous durability of wasteforms – to understand the corrosion of wasteforms
- actinide behaviour, transport and speciation – more information is still needed to better understand how radioactive actinide compounds behave
- waste containers - there is a need to consider materials engineering issues such as the type of materials selected for use as waste containers

In addition a great deal of work will still needs to be done on the economics of nuclear waste management, in terms of the chosen option for the management of present nuclear waste, and a realistic assessment of the costs of storing any future waste. Such costs will need to be built into the costing of any future nuclear build.

It was also felt important that previous research is well studied so that the community doesn’t reinvent the wheel. The right research must be done to consolidate current knowledge, although this can be hampered by a lack of openness in sharing information.

The skills problem
There is a lack of skilled personnel to carry out the necessary research in all areas involving nuclear research. In particular radiochemists are becoming rare. We need to ensure that undergraduates are educated in radiochemistry and that postgraduate training also exists. The same is applicable to nuclear engineers. More funding will go some way to redressing this skills gap – attracting academics to carry out more nuclear projects which will offer a route for postgraduate students to pursue research in this area.

The workshop felt that there is a risk that the depletion in skills has gone too far to recover in the short term. The nuclear industry may have to imports skilled personnel from elsewhere.

A central nuclear skills register was thought be a valuable resource, however, this is substantial task and could not be achieved by one organisation alone. A joint societies venture might be the best way to achieve this.

Funding issues
The community perceives funding as a big issue – in particular, that there is no managed programme set aside for waste research. Research Council funding is awarded either through managed programmes or via ‘responsive mode’ which is competitive with other areas of research. The community feels that they are at a disadvantage when applying via responsive mode. Research into nuclear waste management, although crucial, can not always compete in terms of the demands of selection panels for innovative and ground-breaking work. In addition, working with radioactive materials is expensive and would demand a large share of the potential funding awarded by a panel.

To create a coherent short and long term research programme the link between the Research Councils, the Department of Trade and Industry and the Nuclear Decommissioning Authority need to be strengthened. Joined up thinking and funding are needed but this is not perceived to be occurring.

European Commission funding is available via the framework programmes, but this requires partnerships from several European countries as well as industry involvement to fund at least 50%. These funded ‘Networks of Excellence’ (NoE) have successfully created research communities in other fields and a NoE in nuclear waste management as part of the next European Commission framework programme (FP VII) could be a useful mechanism for broadening the scope beyond the present nuclear community. There is an actinides network, ACTINET (European network in actinide sciences NoE), which was created in the last framework programme. At present little European funding in this area is coming to the UK, perhaps understandable with the lack of skills and facilities already highlighted.

The disposal of our weapons waste legacy brings some specific problems with it that will need considerable research funding, particularly that of plutonium waste. This funding should come from the Ministry of Defence. But there is pressure on the civil nuclear waste programmes to work on plutonium as this is considered a priority as it is an unsolved problem in terms of finding a suitable wasteform.

Unless nuclear waste is a considered a high priority with its own ring-fenced funding, then there will not be significant sums available. A research council initiative is needed. The CoRWM announcement on long-term nuclear waste management in July is a key date and; once the announcement is made, it is hoped that a more coherent funding programme will be formulated.

Exploiting developments from other technologies
In the workshop examples of technologies that have been developed in other fields but may be applicable to nuclear waste management were given as illustrations of the type of technology transfer that is needed:

- A product developed as electromagnetic shielding has been found to be a shield against radiation.
- Smart Technologies produced a small sensor product that can be followed by GPS and could be developed for remote sensing applications in vats or sludges of nuclear waste. British Nuclear Group are looking to fund further research into such small sensors.

Advances made in nanotechnology are likely to provide some solutions to nuclear waste challenges as may smart materials and biomimetric materials. New characterisation techniques and life cycle analysis methods will also be useful.

The oil drilling industry has significant expertise in sludge and slurry handling; which may be of use to the nuclear industry in examining radioactive sludges. Mining and retrieval could provide a useful source of skills and collaborations. The experience being built up in carbon dioxide sequestration could also be applicable to the nuclear industry, in relation to geological disposal and the grouting technologies employed in capping carbon dioxide storage.

But the workshop also heard that Johnson Matthey had suggested that a number of their materials were relevant to the nuclear industry. Platinum had been proposed to line crucibles in the vitrification of nuclear waste. It protects both the glass and the crucible. But attempts to communicate with the nuclear industry had failed. At the moment they don’t see an incentive for private industry to engage with the nuclear industry as there is no payback.

Further efforts are need to make sure that the nuclear industry is aware of other technologies that may be applicable to its own problems and the appropriate incentives exists to provide other industries with the motivation to provide solutions.

The public and nuclear waste

The selection of nuclear waste storage sites in the UK is likely to be contentious and of great public interest and concern. Workshop participants felt we could learn from the geological repository consultation process that was recently successfully carried out in Finland. The local population were encouraged to see the nuclear waste management programmes as an opportunity instead of a burden. Incentives could be used to assist in this encouragement, for example the improvement of facilities such as hospitals and schools although this may risk the accusation of bribery.

Currently, the general connotations that are associated with the term nuclear are those of weapons and the relations between Britain, the UN and Iran. These ideas, along with accidents such as Chernobyl have generated a level of suspicion which is reflected in some people's objections to proposals for nuclear waste repositories. In order to overcome this suspicion, firstly their needs to be a clear distinction made between civil nuclear power and the nuclear weapons programme.

A nuclear waste repository need not be seen as a burden; in Finland and Sweden, regions actually competed for nuclear waste repositories, because they were fully engaged in the process and had the option to walk away at any point. A similar approach must be employed in the UK. Ultimately, the country must be satisfied that scientists have provided a safe, long term storage solution for our existing and future nuclear waste.

Delegates list

Name	***Affiliation***
Lois Armstrong	Nexia Solutions
Dr Chris Bates	British Energy
Paul Bingham	University of Sheffield
David Brazier	Environment Agency
Dr Rachel Brazil	Royal Society of Chemistry
Dr Richard Brown	National Physical Laboratory
Jonathon Brown	NSG Environmental
Rob Burrows	Nexia Solutions
Dr Gareth Cairns	Leverton Contracts Ltd
Sebastian Charles	Kirkpatrick & Lockhart Nicholson Graham LLP
Peter Clarke	SCI
Professor Richard Clegg	Director of the Dalton Nuclear Institute
David Colley	Formerly BNFL Magnox
Dr Alan Comyns	
Martin Constable	AEA Technology plc
Dr Lisa Cowey	Oxford University
Dr Chris Crawley	Victrex plc
Professor Charles Curtis	Nirex UK
John Dawson	Centronic Raditec
Dr Ronald Dell	RSC Thames Valley Section
Professor Ian Donald	AWE
Dr Feroze Duggan	Independent Consultant
Peter Duncan	Johnson Matthey plc
Stuart Eldridge	Loughborough University
John Eldridge	British Nuclear Group
Professor Derek Ellwood	University of Southampton
Dr Nick Evans	Loughborough University
Dr Graham Fairhall	Nexia Solutions
Professor John Finney	UCL

Nicola Fletcher	AMEC NNC
Dr Shirley Fong	AWE
Dr Mark Foreman	University of Reading
Dr Michael Fowler	Unversity of Gloucestershire
Dr Richard Garnsey	Independent Consultant
Dr Lee Gerrard	AWE
Peter Gill	Chair of the Energy Group, Institute of Physics
Richard Giubertoni	AWE
David Grant	AWE
Dr Nicholas Green	KCL
Dr Trevor Griffiths	Redston Trevor Consulting Ltd
David Hardy	Mitsui Babcock Energy Limited
Dr Jeff Hardy	Royal Society of Chemistry
Elizabeth Harvey	Cambridge University
Charlotte Heath	Loughborough University
Dr David Hebditch	British Nuclear Group
Dr Joanne Hill	NIREX
Nick Howard	Mitsui Babcock Energy Limited
Dr Joe Hriljac	University of Birmingham
Michael Hubbert	Graham Engineering Ltd
Dr Neil Hyatt	ISL, University of Sheffield
Philip Isgar	Pell Frischmann Consultants Ltd
Dr Hywel Jones	Materials & Engineering Research Institute (MERI)
Philip Jordan	Watson Burton LLP
Dr Peter Kayes	Environmental Dynamics
Desmond King	
Douglas Kirk	RTS Innovation Ltd
Dr David Lee	AEA Technology plc
Professor Bill Lee	Imperial College London
Tara Lewis	Loughborough University
Gemma Little	University of Birmingham

Professor Frances Livens	Manchester University
Michael Lucas	Consultant
Hao Ly	Tetronics Ltd
Dr Donald Macphee	University of Aberdeen
David Mander	D C Mander & Partners
Brian Metcalfe	AWE
Dr Neil Milestone	Immobilisation Science Laboratory
Tony Milodowski	British Geological Survey
Dr Philip Mitchell	University of Reading
Sam Moore	British Nuclear Group
Dr Jenny Morris	AWE
Dr Mario Moustras	Royal Society of Chemistry
Chris Nelson	AWE
Dr Jon Newton	Salford University
Elsie Onumonu	Manchester University
Stephen O'Toole	Manchester University
Dr Scott Owens	Nexia Solutions
David Park	Larox
John Peace	J&S Technical Services Ltd
Malcolm Pick	British Nuclear Group
James Porter	NSG Environmental
Dr David Price	AWE
Jeremy Rabone	IMG Birkbeck/UCL
Professor Simon Redfern	University of Cambridge
Nigel Reeves	AMEC NNC
Professor Adrian Rennie	Uppsala University
Professor Chris Rhodes	Independent Consultant
Dr John Roberts	Immobilisation Science Laboratory
Dr Brooke Rogers	King's College London
Dr Elizabeth Rowsell	Johnson Matthey plc
Jane Sagar	Castle Cement Ltd
James Schofield	ISL (Sheffield University)

Gareth Sheppard	University of Birmingham
Professor Nihal Sinnadurai	YP - Powders Ltd
Dr Nicholas Stevens	Manchester University
Dr Mark Storr	AWE
Richard Taylor	Nexia Solutions
Dr Geoffrey Taylor	AWE
Dr Marina Taylor	University of Reading
Dr Derek Taylor	Directorate - General for Energy and Transport
Dr Andy Thomas	Future Solutions
Katie Titley	Loughborough University
Christopher Tombs	British Nuclear Group
Dr Mark Tyrer	Imperial College
Dr Etienne Vernaz	CEA-Valrhô
Dr Malcolm Wakerley	DEFRA
Colin Walters	TWI Ltd
Dr Anthony Ware	Environmental Energy Consultancy
Samantha Watson	HPA
Dr Richard Wells	University of Aberdeen
Dr Chris Wilding	Serco Assurance
Dr Peter Wood	NIREX
Guy Woodhouse	Manchester University
Dr James Young	University of Leeds

For further information, please contact:

Dr Jeff Hardy
Manager, Environment, Sustainability and Energy Forum
Royal Society of Chemistry
Burlington House
London W1J 0BA

Email: hardyj@rsc.org
Tel: +44 (0) 20 7440 3395

Dr Rachel Brazil
Manager, Materials Chemistry
Royal Society of Chemistry
Burlington House
London W1J 0BA

Email: brazilr@rsc.org
Tel: +44 (0) 20 7440 3305

Front cover images Images anti-clockwise starting from bottom left:
Intermediate Level Waste BNF 1924 RS P10 from the BNFL online asset library
AFM image of a uranium- containing phase growing on a cement surface kindly provided by Professor Francis Livens
CEA picture of Nuclear Waste Vitrification provided by Professor Etienne Vernaz Waste Encapsulation Plant (WEP) - recovery station CL0144 from the BNFL online asset library