The DIAMOND University Consortium: Decommissioning, Immobilisation and Management of Nuclear Waste for Disposal - 11097

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ABSTRACT

The DIAMOND (**D**ecommissioning, **I**mmobilisation **A**nd **M**anagement **O**f **N**uclear wastes for **D**isposal) university consortium was formed in response to a call from the Research Councils' UK Energy Programme "For a Low Carbon Future". The consortium comprises six of the foremost UK academic institutions in the field of nuclear science and engineering, namely the universities of Leeds, Sheffield, Imperial College London, University College London, Loughborough and Manchester. With an academic membership of approximately 50, supervising 35 individual research projects, the DIAMOND consortium represents the largest research group in the UK specifically targeting nuclear waste issues. Research activity within the consortium is divided into three work packages focused on radionuclide migration, waste characterisation and materials performance. These work packages include many of the technology challenges being faced today within the decommissioning sector and the consortium has been proactive in its approach to engage with industry stakeholders to ensure research work remains relevant and has a meaningful impact on key challenges being faced in the medium- to long-term. All projects have an industry mentor who can advise on project direction and facilitate access to specialist equipment and services that might otherwise be difficult to obtain. This has multiple benefits of enhancing the research output from the individual projects whilst giving the researchers a deeper insight to the industry, improving their industrial experience and having a positive influence on the researcher's preferred choice of future employment. Equally important are the industrial network connections being made with academic members of the consortium, many of whom have had little or no previous experience of working with the nuclear sector but have expertise that is readily applicable to nuclear-related research.

INTRODUCTION

The UK's nuclear industry dates back to 1947 when the Windscale site in West Cumbria was developed to generate weapons grade material for the UK nuclear deterrent programme. Two Pile reactors and a fuel processing plant used to recover plutonium were in operation until 1957, when the Windscale Pile 1 fire halted future operation. In 1953 the Government announced the UK's first civil nuclear power programme and a new design of gas-cooled reactor (Magnox) based on naturally enriched uranium metal fuel was built and commenced operation in 1956 at the nearby Calderhall site. This was the first reactor site to be used for commercial generation of electricity with approximately 40 MW being put into the national grid. Since then a further ten power-generating stations based on the Magnox design have been built. However, the majority are now being decommissioned, with only Oldbury and Wylfa power stations still in operation and Oldbury scheduled for defuelling in July 2011.

The primary disadvantage of the Magnox design was the limited power output, typically 300-500 MWe, due to the combined effects of using naturally-enriched uranium metal fuel and a magnesium alloy fuel casing. Other disadvantages included the cost of manufacturing the fuel casing, the relatively short burn-up period of the naturally enriched uranium fuel and the associated refuelling costs. These problems prompted the Magnox design to be superseded by the Advanced Gas-cooled Reactor (AGR), with an output of 1200-1350 MWe, using enriched (approximately 3%) oxide fuel capable of withstanding higher temperatures whilst increasing the duration that fuel could remain in the reactor. Seven AGR stations were commissioned between 1976 and 1988 however many are coming toward the end of their estimated life (two by 2014) and it is estimated that all generation capability from the AGR fleet will cease by 2023 [1]. The only nuclear reactor currently in operation that will continue generating beyond this date is the Sizewell B Pressurised Water Reactor (PWR), which commenced operation in 1995 and is scheduled to continue until 2035 [1].

The number of civil nuclear licensed sites in the UK extends well beyond the power generating stations and includes fuel reprocessing (Sellafield, Dounreay), fuel enrichment (Capenhurst), fuel manufacturing (Springfields) and experimental reactor sites (e.g. Windscale, Dounreay, Harwell). Additionally there are many facilities dating from the early days of the Pile reactors at Windscale that have been on a prolonged care and maintenance programme that must be addressed without further delay. In view of this impending decommissioning programme the UK Government's Energy Act [2] in 2004 established the Nuclear Decommissioning Authority (NDA) whose remit was to oversee the decommissioning of all civil nuclear plant after reaching the end of its productive life.

Many of the nuclear sites, and in particular Sellafield, hold significant challenges to current decommissioning technologies. These challenges have been, in part, exacerbated by the UK not having until recently an agreed policy on permanent nuclear waste disposal and all intermediate and high level waste arising e.g. from fuel reprocessing is currently stored temporarily in above-ground facilities, some of which are showing signs of aging and must be decommissioned in the short-term. In 2006 the UK Government advisory Committee on Radioactive Waste Management (CoRWM) recommended that geological disposal in a mined repository offers the "best available approach" [3]. The UK Government has initiated the Managing Radioactive Waste Safely (MRWS) programme which relies on a volunteerism approach in which communities come forward who are willing to host repositories. Nonetheless, it will be many years before such repositories can accept the first wastes and should not detract from the urgency in remediation of wastes, particularly those stored in liquid or sludge form.

The estimated cost of the nuclear clean-up programme to the UK tax payer is £70b and the NDA are responsible for delivery of solutions that will see the majority of sites decommissioned and cleared within the next 100 years [4, 5]. In some cases the timescales are significantly shorter and this will prove to be a considerable undertaking given the diversity of challenges that lie ahead, many of which will require new facilities to be built and new technologies to emerge from the research environment if safe, sustainable and publicly acceptable solutions are to be developed.

It is recognised that research and development within universities and companies is critical to deliver the NDA strategy on efficient clean-up of legacy wastes and storage and disposal of the resulting wasteforms [6] and in August 2007 the Research Councils' UK Energy Programme "For a Low Carbon Future" [7] issued a call for consortia proposals in the area of "Nuclear Waste Management and Decommissioning". The call for research proposals required a multidisciplinary and multi-institutional consortium to carry out underpinning science and engineering, tackling existing and future nuclear waste management challenges. The proposal was required to encourage bold and innovative thinking from multidisciplinary teams that could cross technical boundaries to provide practical solutions to complex issues. The proposal was also required to demonstrate collaboration with established research teams in both industry and in universities in addition to encouraging new partnerships with universities with limited capacity in the nuclear research sector. The value of the call was a maximum of £4m over a four year duration.

DIAMOND CONSORTIUM

Academic Membership

Much of the groundwork in forming the consortium membership had been prepared approximately 8 years previously by British Nuclear Fuels Ltd (BNFL) with the creation of four University Research Alliances at the universities of Manchester, Leeds, Sheffield and UMIST (later to merge with Manchester). These Alliances addressed the prevalent challenges at that time, namely, radiochemistry, particle science, immobilisation technology and materials performance, respectively. During this period the Alliances formed many successful working relationships within the nuclear industry and had a specific responsibility to turn around the prevailing negative perception of the industry and to generate an enthusiasm within academic circles to provide underpinning science and engineering capability to an industry that had lost much of its research and development capability over the previous 20 years. The Alliances also were responsible for promoting the nuclear industry to PhD students and postdoctoral researchers with a view to employment within the sector.

The call for proposals highlighted seven key thematic activities of interest namely, materials characterisation, waste treatment, plant termination, site restoration, immobilisation, disposal of nuclear waste and concepts for future spent fuel management. The thematic areas were covered to a large extent by the BNFL University Research Alliances since the themes were closely related to the original research challenges of the Alliances. However the extent of the call required additional expertise which was amply offered by the universities of Loughborough, Imperial College London and University College London. Combining these six universities, and led by the University of Leeds, the DIAMOND (**D**ecommissioning, **I**mmobilisation **A**nd **M**anagement **O**f **N**uclear wastes for **D**isposal) consortium was formed and officially started operations in July 2008.

DIAMOND Consortium Aims

The consortium was built around the established expertise of a small number of key individuals who had received significant support from the industry and research councils over recent years, including the Directors of the University Research Alliances at Manchester and Leeds, and the leaders of the Research Councils' Energy Programme funded "Keeping the Nuclear Option Open" and Nuclear Engineering Doctorate programmes. Within the consortium, however, the role of these established partners is to provide a strategic overview to the research programme, co-ordinate the activities of the consortium with existing initiatives and facilitate links to industry for the less well-established consortium members. In addition, they make industry aware of the skills offered by members new to the nuclear scene and of their potential benefit in the UK nuclear waste agenda. Broadly, the strategic aims of the consortium are:

- To carry out internationally-leading science and engineering in the broad area of decommissioning and nuclear waste management.
- To support research that underpins the development of innovative technologies for nuclear decommissioning, waste management and disposition.
- To broaden the UK research base in science and engineering focused on nuclear waste technologies and thereby help address a developing skills gap.
- To develop and support new links between investigators in universities that have established nuclear science programmes and those universities that are developing such programmes.
- To develop new inter- and intra-university links to facilitate multi-disciplinary collaboration and stimulate new applications of knowledge at the interface between disciplines.
- To train the next generation of UK scientists and engineers with skills and expertise in nuclear waste management and decommissioning issues.

INDUSTRIAL MEMBERSHIP

The formation of the DIAMOND consortium generated a significant response from many companies in the UK's nuclear supply chain as well as the site licence companies. Industry members can access expertise through a single point of contact which is viewed very favourably, knowing that their enquiry will be directed efficiently to the relevant expert, without the need for them to look for specialist advice through multiple university contacts. Approximately 25 different companies have now participated in DIAMOND activities such as the steering committee, training exercises for researchers, site visits, project supervision, arranging access to specialist facilities, attending meetings and conferences, etc.

This engagement with industry has two primary benefits, assuring the research projects remain relevant and offering the researchers an enhanced PhD/postdoctoral experience. Industry colleagues have been enthusiastic in becoming involved in individual research projects with all projects having some form of industrial supervision or mentoring. The longer term aspiration of fostering a close working relationship between companies and our researchers is that they will consider the nuclear industry as their preferred career option. Initiatives such as DIAMOND will help industry address the challenge of recruiting sufficient personnel to enable current and future operations to continue according to the NDA's estimated timescales [4]. This is a critical role for the consortium since the nuclear industry faces stiff competition from other engineering sectors and poaching of employees from companies inside and outside the nuclear sector is now relatively commonplace, adding to the pressure felt by companies desperately trying to retain their workforce [8].

DIAMOND CONSORTIUM MATRIX

The call for proposals was developed jointly between the Research Councils' Energy Programme and key industrial stakeholders such as the NDA and the National Nuclear Laboratory. Within the call 49 priority research areas were highlighted within the seven key thematic activities previously described, as shown in Table I. With the funding available it was not feasible to cover every priority area in great depth, nor was it possible to employ postdoctoral researchers in large numbers. Therefore, it was decided to address the majority of these areas using 28 PhD studentships with seven postdoctoral fellows, one associated with each thematic activity but working on a priority area.

With only 35 research projects within the consortium each project addresses one or more of the priority research areas in Table I, and these were incorporated into a project matrix as shown in Table II. This matrix consists of three work packages (WPs), each with a designated leader who is responsible for the delivery of the WP, reporting on progress and organising WP meetings to encourage dissemination of results throughout the academic and industry members. The general aim is to link activities that can take a particular waste type (for example corroded Magnox sludge) from its current state through characterisation and handling to treatment and packing, interim storage and finally into secure disposal. The cross cutting theme leaders within DIAMOND are recognised experts who take responsibility for maximising knowledge and technology transfer opportunities between the three WPs and we believe this provides an environment that optimises opportunities for collaboration, training, and knowledge/technology transfer across the consortium. Note that the individual project codes (3-digit number) in Table II can appear in more than one matrix column. This is due to the project being relevant to more than one cross cutting theme. The project titles to which the codes in Table II refer are given in Table III

Table I. Priority research areas identified in the call for proposals.

Thematic Activities	Priority Research Area
Waste characterisation	• Spatial distribution of radionuclides in irradiated graphite • Co-polluted sites/rubble etc • Post operational clean-out (POCO) wastes • Non-destructive assay • Sludges, mixed wastes • Robotic sampling/remote techniques • Improved characterisation techniques
Waste treatment	• Retrieval techniques • Leaching of radioactivity from irradiated-graphite • Decontamination of irradiated-graphite of ^{14}C • Re-use/recycling of waste materials • Sludges, ion exchange resins • Mobile treatment technologies • Compaction technology • Minimisation at source • Separation technologies • Co-contaminated wastes, including pyrochemical and mercury alpha wastes • Re-categorisation technologies
Plant termination	• Decontamination techniques/methodologies • Methodologies for radiological data mapping • Contamination/radiation surveys • Waste handling and size/volume reduction
Site restoration	• End point criteria • *In situ* and *ex situ* technologies • Standards for characterisation of sites • Long-term care and maintenance • Environmental monitoring • Minimising impact of buried radioactivity • Remediation of buried radioactivity
Immobilisation	• Product integrity and longevity • Alternative/novel encapsulants • Modelling of long-term performance of waste products • Improved cementation technology • Reduction of waste volumes • *In situ* treatment • Minimum additive waste stabilisation • Use of novel ion exchange materials • Design of wastes forms in line with repository geology and materials • Rework of failed waste forms
Disposal	• Tritiated wastes • Behaviour of wastes in repository environment (durability, heat loading, radiation damage, etc) • Alternative disposal concepts such as boreholes • Development of novel monitoring techniques for storage and disposal repositories • Understanding spent fuel disposal
Future spent fuel management	• Single waste form processes capable of treating a number of waste streams • Inert matrix fuels - can they be designed for disposal • Development of materials technologies for immobilisation of streams from non aqueous spent fuel management technologies • Use of nanotechnology to increase reactivity and throughput • Design of materials capable of producing low cost solutions for short term storage but which are then capable of being converted into materials for disposal

Table II. Project matrix capturing most of the priority research areas identified in Table I.

			Cross Cutting Themes		
			CCT1 Characterisation	CCT2 Treatment & Packaging	CCT3 Disposal
		WP & CCT Leaders	Francis Livens (Manchester)	Neil Hyatt (Sheffield)	Howard Wheater (Imperial)
Work Packages	WP1 Environment, Migration & Risk	Nick Evans (Loughborough)	1.1.1 1.1.2 1.1.4 1.2.1	1.1.1 1.1.3 1.1.4 1.2.2 1.3.1 1.3.2	1.1.1 1.1.2 1.1.3 1.1.4 1.2.1 1.2.2 1.3.1 1.3.2 1.3.3 1.3.4
	WP2 Decommissioning, Legacy & Site Termination	Michael Fairweather (Leeds)	2.1.1 2.2.1 2.2.2 2.3.2 2.3.3	2.1.2 2.1.3 2.1.4 2.2.2 2.2.3 2.2.4 2.3.1 2.3.2 2.3.3	2.1.4 2.2.4
	WP3 Materials Design, Development & Performance	Bill Lee (Imperial)	3.1.3 3.3.2	3.1.1 3.1.2 3.1.3 3.2.1 3.2.2 3.2.3 3.2.4 3.3.2 3.3.4 3.4.1 3.4.2 3.4.3	3.1.1 3.1.2 3.1.3 3.2.1 3.2.2 3.2.3 3.2.4 3.3.1 3.3.2 3.3.3 3.3.4 3.4.1 3.4.2 3.4.3

Table III. Project codes and titles within the DIAMOND consortium.

Work Package 1			
Cluster 1.1	Speciation	1.1.1	Modelling the environmental speciation of uranium at the molecular scale.
		1.1.2	Pu colloidal ternary systems.
		1.1.3	Investigation of the radionuclide complexation capabilities of superplasticisers.
		1.1.4	The interaction of Cs^{+}, Sr^{2+} and UO_2^{2+} ions with Brucite surfaces.
Cluster 1.2	Microbial Processes	1.2.1	Microbial-geochemical-hyrogeological interactions influencing radionuclide mobility in the subsurface.
		1.2.2	Impact of microbial metabolism on radioactive materials.
Cluster 1.3	Transport, Modelling and Risk Assessment	1.3.1	Diffusive transport in low permeability systems.
		1.3.2	Bench-scale visualisation of reactive transport for site remediation systems.
		1.3.3	Modelling heterogeneity effects on radionuclide transport in the far-field.
		1.3.4	Risk assessment tools for deep disposal of nuclear waste – development of coupled models of radioactive transport processes for integrated safety assessment and site characterisation.

Work Package 2			
Cluster 2.1	Technology for Decommissioning	2.1.1	Analysis of key radionuclides in decommissioning of nuclear sites.
		2.1.2	Numerical and physical modelling of an impinging jet on a settled bed.
		2.1.3	Anion exchange materials for radiochemical applications.
		2.1.4	Designing wasteforms for Tc.
Cluster 2.2	Characterisation, Retrieval and Treatment of Waste	2.2.1	*In situ* waste characterisation.
		2.2.2	Colloidal interaction during sedimentation and filtration.
		2.2.3	Combined microfiltration and ion exchange.
		2.2.4	Development of an integrated processing method for management of orphan waste materials.
Cluster 2.3	Site Termination	2.3.1	Contaminated land and radioactive waste scenarios in UK nuclear legacy sites.
		2.3.2	Flow and settling behaviour of low concentration heavy particles.
		2.3.3	Sensor for monitoring *in situ* remediation of radionuclide contaminated groundwater.
Work Package 3			
Cluster 3.1	Radiation Effects	3.1.1	Quantum-mechanical modelling of electronic effects of irradiation in ceramica
		3.1.2	Understanding radiation damage and noble gas accommodation in ceramic matrices for inert matrix fuels and plutonium disposition.
		3.1.3	Radiation induced hydrogen production from Pu-containing materials.
Cluster 3.2	Geopolymers and Cements	3.2.1	Novel metakaolin-derived geopolymer binders for radioactive wastes.
		3.2.2	Characterisation, treatment and performance of encapsulated irradiated graphite waste.
		3.2.3	Effect of composite cement formulation on waste corrosion within the cement matrix.
		3.2.4	Improved cementation technology for stable and secure waste immobilisation and disposal.
Cluster 3.3	Materials Performance	3.3.1	Corrosion of spent AGR fuel.
		3.3.2	Fission product and actinide retention in high level waste.
		3.3.3	Durability of spent MOX.
		3.3.4	Performance and condition monitoring of steel waste container materials.
Cluster 3.4	New Materials	3.4.1	Nanoparticle oxide clusters for next generation inert matrix fuels and waste containment matrices.
		3.4.2	Glass-ceramic immobilisation of wet heterogeneous sludges and fuel element debris.
		3.4.3	Haloapatite-mullite glass-composite wasteforms.

A schematic representation of the matrix in Table II showing where projects are targeted with respect to the back-end of the fuel cycle is depicted in Fig. 1.

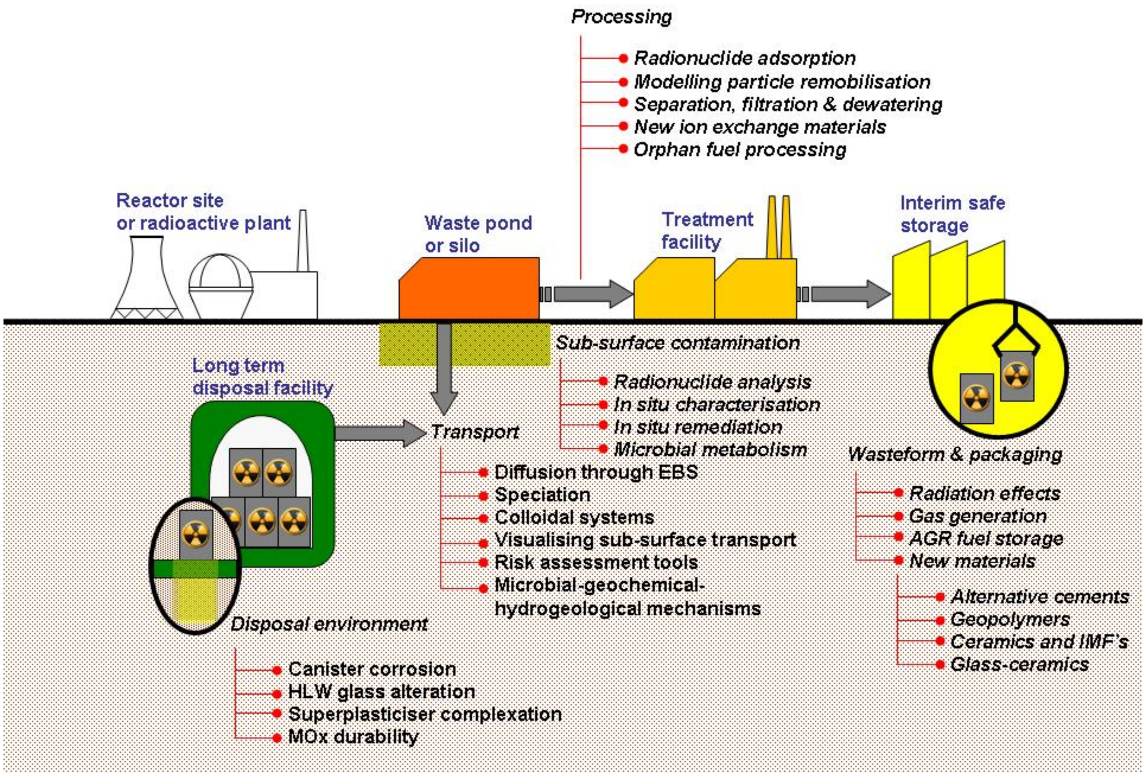

Fig.1. Schematic representation of the back-end of the nuclear fuel cycle and the priority research areas contained within the project matrix in Table II.

WORK PACKAGE SUMMARY

Work Package 1: Environment, Migration and Risk

WP1 comprises three project clusters namely (i) speciation, (ii) microbial processes and (iii) transport, modelling and risk assessment with an aim of defining processes which control transport of key radioactive contaminants in natural and engineered environments. The primary objectives of WP1 are;

- To define the chemical speciation of critical radionuclides, a key control on behaviour, defining oxidation states and complex form in the solution and solid states, and at interfaces;
- To develop a quantitative, mechanistic understanding of radionuclide retardation both theoretically and experimentally;
- To explore the role of biological processes in radionuclide mobility and the potential for *in situ* remediation;
- To define key processes in a generic waste repository which dictate a source term for radionuclide release into the far-field;
- To develop and apply environmental transport models for radionuclides over a range of spatial scales from nanometres to tens of metres, including integration and up scaling of models.

A comprehensive environmental remediation of the UK's licensed nuclear sites must take place if they are ever to achieve an end-point of brown or green field status. Significant volumes and types of soil materials must be tested and characterised, with an estimated volume of up to 20 million m^3 of soil requiring treatment for Sellafield alone [9]. At any given site, the soil may contain a range of radioactive and non-radioactive contaminants. Mixed contaminant effects [3, 5, 10] and the potential for migration of soluble and colloidal species in the subsurface are central to the challenges in clean-up and remediation. The uncertainties and technical challenges associated with geological disposal of immobilised radioactive wastes have considerable synergies with our site remediation research.

The research in WP1 concentrates on a detailed characterisation of key fission products (Sr, Cs, I, Tc, Eu) and actinide (U, Np, Pu) species, in terms of oxidation states and complexation, across the range of aqueous environmental conditions. The interaction of these radionuclides with particulate surfaces is also a crucial component of our work and the development of a mechanistic understanding of retardation will be a key outcome. Both these surface data and the speciation information is being linked to other research, developing a better understanding of the transport of radioactive elements through a variety of media and across a range of length scales from nanometres to tens- or hundreds of metres. Information on diffusive transport mechanisms through rock media will prove invaluable in determining long-term containment properties of deep geological depository. Microbial interaction with radionuclides is also a key component in this WP which complements and significantly enhances the work on non-biological soil components. The impacts of microbial processes will be critical in controlling radionuclide behaviour within the biosphere and the effects of biogeochemical processes on radionuclide behaviour, as well as the reverse impact of microbiological factors of the available atoms and ions will need to be characterised and quantified prior to complete site remediation strategies and repository performance modelling approaches being available. The WP targets uncertainties and thereby helps to improve predictions (and hence environmental impact assessments) and potentially provide improved technologies for addressing these technical challenges. Furthermore, current plans for clean-up envisage large-scale invasive technology and so the work here will provide important knowledge that may facilitate more efficient *in situ* approaches, or even support natural attenuation as a management strategy, with significant associated cost savings.

Work Package 2: Decommissioning, Legacy and Site Termination

Three project clusters in WP2 are (i) technology for decommissioning, (ii) characterisation, retrieval, and treatment of waste and (iii) site termination. The aim of WP2 is to provide new techniques and new technologies in support of legacy waste management, decommissioning and the monitoring of site end points. The objectives of WP2 are;

- To develop innovative approaches to characterisation, retrieval, dewatering, volume reduction and treatment of heterogeneous particulate wastes;
- To promote the transfer of relevant engineering knowledge from, for example, oil/gas, aerospace and medical technologies into nuclear decommissioning;
- To develop methods for treatment of Low Level Waste aqueous streams, particularly those containing anionic contaminants;
- To develop rapid, selective and sensitive methods for the quantitative measurement of key radionuclides in decommissioning wastes;
- To develop a treatment process for halide-containing orphan wastes compatible with a wasteform suitable for storage and disposal;
- To develop a predictive understanding of preferential contaminant transport *via* engineered drainage systems;
- To develop approaches for the long term passive monitoring of contamination.

The UK has significant issues associated with the storage, management, treatment and immobilisation of heterogeneous waste materials [5, 11]. Improved characterisation, retrieval and treatment technologies are required to underpin safe interim storage of such wastes. For example, there are substantial volumes of corroded Magnox fuel casing sludges across a wide range of sites stored under a wide range of conditions.

The most efficient methods for re-mobilisation, transport, de-watering and immobilisation of these sludges have yet to be identified. In many cases, the current state of these sludge materials and their exact location in large storage tanks is also inadequately known. This is a significant hindrance in the design of appropriate treatment strategies, especially since subtle variations in properties such as particle size, size distribution and shape can have dramatic effects on unit operations such as filtration. Across the UK nuclear industry there is a broad range of different solid-liquid systems that require treatment. Despite system-specific differences, a number of common features that cause difficulties in developing a treatment strategy are apparent. The lack of basic characterisation data is foremost amongst these but the lack of reliable and validated computational models for solid-liquid systems is an associated problem. We have therefore initiated an integrated programme of physical and computational modelling of solid-liquid systems into this work package with the eventual aim of defining the set of parameters needed to specify a treatment strategy for a given particulate dispersion such that, when these data are available from *in situ* characterisation, we will be able to predict system behaviour accurately and hence design the strategy for treatment with confidence. We are developing novel approaches for the remote and/or *in situ* characterisation of sludge materials. Material characterisation is considered baseline knowledge in most industries where sludges require treatment and handling, such as minerals processing and water treatment. However, these sludge materials are potentially highly radioactive in nature and the need to minimise operator exposure means we require new approaches to gain this information. One example of new approaches being investigated is the development of disposable rheometers which can be introduced remotely into the tank or silo and are capable of measuring and reporting key rheology parameters, such as the yield stress. Other opportunities to explore the 'nuclearisation' of technology commonly used in other industries is being explored; for example sonar mapping of ponds through optically opaque media. As well as developing an ability to handle these legacy materials efficiently, it is also apparent that there remains a need to develop suitable wasteforms for different wastes. It is also clear that linking the development and testing of different immobilisation matrices to the characteristics of the waste material after transport and de-watering would have significant benefits in ensuring consistent performance and behaviour of these immobilised materials.

All licensed nuclear sites must ensure that radioactive particulates can be located and trapped from within larger solid-liquid transport systems, such as drainage networks from sites, including rain/surface water drains. Free release to the environment is not an option; therefore, we are developing methods to help predict and detect such radioactive particles from much larger volumes of inert waste. *In situ* monitoring techniques capable of detecting picomolar levels is under development with a view to being deployed to measure transportation of key radionuclides such as Sr-90 in groundwater flow.

Work Package 3: Materials – Design, Development and Performance

There are four research clusters within WP3, (i) radiation effects, (ii) geopolymers and cements, (iii) materials performance and (iv) new materials. The aim of WP3 is to provide innovations in the processing and immobilisation of problematic wastes, the synthesis of novel wasteform materials and improved understanding of wasteform and container performance in interim storage and disposal environments. The objectives of the work package are;

- To develop a predictive understanding of the effects of radiation and radiolysis in actinide-containing materials and the impact on performance and stability, during interim storage and ultimate disposal;
- To devise innovative approaches to the processing of legacy and orphan wastes, including graphite, and their immobilisation in wasteforms suitable for interim safe storage and disposal;
- To understand durability and stability of steels used as packaging for interim safe storage and disposal;
- To develop a predictive understanding of AGR and MOX fuels during interim storage;
- To develop synthetic methods for the fabrication of next generation Inert Matrix Fuels;
- To understand actinide and fission product retention in the gel-layer and alteration products formed during HLW glass dissolution, to underpin eventual disposal.

The central aim of the UK clean-up and decommissioning programme is the stabilisation and packaging of radioactive wastes in a form suitable for interim storage and disposal. Geological disposal, in a mined repository, has been accepted as the end point for this activity [3] however precise disposal routes and periods of storage have yet to be defined. The focus of research in this work package is therefore to address key knowledge gaps in the conditioning, storage and disposal of wastes, in order to underpin future decision making in waste management.

A key activity in this work package is to develop innovative immobilisation solutions for large volumes of hazardous legacy wastes which exist principally at the Sellafield site but also at a various nuclear sites in smaller volumes. We are looking to develop a suite of glass-ceramic materials capable of immobilising a spectrum of wet (physically heterogeneous) sludges, fuel element debris, and legacy defence and pyrochemical reprocessing wastes in a product suitable for passive storage and disposal (with minimal generation of secondary wastes). This research is complemented by development of novel encapsulants to immobilise reactive metals and improved cementing systems with tailored properties, such as grout fluidity, to permit impregnation and encapsulation of loosely packaged wastes. Research in this area is closely integrated with activities in WP2 to ensure mutual compatibility between processes for waste retrieval, treatment and immobilisation.

A further important activity in this work package is to develop a predictive understanding of the behaviour of spent fuels, separated plutonium and conditioned wasteforms under conditions of interim storage and disposal. This is a primary requirement to underpin future decisions on re-use, re-packaging, storage and disposal of these materials and will link with projects in WP1 examining the far-field. Key knowledge gaps being addressed in a programme of research include developing a mechanistic understanding of AGR and MOX fuel corrosion and effects of radiolysis on PVC-packaged PuO_2, under conditions of wet and dry storage. This is being supported by computational modelling studies to improve our understanding of radiation damage of materials at a fundamental level, combined with ion-implantation and advanced electron microscopy investigations aimed at understanding the behaviour of noble gas accommodation and macroscopic swelling in nuclear ceramics. We are also addressing the existing knowledge gap in our understanding of the corrosion behaviour of UK HLW waste glasses, with particular reference to the retention capacity for fission products and actinides. A mechanistic understanding of this behaviour, combined with radionuclide transport models, developed in WP1, may allow potential savings in repository construction and will enhance public acceptability of geological disposal.

CONCLUSIONS

New technologies must be developed to facilitate the safe and timely decommissioning of existing nuclear plant with minimal environmental impact and thereby address the diverse nature of the challenges ahead. These challenges will inevitably require a multidisciplinary approach, using a combined expertise spanning traditional engineering and science boundaries. DIAMOND has taken a major step forward along this path by instilling a team approach, utilising complementary academic expertise and encouraging industry to play a major role within the programme.

A key aim for DIAMOND is to facilitate new networks across the industry-academe interface and broaden the vision of our academic members, increasing their awareness for the potential for knowledge transfer into this sector which many may not have considered relevant to their skill-base. Similarly, there have been many new links made between members at different academic institutions, fostered through the sharing of information during project co-supervision and work programme meetings leading to a stronger research base whilst offering an enhanced research opportunity to our young engineers and scientists in developing innovative technologies for nuclear decommissioning, waste management and disposition.

As the UK moves toward, (i) the decommissioning of multiple nuclear sites, (ii) constructing a nuclear waste repository and (iii) building a new nuclear power generation capability, it is essential for the higher education sector to deliver sufficient skilled personnel into the nuclear workplace. Due to the renaissance of the industry and an ageing workforce, in excess of 15,000 degree-level professionals will be required to fill job vacancies in the nuclear sector over the next 15 years. This coincides with a period where the population of university starters is predicted to fall by 16% on current figures by the year 2020. Assuming that the proportion of students entering the science and engineering disciplines at universities remains constant, an increased competition between employers for new graduates will be the inevitable result. If the nuclear sector is to attract sufficient personnel it is essential that the opportunities given to young professional recruits is second to none and that the industry maintains a high level profile across all levels of education, i.e. from secondary schools to PhD graduates.

We believe that continued interaction and support for research programmes such as the DIAMOND consortium will prove critical if the nuclear industry sector is to achieve the necessary recruitment levels and address the complex challenges in the coming years.

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