National and International Programs
The UK National Nuclear Laboratory and Waste Management R&D

Graham A. Fairhall
Nexia Solutions,
Sellafield, Seaside,
Cumbria, CA20 1PG, UK

INTRODUCTION

In the autumn of 2006, the UK government declared its expectation to set up a National Nuclear Laboratory (NNL) as soon as possible (subject to satisfactory contractual terms). The aim would be to base the Laboratory around Nexia Solutions and its ‘state of the art’ facility at Sellafield in Cumbria. The initial phase of the work to recommend formation of the laboratory is well advanced, and the NNL is expected to have a remit for the following roles:

— to play a key role in supporting the UK’s strategic R&D requirements
— to operate world-class facilities
— to ensure key skills are safeguarded and enhanced
— to play a key role in the development of the UK’s R&D supply base.

Within this remit it is to be expected that the NNL will play a key role in the R&D for successful management of radioactive waste that the UK will need for at least the rest of this century. This paper provides an overview of the role expected to be required of the NNL and the likely scope of its waste management R&D. Examples are given from current programmes which the NNL’s predecessor (Nexia Solutions) is undertaking.

WHAT IS THE NATIONAL NUCLEAR LABORATORY?

The National Nuclear Laboratory will be a customer-funded organisation which will undertake R&D for nuclear-fission related applications across the entire UK nuclear industry. Placing Nexia Solutions at the heart of the NNL will ensure that the laboratory has a strong heritage of nuclear-related skills and expertise. This unique skill base was assembled when Nexia Solutions was established out of the former Research & Technology division of BNFL. It encompasses the nuclear fuel and waste management expertise of BNFL, the reactor R&T activities of the former Magnox Electric and the nuclear science skills from AEA(T), which was acquired by BNFL in 2003. Consequently the NNL is expected to constitute the bulk of the UK’s remaining civil nuclear fission research capability and all of the active research facilities.

The technical skill base is impressive in its scope; it covers the full scope of fission reactors and their associated fuel cycles. Also included is the necessary challenge of decommissioning and clean-up. The figure below illustrates the range of the skills and expertise available in Nexia Solutions.
**Reactor Systems & Services**
- Reactor system support
- Support to reactor operations
- Nuclear analysis
- Post-irradiation examination
- Fuel design & performance
- Production of experimental fuels

**Fuel cycle & waste management**
- Reprocessing & wastes management technical support
- Development & testing services
- Plant monitoring
- Inspection, asset care & life-time extension
- Remote engineering solutions
- Waste characterisation
- Aerial & liquid effluent treatment
- Cementation/encapsulation
- Vitrification

**Decommissioning & Clean-up**
- Waste retrieval
- Waste process development
- Decontamination
- Clean-out of residual materials
- Dismantling of radioactive plant
- Characterisation of contaminated land
- Environmental impact assessment.

### Scope of skills available to the UK’s National Nuclear Laboratory

**WHY IS THE NNL NEEDED?**

The intent to establish the NNL recognises the key element that technology, and R&D in particular, plays in the safe and effective utilisation of nuclear fission. The UK has a long term need to secure its technology base in this area, which can be summarised as follows:

- The UK has a need for civil nuclear fission technology beyond the timescales in which commercial R&D organisations work
- Facilities for the study of radioactive materials need to be used effectively for the benefit of the entire UK nuclear industry
- A stable sustainable technology and skill base will be needed
- An approach is required to address the loss of skills in nuclear technology
- R&D plays a critical role in helping to deliver programmes of work cheaper, safer and faster through innovative technologies, it also helps to train and develop the skill base of the future and allow the UK to assess future options

**VISION FOR THE NNL**

The stakeholders who have been advising the UK government on the formation of the NNL recommend that it should:

> “Lead the application of world class science and technology, in the field of national and international nuclear energy and associated fuel cycles, to enhance the social and economic value of the UK economy, whilst maintaining and developing key strategic skills and facilities”.

The scope of the NNL’s mission will be 3-fold:

1. Maintenance of capability in existing nuclear power and fuel cycle systems
2. To provide the UK with the technology in order to exploit the use of power generation by nuclear fission in the future
3. To enable the UK to undertake the necessary clean-up of the historic legacy and to develop long term solutions to the disposal (or disposition) of radioactive waste.

**Strategic R&D programmes**

The figure below proposes a future scenario for nuclear fission-related activities in the UK from which it is possible to understand the scope and duration of strategic R&D programmes
which the National Nuclear Laboratory might undertake. While this scenario is not unique (certainly the timescales are not fixed) it does illustrate the challenges that a National Nuclear Laboratory would be well placed to address:-

- There is a need to maintain national priorities in nuclear technology over many decades
- There is a need to renew the skill base over more than one generation of scientists and engineers
- There is a need to ensure co-ordination between the different parts of the scenario to gain maximum benefit from the technology.

![Scenario for future nuclear-fission related activities in the UK](image)

**Figure 1.** Scenario for future nuclear-fission related activities in the UK
NNL RESPONSE TO THE CHALLENGE OF MANAGING RADIOACTIVE WASTES

A major aspect of the National Nuclear Laboratory’s programmes can be expected to include all aspects of managing radioactive wastes, both from the UK’s legacy from its early decades of developing nuclear power and from its current nuclear generation systems.

In general terms the challenges are covered by simple statements, such as, to achieve the safe and effective management of radioactive wastes for the medium term and to ensure that conditioned radioactive wastes are compatible with the schemes eventually developed for final and permanent management. In reality this requires a range of R&D programmes to address the different aspects of the issues in detail.

If one concentrates solely on the waste management aspects of the scenario, it is possible to identify the major elements of the R&D programmes likely to be required. The following table illustrates the scope and timescales of potential R&D programmes in the waste management area.

Table I. Suggested strategic programmes for radioactive waste management
Advanced decontamination techniques
Decontamination of graphite cores to permit treatment as LLW
Remote dismantling
Treatment of degradable & combustible materials
Development of dose rate mapping and remote viewing techniques

**Management of end-points for nuclear sites**
Transparent, defensible decision making and optioneering processes
Non-intrusive site characterisation for contaminated land
Understanding contaminant behaviour
Modelling current and future impacts of contaminated land/water and disposal facilities on human health and the environment
Evaluating of remediation technologies
Impacts of future climate and environmental change on site end points
Monitoring and validation of site end points

**Low level waste disposal**
Modelling impacts of disposal facilities on human health and environment.
Techniques for undertaking BPM studies and SEA
Impacts of future climate and environmental change on LLW disposal facilities.
Development of wasteforms suitable for new disposal facilities
Establishment of new LLW disposal facilities
Improved national LLW inventory dataset

### Examples of Radioactive Waste Management R&D

Obviously the R&D programmes in the NNL have not be formed but an understanding of the nature of its work can be obtained from examples of R&D that Nexia Solutions has been undertaking to address a variety of challenges from radioactive waste management.

### Characterising legacy waste and decommissioning wastes

The UK has a wide range of challenges from radioactive materials and radioactive facilities some derived from reactor and fuel processing programmes carried out in the 1950’s and ‘60s, others from ongoing operations. In most cases successful treatment requires a more thorough understanding of the materials to be treated. Examples on R&D in this area are:

### Impact of hydrided fuel

Uranium metal fuel still present in the graphite core of one of the UK’s ‘original atomic piles' may contain potentially hazardous quantities of uranium hydride. A programme of research using knowledge of oxidation chemistry coupled to a thermal analysis using
Computational Fluid Dynamics (CFD) has been used to predict the temperature distribution within fuel channels and surrounding graphite. It has been successfully shown that pessimistically assessed amounts of uranium hydride in the core, reacting after seismic disturbance, lead to only very slight temperature rises in the adjacent core materials. The implications are significant, demonstrating that the core is sufficiently benign to allow physical intrusion into the core.

**Sampling of sludge**

A different challenge is to be able to characterise waste material in-situ. One example, (reported in detail elsewhere in this conference) results from the need to retrieve large quantities of corroded fuel cladding material from a reactor fuel storage pond. There are concerns about the amount of radioactivity that will be leached from the sludge as it is agitated during hydraulic retrieval operations and this will impact on subsequent effluent treatment. The R&D response has been to develop a method of measuring the activity released from samples of the real material during simulated retrieval operations. A ‘bell jar’ apparatus has been developed which can be immersed in the sludge within the fuel storage pond in question. The apparatus is designed with the means to sample the sludge, before and after controlled agitation.

Improving the knowledge of the waste behaviour has a great impact downstream on the provisions to treat waste and effluent arisings.

**Advanced monitoring and interrogation techniques**

The difficulty of obtaining access to radioactive wastes and facilities remains a major challenge to any need to improve understanding through characterisation. The NNL will be expected to bring new approaches and techniques to bear that overcome the inherent difficulties of high radiation fields, thick biological shielding and hazardous levels of contamination.

As an example, Nexia Solutions has been leading a programme to exploit the properties of cosmic rays as a way of imaging radioactive wastes and facilities. Naturally occurring muons, produced from cosmic rays have great potential for imaging through thick biological shielding because of their high energies (up to $10^{12}$ GeV) and therefore offer a superior penetrative power than X-rays or gamma rays. An initial programme of studies, working with a consortium of UK universities has already shown that there is sufficient flux of muons at ground level to offer the basis of viable measurements. Simple planar arrays of detectors have also shown the ability to track muon events both entering and leaving the object of interest. Further work on large and more sensitive detectors offers promise that a prototype device to interrogate waste packages and even whole building could be constructed.

**Optimising waste treatment from current operations**

Even within a fully operational industrialised process there are often opportunities to improve operations and reduce wastes. The NNL will be expected to work closely with customers and undertake R&D that can be applied to an industrial setting.
Vitrification Test Rig

One example, from the Nexia Solutions portfolio, is the construction and operation of a full size non-active vitrification facility to develop process improvements that can then be applied to the vitrification plants at Sellafield. The aims are to provide the necessary underpinning development work so that the Sellafield customer can:

- Process highly active liquor faster
- Improve understanding of process and its limitations
- Develop flowsheets for alternative waste compositions
- Provide underpinning product quality and operability data

A number of campaigns of non-active, full-scale operation have already provided the customer with the basis to increase the incorporation rate of waste in the glass, increase the rate of calcination of the highly active liquid waste and understand how to vitrify non-standard waste more efficiently.

Optimisation of encapsulated sludge

Operations to treat intermediate-level waste are also amenable to optimisation and, as an example, a couple of years ago Nexia Solutions was able to make a significant contribution to radioactive waste clean-up at Sellafield involving radioactive sludge stored in concrete tanks since the 1950’s. The intention was to treat the sludge by dewatering in an existing ultrafiltration facility and to cement the concentrated sludge to produce a radioactive waste suitable for long term storage and disposal. It was clearly necessary to confirm that the sludge could be treated satisfactorily through the existing ultrafilter and cementation plants and this was achieved by a programme of laboratory and pilot scale work using simulated waste. Once this was successfully achieved attention then focussed on the large volumes (12,000 x 500 litre drums) of cemented waste product that would be produced. A further research programme then addressed the potential for cementing a more concentrated sludge. It was
necessary to work within the constraints of the existing cementation plant to ensure that the sludge and cement powders could be satisfactorily mixed.

Experimental trials were undertaken based on a step-wise increase in the floe concentration ensuring that the process could at all times be compatible with the active cementation plant. Testing of the products produced confirmed that they met requirements for long term storage and eventual disposal. The final encapsulated sludge concentration was double the design intent resulting in a predicted final waste arising of some 6000 drums rather than the predicted 12000.

**Alternative and high performance waste forms**

Given the variety of radioactive wastes that already exist in the UK and ones that are yet to arise, it is not surprising that not all challenges can be met by the currently deployed waste immobilisation technologies. The National Nuclear Laboratory is expected to have a capability to address all such challenges ensuring that the UK obtains the most appropriate technical answers to minimise the liabilities associated with waste treatment, storage and disposal.

**Pu residues**

Some of the more demanding wastes which will need to be treated are plutonium residues which have accumulated over the previous 5 decades of nuclear power and which are currently arising from fuel and nuclear material processing operations. A key priority is for the residues to be packaged in a stable form, using packaging materials which will not degrade, thus eliminating the need for repackaging in the future. In the longer term, the aim is to have a wasteform suitable for geological disposal or other long term treatment options. Nexia Solutions has been pioneering the use of ceramics to produce compact and stable wasteforms, suitable for many of the plutonium residues. A vital part has been to leverage knowledge from elsewhere in the world and this has led to a successful collaboration with ANSTO (Australian Nuclear Science & Technology Organisation). The work has shown that a glass-ceramic wasteform, combines the necessary processing flexibility of glasses with the chemical durability of ceramics and promises to provide an ideal solution for immobilising actinides.

The key crystalline phase in the glass-ceramic is zirconolite (ideally CaZrTi2O7), a naturally occurring titanate mineral and the main host for plutonium and other actinides in the Synroc formulation developed by ANSTO. Zirconolite has considerable chemical flexibility, allowing cationic substitutions in its structure in addition to the actinides. Extensive complementary studies on naturally occurring zirconolites have confirmed that they survive in the natural environment and are capable of locking up actinides in the crystalline matrix for millions of years.