



Committee on Radioactive Waste Management

**Position Paper on Research and Development for
Conditioning, Packaging and Interim Storage of
Higher Activity Wastes and the Management of
Spent Fuels, Plutonium and Uranium**

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EXECUTIVE SUMMARY

CoRWM's recommendations to Government in 2006 highlighted the need for a commitment to an intensified programme of research and development (R&D) into geological disposal aimed at reducing uncertainties at generic and site-specific levels, as well as into improved means for interim storage of wastes. This position paper provided input on the UK's storage R&D programme for the CoRWM 2009 report to Government on interim storage. It will form the basis, with additional scrutiny of disposal-related R&D issues, of CoRWM's full R&D report to Government, now due in October 2009.

Scope of position paper

This paper is about CoRWM's work during 2008/09 on R&D into the conditioning, packaging and interim storage of higher activity radioactive wastes and the management of nuclear materials that may be declared to be wastes in the future, that is spent nuclear fuels, plutonium and uranium

How we worked

We worked by gathering information from the Nuclear Decommissioning Authority (NDA), its site licence companies (SLCs), British Energy, the Ministry of Defence (MoD), regulators, learned societies, universities and others. As part of this process we helped arrange a 1-day technical meeting on storage R&D issues at Sheffield University and a round table, invitation only, discussion at the Institute of Physics in London. Notes of all of these meetings are available on our website. We also sought the views of stakeholders and the public via our website and at a CoRWM public and stakeholder event in October 2008. A draft of this paper was sent to key stakeholders for comment and placed on our website for public comment.

Emerging Conclusions

This paper sets out the information we gathered on how storage R&D requirements are established in the UK, the current UK R&D programmes and on specific R&D issues associated with the UK's plethora of wastes, spent fuels and other nuclear materials. Our emerging conclusions, which will contribute to the full R&D report to Government, are as follows.

The NDA has made considerable progress in co-ordinating R&D on the conditioning, packaging and storage of higher activity wastes and the management of spent fuels, plutonium and uranium. Its Nuclear Waste Research Forum (NWRF), which involves all its SLCs and other waste producers, is an appropriate mechanism for determining the topics on which R&D related to waste conditioning, packaging and storage is required. Its R&D programme on plutonium management is a good example of co-ordination between the NDA, the National Nuclear Laboratory, universities and other organisations. However, these are bottom-up approaches and need to be supplemented by mechanisms to produce prioritised R&D strategies within the NDA and for the UK as a whole.

The NDA's mechanisms for developing high level R&D strategy are evolving but are at an early stage. We do not understand how the approach of the NWRF and the SLCs relates to the R&D strategy of NDA's Radioactive Waste Management

Directorate (RWMD) or how the RWMD R&D strategy feeds into the NDA's overall R&D strategy. There is no obvious mechanism for coordinating the NDA's R&D strategy with those of MoD, British Energy, the regulators and others, nor is there a means of setting national R&D priorities at the strategic level.

A clear process is needed for checking that there is a suitable balance between strategic/fundamental research and short-term, applied, needs-driven R&D, that both are funded at an appropriate level, that they are done to acceptable standards and have led to timely improvements in the UK's radioactive waste management programmes. A procedure should be in place to close the R&D loop. This scheme needs to be open, transparent, wide ranging and industrially relevant and should involve all key stakeholders (i.e. the NDA, the Government, the regulators, MoD and all the nuclear site licensees).

1 INTRODUCTION

CoRWM's 2006 recommendations (CoRWM doc 700) to Government, which were accepted in the Government response (Defra *et al.*, 2006), included the statement that a robust R&D programme was needed:

Recommendation 4: "There should be a commitment to an intensified programme of R&D into the long-term safety of geological disposal aimed at reducing uncertainties at generic and site-specific levels, as well as into improved means for storing wastes in the longer term".

In the reconstituted CoRWM's Work Programme for 2008-09 (CoRWM Doc 2266) and Working Group C's work plan (CoRWM doc 2323) we stated that CoRWM would be seeking to reassure itself that the technical R&D carried out would be:

- of appropriate scope and breadth to underpin the MRWS programme;
- at the forefront of innovation and international developments in the field;
- performed by the most appropriate people and institutions;
- cost-effective;
- aligned with the needs of the MRWS programme;
- able to access the specialised infrastructure needed to work safely with radioactive materials;
- of quality at least comparable to that in countries with similar waste inventories and demonstrated through a well defined independent peer review process;
- integrated into skills development activities as an essential component in developing high level skills;
- funded openly and transparently, and performance monitored objectively;
- appropriately resourced;
- an appropriate mix of applications-focused applied and underpinning fundamental science programmes;
- conducted in a manner which ensures effective coordination between different funding bodies (e.g. the Nuclear Decommissioning Authority (NDA), nuclear site licensees and Research Councils) and activities (waste conditioning, packaging, storage, disposal).

CoRWM's 2006 report (CoRWM doc. 700) also stated:

"If the public are to have confidence in the proposals for the long-term management of radioactive waste, it is essential that the areas of uncertainty and the plans for addressing them are clearly identified from the outset. Wherever possible, uncertainties should be reduced through further research. Where this is not possible, the implications for the success of the programme should be explained along with proposals for managing the programme in the face of these uncertainties."

The responses to the 2007 MRWS consultation document (Defra *et al.*, 2007), our meetings with Friends of the Earth and Greenpeace (CoRWM docs. 2290, 2272) and CoRWM's October 2008 PSE event (CoRWM doc. 2488) at which stakeholders highlighted to us the importance of R&D. We believe that R&D is essential for the safe conditioning, packaging and interim storage of higher activity wastes as well as for their geological disposal.

R&D can also make other contributions to managing higher activity wastes, because innovation has the potential to achieve substantial cost savings in treating and disposing of waste, because use of good science is an essential element in winning public confidence, and because a thriving R&D programme is essential in attracting high quality personnel into radioactive waste management. There is a spectrum of problems to solve in this field. Some of these may need fundamental research but others could use off-the-shelf solutions that have resulted from previous R&D (for example, in other countries or in non-nuclear spheres). We need to assure ourselves that the process in place in the UK for supporting R&D is able to address the full spectrum of problems in appropriate ways. CoRWM therefore sees R&D as an indispensable part of the MRWS programme and will provide advice on, and scrutiny of, R&D activities.

As stated in our 2008-09 workplan, Working Group C asked the NDA to summarise UK R&D for interim storage, including condition monitoring and the state of currently stored wastes, and options for potential repackaging (draft seen by CoRWM). We liaised with the Health and Safety Executive's Nuclear Safety Advisory Committee (NuSAC) to avoid overlap with their programme (CoRWM doc. 2460).

We agreed to comment on whether the R&D identifies and lessens:

- the main risks or uncertainties relating to operation and long-term safety of current storage arrangements (facilities and waste packages)
- the main risks or uncertainties relating to construction, operation and long-term safety of planned future storage arrangements (facilities and waste packages).

Our approach to this work has included meeting with, and seeking information from, the NDA (CoRWM docs. 2373, 2397), its SLCs, BE, MoD, regulators, learned societies, universities and others. As part of this process we helped arrange a 1-day technical meeting on storage R&D issues at Sheffield University Oct 16th 2008 (CoRWM doc. 2480) and a round table discussion at the Institute of Physics (IoP) in London Nov 26th 2008 (CoRWM doc. 2519).

This position paper is a stand alone CoRWM document that enabled R&D issues to be highlighted in CoRWM's Interim Storage Report (CoRWM doc. 2500) and will be incorporated in CoRWM's overall R&D report due in October 2009. We have examined the UK's current process of managing such R&D and begin by highlighting the scope of storage-related R&D and the need for it to address the risks and uncertainties in the UK's radioactive waste

management programme. We emphasise issues which have led, or may be leading, to problems but the omission of any topic does not imply it is not important, only that CoRWM has only finite resources and time in which to produce this paper. Such issues include the complex nature of the industry and thus the national R&D situation due to the number of nuclear site licensees; all with individual R&D programmes, in addition to that of the NDA. We consider some issues for particular types of waste, for example the encapsulation of reactive metals and management options for large volumes of graphite. Spent fuels, plutonium and uranium are all discussed to varying levels of detail, the issue in these cases being the R&D needed to identify and implement appropriate long-term management methods. We emphasise that this paper is by no means exhaustive but highlights our initial thoughts on the UK situation.

2 ESTABLISHING R&D REQUIREMENTS FOR STORAGE

This paper is about R&D and defining its needs and objectives, for conditioning, packaging and storage of higher activity wastes, and for the management of spent fuels, plutonium and uranium, which may be declared wastes in the future. In our October 2009 R&D report we will examine what is meant by R&D in different contexts. In this report when considering R&D requirements, we start by putting these topics in the context of radioactive waste management as a whole. It is important to note that research must be considered in the context of a holistic examination of the overall storage and disposal system.

2.1 Scope of Radioactive Waste Management R&D

Radioactive waste management is usually taken to cover a wide range of topics in addition to conditioning, packaging and storage. These topics include:

- minimising arisings of all radioactive wastes (solids, liquids and gases) – for example through appropriate designs of nuclear facilities and appropriate operating and decommissioning procedures
- waste characterisation – determining the radionuclide content of waste, its non-radioactive content, and the physical and chemical forms in which radionuclides and other potentially harmful constituents are present
- minimising arisings of each category of solid radioactive waste (low, intermediate and high level) – for example, through sorting, segregation, decontamination and allowing radioactive decay
- treatment of liquid and gaseous effluents prior to discharge to the environment
- retrieval of wastes from legacy facilities
- near-surface disposal
- transport of wastes – for example between stores and disposal facilities
- geological disposal.

Wastes will follow a sequence of conditioning, packaging, storage, transport and disposal, so R&D can be used to provide confidence that the waste packages will be storable, transportable and disposable. This sequence, from the initial processing of raw waste to final sealing into a closed disposal facility, is likely to take many decades, so the durability of the packaged wastes is critical. The waste packages must retain sufficient integrity during interim storage to allow them to be transported to a geological disposal facility (GDF) and emplaced. They then may have to remain intact during a period before the disposal facility is backfilled and sealed. Lastly, they may fulfil important safety functions in the long-term, post-closure safety of the disposal facility. R&D related to many of these topics is covered in this, or will be dealt with in other, CoRWM reports. In particular, the CoRWM report to Government on R&D, due in October 2009, will deal in detail with geological disposal related research. CoRWM is scrutinising how research requirements related to these topics are established and prioritised, how R&D is co-ordinated and how the R&D results are used in radioactive waste management programmes.

It is important to recognise that R&D relevant to radioactive waste management is also carried out in two other contexts: nuclear safety, and health and environmental protection. Nuclear safety R&D is mainly about preventing accidents, minimising their consequences, and protecting workers and the public, during the operation and decommissioning of nuclear facilities, including radioactive waste management facilities. In the UK nuclear safety research is co-ordinated by the Health and Safety Executive; this is discussed further in Section 3.3. Health and environmental protection research related to radioactive waste management is about the movement of radionuclides through the surface and near-surface environments, and the effects of radiation on people and biota. This research is discussed briefly in Section 3.8. For both nuclear safety research and health and environmental protection research, CoRWM's concern is with links and overlaps with radioactive waste management research, and gaps that may need to be filled. Finally, we should mention that OCNS (Office for Civil Nuclear Security) who regulate the security of civil licensed nuclear sites, nuclear materials and sensitive nuclear information, are connected into national groups considering R&D on wider security issues, such as those led by the Home Office Scientific Development Branch (CoRWM doc. 2414).

2.2 Waste Conditioning and Packaging R&D Requirements

Less than 10% (in terms of volume) of the total predicted UK arisings of ILW have been conditioned to date (CoRWM doc. 2459; NDA, 2008a). Conditioning and packaging options have been identified for many of the remaining wastes but R&D is needed to choose between the options and to enable the chosen option to be implemented in the most appropriate way. There are also some wastes for which no appropriate conditioning method has yet been developed, and for which research of a more fundamental nature is needed to develop options. Examples of the issues on which R&D is in progress are as follows.

Most of the ILW that has been conditioned so far has been encapsulated in cement. This matrix could also be used for many other types of ILW but there are other conditioning options that may be better. For example, in the case of ion exchange resins and so-called “wet wastes” (e.g. sludges), techniques that involve dewatering and/or high temperature processes may be able to produce more durable waste forms with lower volumes, and hence lower storage and disposal costs. These techniques are being investigated by several waste producers. There are also wastes such as reactive metals for which many formulations of cement are not ideal and for which alternative treatment and encapsulation methods are being sought.

To date, most waste containers have been made of various types of stainless steel. There are questions as to whether more corrosion resistant steels should be used in future for some ILW containers. There are also proposals to use thicker steel containers, which would have a longer life simply through their size. The various possibilities are under investigation at a number of nuclear sites. For vitrified HLW a number of potential over-pack canister materials for disposal have been proposed and will be investigated by the NDA.

A further area of R&D is on the behaviour of some waste packages that are already in store. This is needed to improve understanding of the evolution of the wasteforms and their containers, and hence both to predict their likely performance and to learn lessons for future conditioning and packaging.

A related area is R&D on the remediation of waste packages, either because they have deteriorated in some way during storage, or because they were not manufactured to the correct specifications. Remedial actions could range (EA 2005) from a simple repair of a waste container (e.g. re-sealing a lid), to placing the container inside a new one (overpacking), to removing the waste, reconditioning it and placing it in a new container (sometimes called “reworking”).

Much of the above R&D informs the drawing up and the review of waste package specifications. These are set by the NDA, which operates the “Letter of Compliance” system (CoRWM doc. 2459; NDA 2008b). This system is designed to make sure that wastes are conditioned and packaged in ways that enable them to be stored and disposed of. It does not provide guarantees but should mitigate the risks of finding in the future that packages are unsuitable in some way (See Section 5.3 and CoRWM docs. 2389, 2500).

2.3 Waste Storage System R&D Requirements

It is necessary to ensure the whole storage system is stable for a long enough period (including any potential delays in the GDF programme) so that, when desired, the stable waste packages can be transported and emplaced in a GDF and remain stable until closure and beyond. We define the storage system as encompassing the wasteform, its container, the building or other structure in which the packaged waste is housed, the environment in the building, the means of controlling that environment, other equipment in the

building such as cranes and other handling equipment, and the monitoring, inspection and maintenance regime. The reason for defining the storage system in this holistic way is that all these factors interact to govern the safety, security and robustness of storage (CoRWM doc. 2500).

The most modern purpose-built stores are the new ILW stores at Trawsfynydd and Hunterston A. These are large concrete buildings that are designed to hold ILW in steel drums or boxes. The stores are seismically qualified and designed for ease of maintenance over their entire lifetimes (100-150 years). The Trawsfynydd store uses passive environmental control (natural ventilation etc.) while the Hunterston store is actively controlled. The stores also have good arrangements for the monitoring and inspection of waste packages. R&D requirements for such stores include improving predictions of the lifetime of the concrete structure.

Some future ILW stores will be similar to those at Trawsfynydd and Hunterston. However, various nuclear sites are considering other types of storage system, in which wastes are placed in very robust containers that are then housed in simple buildings (see section 5.5). Such systems are being developed to the point where a safety case could be made for them.

Existing stores vary from the relatively modern and purpose-built to older facilities, some of which were only intended as temporary. There are a number of topics on which applied research and development is required to improve these facilities or predict or extend their lives. These topics include atmospheric control systems, monitoring and inspection regimes, means of recladding buildings, and means of replacing cranes, ventilation systems and other equipment.

3 CURRENT UK R&D PROGRAMMES

In this section we describe the current UK process for establishing and funding waste storage-related R&D needs. This includes the NDA's process that is attempting to unify R&D across the NDA's site licence companies (SLCs), who historically had developed their own R&D programmes. It should be noted however that the NDA does not have immediate responsibility for carrying out storage and conditioning, including R&D. This resides mostly with the nuclear site licensees, i.e. the SLCs, British Energy (BE), and others.

3.1 NDA Storage-Related R&D

The NDA is required by the Energy Act 2004 to undertake R&D relevant to its mission. It funds research both directly via its Direct Research Portfolio (DRP) and indirectly via its SLCs. Its quoted annual budget for all R&D relevant to its mission is about £60M (including that of the SLCs). The NDA's non-site R&D budget is £33.1M for 2009/10.

The SLCs are responsible for decisions on their own radioactive waste management R&D. They have their own programmes of work; these are

driven by the task in hand including meeting regulatory requirements for safety and environmental protection. The SLCs' R&D programmes are defined in Technical Baseline and underpinning R&D documents (TBuRDs) linked to the SLC Life Time Plans (LTPs). The TBuRDs set out the technical baselines for the site, describe the technical challenges that the SLCs face and summarise the R&D that is deemed necessary to meet them. For each NDA site, it is the contractual responsibility of the SLC to develop an LTP and assess the associated timescales and costs. Thus included in the LTP are the reference means of conditioning, packaging and storing wastes. Where there are unknowns or significant uncertainties, the need for R&D is identified. The R&D requirements are compiled in the TBuRD, which is updated annually (NuSAC 2008).

The "NDA Research and Development Needs, Risks and Opportunities" (NDA 2006a) document is a compilation produced before the introduction of the TBuRD system. It states that "Historically, the short-term benefits gained from carrying risks associated with the technical underpinning of projects led to significant cost implications and delays to projects and programmes. Today, we believe the technical baselines and identification of R&D requirements will help the SLCs to focus on overall programme delivery and not just short-term activities".

The NDA role is primarily one of strategic and contract management, helping to avoid duplication of similar work over its 7 SLCs. The NDA Research Board on Nuclear Decommissioning and Waste Clean Up (NDARB) is an advisory body which provides high-level oversight, and has members from government departments, regulators and research councils (RCs). It also has two independent members including one from Health and Safety Executive's Nuclear Safety Research Review Group (previously a sub-committee of the Nuclear Safety Advisory Committee (NuSAC), which has been disbanded). The primary objective of the NDA Research Board which meets every 4 months (see NDARB Terms of Reference on www.nda.gov.uk) is to:

"promote a common understanding and collaboration between relevant bodies across the UK about respective R&D needs, risks and opportunities required to enable the delivery of the NDA mission. Where appropriate these activities will be linked to long term skills and capability requirements."

At the operational level the Nuclear Waste Research Forum (NWRF) was set up to share information and create networks between SLCs. It reports to the NDARB. From feedback CoRWM has received at meetings with regulators and the SLCs involved, the NWRF is perceived to generally be working effectively. Representatives on the NWRF include people from NDA, its SLCs, the regulators, the Ministry of Defence and British Energy. It meets every 3 months and a number of NWRF sub-groups have been established to look at generic topics common across SLCs and other waste producers. These topics include waste packaging, wet wastes, sludge and heels characterisation, remote size reduction and dismantling, categorisation and re-categorisation of wastes, decontamination, high temperature processes, orphan wastes, and contaminated land and site end states. A new sub-group

on interim storage held its first meeting June 2009. NWRF is recognised as a good meeting point to share ideas and identify areas of common interest. Progress has been made where it is possible to find simple pragmatic solutions to short-term operational problems, and to put in hand R&D which addresses specific problem areas and delivers solutions. Issues such as local encapsulation and graphite are examples of good practice.

We recognise the importance of this short-term R&D for delivery of ongoing waste retrieval and conditioning projects. However, we understand progress has been hindered by lack of technical personnel to do the work or by limited access to funding for longer-term R&D because of competition with short-term operational claims (CoRWM docs. 2386, 2519 and 2464).

NDA's Direct Research Portfolio (DRP) process was developed to support strategic and national R&D issues which are not funded directly by SLCs. It is a component of the broader R&D portfolio and has an annual budget of £6M. It started in 2005 as a single research contract with Nexia Solutions but has since been opened out and a tranche of DRP research was awarded to various organisations in 2008. The programme was determined from a review of the SLC TBuRDs. It is split into 4 lots covering support for University Interactions (Lot 1, awarded to NNL/Serco), Waste Processing (Lot 2 awarded to NNL/UKAEA/Hydr), Materials Characterisation (Lot 3, awarded to UKAEA/NNL/Serco) and Actinide/Strategic Material Investigation (Lot 4, awarded to NNL/UKAEA). NWRF contributed to a prioritisation of proposed DRP work areas. This is a more open process than that used since the NDA's inception in which review of Nexia Solutions (now NNL) proposals was done by NDA staff.

The NDA's schemes appear entirely appropriate for determining its SLCs research areas and the NWRF attempts to include other waste producers. However, the NDA's mechanisms for developing high level R&D strategy are not well developed. It is not clear how the bottom-up approach of the NWRF and the SLCs feeds into the RWMD R&D strategy or how this feeds into the NDA's R&D strategy. There is no obvious mechanism for coordinating the NDA's R&D strategy with those of MoD, BE, the regulators and others, nor is there a means of setting national R&D priorities at the strategic level.

A significant recent development is the setting up of the NDA Strategy Management System (SMS) which will endeavour to understand the key issues surrounding topics such as ILW and nuclear materials and then, it is planned, will develop a strategy to manage the topic including R&D. We have also recently become aware of the Higher Activity Wastes Strategy (HAWS) Group which is strategically focussed with representatives from the regulators, NDA, BE, MoD and SLCs and which reports into the NDA SMS. We do not believe, however, that this or the UK Spent Fuels and Nuclear Materials Topic Overview Group which we understand includes representatives of Government, regulators and NDA, will provide the required strategic research coordination and prioritisation covering all wastes and nuclear materials.

Although these current NDA-led groups involve other organisations, their focus is NDA strategy (NDA 2008e). In CoRWM's view these groups will not, in their present form, lead to each waste-producing organisation, and thus the UK as a whole, making the best use of its resources. There is a need for greater co-ordination at a strategic level, involving not only the NDA but also the other major waste producers (BE and MoD), and all the relevant regulators (CoRWM doc. 2500). CoRWM would wish to see agreement between all the organisations on issues such as which types of waste can be conditioned and packaged using commercially available ("off-the-shelf") techniques and which require substantial R&D to develop suitable wastefoms. Such agreements could be followed up by joint procurement of techniques and joint commissioning of R&D. We believe this would lead to both cost savings and faster progress in conditioning and packaging ILW.

3.2 Other Nuclear Industry Organisations

Organisations such as BE, AWE plc and Urenco UK Ltd. (which enriches uranium) also fund R&D but, unlike the NDA, do not have major R&D programmes on radioactive waste management. Their approach is to carry out R&D as and when it is required to solve particular waste management problems. Typically these organisations will do R&D as an input to "optioneering studies", that is studies to identify and evaluate options for managing a particular type of waste. Their studies increasingly involve identifying techniques used in other countries, with the aim of buying "off the shelf" solutions, rather than carrying out any fundamental or applied research. An example of this is the R&D BE carried out when evaluating options for conditioning and packaging the spent ion exchange resins from water treatment at the Sizewell B PWR. This is a good example of where UK wastes are essentially identical to wastes generated in other nations and overseas technical solutions are appropriate.

All nuclear site licensees are also expected to do R&D to support their radioactive waste management safety cases (see Section 3.3) and in response to conditions in authorisations issued by the environment agencies (see Section 3.4). In addition, the NDA requires R&D evidence to be submitted as part of requests for LoCs (see Section 5.3).

3.3 Nuclear Safety Research and the Role of HSE

The management of the UK nuclear safety research programme was transferred from the Department for Trade and Industry to the Health and Safety Commission (now combined with HSE) in 1990. The Government set three primary objectives for the programme (HSE 2008b):

- to ensure that adequate and balanced programmes of nuclear safety research continue to be carried out, based on a view of the issues likely to emerge in both the short and long term
- to ensure that, as far as reasonably practicable, the potential contribution which such research can make to securing higher standards of nuclear safety is maximised

- to ensure that the results of any such research having implications for nuclear safety are disseminated as appropriate.

There were also supporting objectives, namely maintaining a sufficient range of independent capability and taking advantage of international collaboration (HSE 2008b). The legal context for the programme is provided by the Health and Safety at Work etc Act, which places duties on HSE to make arrangements for carrying out research and to encourage research by others, and the Nuclear Installations Act, which states that HSE may recover the costs of nuclear safety research from nuclear site licensees (and applicants for licences).

The latest edition of the HSE Nuclear Safety Research Strategy is published as part of the Nuclear Research Index (NRI) (HSE 2008b). It covers the research that HSE will do and the research that it expects nuclear site licensees, and the nuclear industry in general, to carry out. Within the NRI there is also a HSE Nuclear Directorate Research Strategy Statement for Waste and Decommissioning Research (HSE 2008c). This statement is to ensure that nuclear site licensees consider HSE's needs and concerns in the waste and decommissioning technical area when they are establishing their research requirements (e.g. via TBuRDs in the case of NDA SLCs and via Nuclear Safety Research Schedules in the case of BE). The Statement applies to operating reactors, chemical plants and plants undergoing decommissioning. It is not prescriptive but is intended to list the topics on which, in HSE's view, R&D will be needed to support safety cases. It gives the regulatory and research goals as being (HSE 2008c):

“to ensure a sound technical basis for the safe and timely retrieval, passivation, immobilisation, containment and interim storage of radioactive wastes on both operating and decommissioning nuclear power and nuclear chemical plant sites, both now and in the future.”

The strategy mentions the NWRF (see Section 3.1) as the main means of ensuring collaboration between NDA's SLCs and BE and defence site licensees, so that the benefits of research are shared. It lists technical areas in which licensees are required to do research, and areas where they are expected to have active R&D programmes or at least to be aware of recent developments and have an “intelligent customer” capability. These areas are shown in the Table 1. Much of the research by licensees will fit into an overall project programme and be funded by that project, rather than being part of a programme of fundamental R&D.

The Nuclear Safety Advisory Committee (NuSAC) had the responsibility to inform HSE each year whether the nuclear safety research programmes of the industry and its regulators are adequate and balanced in supporting nuclear safety in the UK. Based on its sampling in 2007/08, NuSAC concluded that good progress had been made to define and develop topics requiring research. It judged the nuclear safety research situation to be satisfactory but, in the longer term, in need of continuing encouragement and scrutiny. The NuSAC review of the NDA SLCs' TBuRDs stated:

“We formed a favourable impression during our review of TBUrDs (2008). Standardisation of format has helped to ensure that all sites are addressing relevant issues, and some topics have yielded results that have been implemented. We did advise where further improvements might still be beneficial.”

This advice is being acted upon by the NDA (HSE 2008c and 2008d). Now that NuSAC has been disbanded, its review group on research has been renamed and will fulfil these roles until HSE has decided how to replace NuSAC.

HSE’s Nuclear Directorate (ND) reported in early 2009 that the 2008/09 nuclear safety research programme for radioactive waste management and decommissioning was being commissioned to plan by ND and the nuclear site licensees (HSE, 2009). The programme is focused on Magnox sites, Sellafield and Dounreay. ND identified the key areas and topics for research. The licensees identified the research required and told ND that it was being progressed (HSE, 2009).

<i>Required to do research</i>	<i>Expected to do research or be aware of recent developments</i>
waste characterisation waste retrieval (from ponds, silos and vaults) decontamination of structural components waste treatment and passivation (including segregation and volume reduction) waste immobilisation (including new encapsulants and processes) effluent control waste packaging (to ensure safe storage and transport for disposal, without reworking or overpacking) plant dismantling	radiological protection fault modelling probabilistic safety analysis human factors control and instrumentation

Table 1 Technical areas where nuclear site licensees are expected to have R&D capability

3.4 The Environment Agencies

EA and SEPA have modest research programmes that include topics of regulatory interest in the areas of radioactive waste management and health and environmental protection (CoRWM doc. 2464). Both agencies aim primarily to influence others to carry out research and can require nuclear site licensees to do research via conditions in authorisations issued under the Radioactive Substances Act.

EA's NWAT (Nuclear Waste Assessment Team) programme, while small, is highly focused and makes good use of its resources. EA has a limited R&D budget including around £1M over the next 5 years for in-house (2 scientists) and commissioned work, supplemented by industry charges levied by NWAT. This covers radioactive waste management and radioactive substances risk assessment, including new-build. While modest, this is partly used to "lever" EA into joint projects and programmes involving NII, industry and international bodies (such as the NEA Radioactive Waste Management Committee's Integrated Group for the Safety Case), giving it wider influence and access to knowledge, helping underpin its regulatory decisions. Current EA storage-related projects include:

- HLW / spent fuel safety cases: how different elements including the waste form, container and disposal facility design contribute to the safety functions
- remediation of ILW packages, including non-intrusive techniques for monitoring the condition of packages in store, and guidance on choosing remediation options so as to minimise health and environmental impacts.

EA plans further projects in

- chemical speciation of radionuclides and non-radioactive elements in the environment,
- site issues such as appropriate characterisation techniques, and managing graphite wastes.

SEPA commissions research mainly via SNIFFER (the Scotland and Northern Ireland Forum for Environmental Research). There is some interest from SEPA in R&D for long term storage, reflecting Scottish Government policy, but as yet little funding appears to be available.

3.5 The Research Councils

Support for R&D is available from the Research Councils and we will cover them in more detail in our R&D report due in October 2009. Storage R&D probably lies mainly within the EPSRC's (Engineering and Physical Sciences Research Council) remit. Some work relevant to storage has been supported through targeted programmes, particularly Keeping the Nuclear Option Open (KNOO) and Decommissioning, Immobilisation And Management Of Nuclear wastes for Disposal (DIAMOND). Some European Union programmes with UK involvement (e.g. CarboWaste which is examining options for graphite wastes) also address aspects of radioactive waste storage.

In 2005 the EPSRC set up the "Letter of Arrangement" (LoA) group with members from nuclear companies and the regulators (EPSRC, HSE, BNFL, AWE, MoD, BE and NDA) which is focussed on nuclear research activities. The LoA group helps to identify high level areas for possible research activity but EPSRC also seeks input from other stakeholders and the academic community. The decision whether to proceed with proposed areas and the

exact scope of an activity rests with the research councils. The EPSRC's stated position (CoRWM doc. 2524) is that it uses this to provide possible areas of focus for activities but ultimately it is up to the researchers to define the exact content of a research proposal and up to independent peer review to decide if a proposal is suitable for support (the final funding decision rests with the research councils). CoRWM have reservations about this statement: the vast majority of funded research in this area is under 'managed calls' (such as used for the EPSRC's KNOO and DIAMOND programmes which accounted for nearly £12M) as opposed to responsive mode (for which we can find few funded projects), hence, the scope of funded research is heavily influenced by the description of the calls themselves. It is not clear how priorities are set for these calls and the extent of influence of the LoA group.

In general, CoRWM and others have some reservations about how much industry input into the RCUK R&D programme is appropriate, how transparent this input is, and we emphasise again the need for R&D to be, and be seen to be, independent. We are aware however of the need for a strategic, top-down view to highlight problems, needs and objectives and will return to this in our R&D report due October 2009.

3.6 The NNL

The National Nuclear Laboratory (NNL) has about 700 personnel, of whom about 400 are technical and a further 150 provide facilities support. Key personnel in the NNL structure are the 7 Technical Authorities, each of which has overall responsibility for defining the technical strategy and maintaining quality within a defined technical area, and 8 Senior Research Fellows, who are NNL's leading technical experts with a responsibility for engaging with universities and other stakeholders and for quality publications within their area of expertise. The NNL supports the nuclear industry in two areas; the production of energy and in the understanding and management of radioactive waste. It currently has a fairly narrow "customer base". 75% of its business is from the NDA and SLCs with a further 20% from British Energy and MoD. Its facilities are owned by the NDA and operated and maintained by the SLCs.

When BNFL was restructured the Government retained NSTS (Nuclear Science and Technology Services) as a subsidiary. NSTS became Nexia Solutions in 2005 and by early 2008 it had a good track record as a business based upon its commercial and safety performance. This gave Government confidence that it could be self-sufficient and it consequently launched the NNL from Nexia in 2008. NNL is 100% owned by the Government and in April 2009 it became a government-owned, contractor operated organisation (GOCO). A consortium of Battelle, Serco and the University of Manchester has been awarded the management and operations contract. The role of the contractor is to provide strategic vision and management to the NNL and to develop it as a stand-alone business. The contract will be for an initial three-year period with options to extend by up to two years.

CoRWM acknowledges the necessity for the NNL to operate in a commercial manner but is concerned that there appears to be no provision for supporting strategic or fundamental long term R&D required by the UK as a whole. In addition, commercial drivers are unlikely to fully support infrastructure costs, such as those associated with building and running active facilities such as hot cells, or the costs of building long term capacity and skills. These are vital for the future management of the UK's radioactive wastes and for the nuclear industry as a whole. The lack of them could also have serious implications for the international reputation of the NNL. We will return to this in our full R&D report to Government.

3.7 Consultants and Contractors

There are a number of consultant and contractor companies that advise on radioactive waste management R&D requirements and/or carry out R&D. Some work largely with nuclear site licensees, carrying out R&D in the course of major radioactive waste management projects. Some have links with universities and seek to develop new processes or techniques in the laboratory and follow them through to full scale implementation on nuclear sites. Some do mainly modelling and other desk-based studies. It is unclear to CoRWM how the views of contractors and consultants are taken into account in establishing research requirements (e.g. in the NDA SLCs' TBuRDs), or how their expertise is used in the NWRF and its sub-groups.

3.8 Health and Environmental Protection Research

R&D relevant to movement of radionuclides in the biosphere and the effect of radiation on people and organisms is carried out by the nuclear industry, universities, NERC institutes, regulators, HPA, MRC and others. It is funded by industry, regulators and government departments (including the Department of Health). NERC's (Natural Environment Research Council) informal group COGER (the Co-ordinating Group on Environmental Radioactivity) aims to ensure information exchange, effective co-ordination of basic and applied research, and to advise on the adequacy of research and highlight gaps and deficiencies in all areas related to environmental radioactivity. COMARE (the Committee on Medical Aspects of Radiation in the Environment) advises Government on the needs for research on the health effects of natural and man-made radiation in the environment.

4 COMMENTS ON THE UK STORAGE R&D PROCESS

When we met the NDA (CoRWM doc. 2373) they made it clear that they were still developing a clear picture of the need for underpinning research and undertaking a management review of their research assets to assess the relationship to needs-driven R&D. The repository programme, inherited with the assimilation of Nirex, had a major impact on their R&D assessment and they were still considering how such a programme, and the need to develop it, would influence things like equipment and facilities. This is highlighted by the NDA Proposed RWMD R&D Strategy (NDA 2008c) which had limited storage R&D content. In addition because "Needs, Risks and Opportunities", was

issued in 2006 (NDA 2006a) and is based on 2005 TBUrDs, it predates changes to the waste package specifications and the incorporation of Nirex into NDA.

CoRWM's PSE Stakeholder Event (CoRWM doc. 2488) revealed a clear public desire for linking the various SLCs' R&D plans to address uncertainty and risks (such as the stability of stored wastes). Since questions of ILW product longevity in storage are relevant to most NDA sites, there is an obvious opportunity for coordination across the NDA and, while there is a mechanism to promote this, CoRWM would like to see the extent to which this is actually happening. This should be facilitated by an updating of "Needs, Risks and Opportunities" which is currently ongoing.

CoRWM's PSE Event also revealed concern over the potential confusion arising from the different R&D that may be needed to address the Scottish Government's developing policy on long term storage.

A stated objective of the NDA's R&D management process is to "help the SLCs to focus on overall programme delivery and not just short-term activities." CoRWM would like to see evidence of the extent to which this is being achieved. In fact, throughout the NDA's R&D process, it is not clear what the process is for checking the R&D has been funded to an appropriate level in a timely manner, done to an acceptable standard, and then whether it has led to improvements in the NDA's mission and programme. A procedure needs to be in place to close the R&D loop.

The process does not yet show a suitable balance between fundamental and applied "needs driven" R&D. For example, we have found little support from RCUK (who might be expected to support fundamental R&D) for storage-related R&D; only small parts of the DIAMOND and, to a still lesser extent, KNOO consortia. In addition we are concerned that the current process, relying as it does predominantly on input from the SLCs and the industry, is too heavily weighted to short term goals and longer term needs may be seen as less important.

As highlighted at the IoP Storage Meeting (CoRWM doc. 2519) the current process based upon TBUrDs is too closed and designed to identify the R&D from a SLC site programme bottom-up approach. A separate process is needed for identifying the UK's strategic needs. Although there is now good co-ordination at the technical level via the NWRF, the overall strategic co-ordination between the NDA and other waste producers is at an early stage of development. Such co-ordination should be at the national level and involve all the regulators, including those for waste transport. It should also be within a holistic framework within which research is undertaken to determine how effective any part of the storage system needs to be to deliver acceptable performance.

The IoP Storage meeting also highlighted the need for a mechanism to transfer innovative technologies such as developments in nanotechnology, sensors and remote handling from outside into the nuclear industry. We

believe routes towards this could be via the EPSRC Knowledge Transfer Account (KTA) or focused RCUK calls and the NDA's recently technology innovation call for proposals with £1M available for development activity is a positive step.

At the Storage R&D meeting organized by CoRWM at the IoP (CoRWM doc 2519) it was recognized that confusion over the time period for storage above ground and the below ground period while the GDF is open, impacted on the community's ability to design clear and focused storage R&D programmes. CoRWM's Interim Storage report has clarified this issue (CoRWM doc 2500) confirming the need to plan now for at least 100 years of above ground storage.

Feedback we have received indicates the NDA's process of funding R&D for SLCs and universities (through the DRP) has been unwieldy and slow and to some extent has alienated the communities on which the NDA must rely for much of their R&D work. However, the DRP scheme seems sensible and, as long as it can be adjusted to take account of user concerns, it has the potential to be successful. The level of funding for the DRP scheme is however small in international terms. A more top-down research programme is desirable and would provide the basis for determining the adequacy of the research budget.

CoRWM has some concern that the dominance of SLCs and RWMD in the DRP process limits R&D to more immediate needs. Previously, much of this R&D was carried out by Nexia Solutions (now NNL) but the work was competed openly for the first time in the run-up to the 2008-2009 financial year. The subdivision of the DRP into four Lots, each containing multiple tasks, suggests that there is little scope to use the DRP funds to develop infrastructure, and the delay in making funding decisions leads to inefficiencies and loss of continuity. In our meetings with the SLC's and others we have been made aware of concerns that research contracts funded by the SLCs are focussed too heavily on the short term with little support for long-term fundamental or basic research. The NDA is aware of the SLCs less than 2 year horizon for R&D via the TBuRD process but needs a process to encourage them to develop a longer term view.

In previous sections we have described and commented upon the UK's process for managing storage-related R&D and we will need to dovetail this into our R&D report, including geological disposal issues, for October 2009. In large part we believe the UK has a process in place to identify the R&D that is needed but it is less clear that a strategic vision, which addresses the major uncertainties, is being developed and acted upon, that the R&D is adequately resourced, is done in a timely manner, or that it feeds back into the processes and practice of making durable storage systems that will link to a GDF programme.

5 SOME SPECIFIC R&D ISSUES

In this section we highlight some key topics of which we have been made aware in several of our meetings with stakeholders which will only be addressed by significant R&D programmes. This is by no means an exhaustive list but serves to illustrate some of the key issues.

5.1 Diversity of UK Higher Activity Wastes

Unlike countries such as Switzerland, Sweden and Finland, the UK has a vast array of various types of radioactive waste, a legacy of its early lead in military and civil power generation nuclear programmes. Higher activity wastes currently being stored (Defra/NDA 2008a and 2008b) include vitrified high level waste (HLW) in over 4300 1.34m high x 0.43m diameter steel canisters in a specialist store at Sellafield and about 40,000 packages of conditioned intermediate level waste (ILW) including several thousand 500 litre drums of Magnox Encapsulation Plant (MEP) wastes containing reactive metals such as Magnox (a magnesium-aluminium alloy used to clad uranium metal fuel in Magnox reactors) and some uranium. Other ILW includes ion exchange resins, graphite, steels, plutonium contaminated materials and some soils. In addition there are some ill-characterised legacy wastes (predominantly at Sellafield), many as sludges for which immobilisation routes are being developed. In due course some spent fuels, plutonium and uranium may be declared to be waste. The diversity, complexity and in some cases poor level of characterisation of the UK's wastes means that fundamental and applied research, specific to the complex UK inventory, is required to support waste conditioning, packaging, storage and disposal programmes. R&D must be directed to those UK-specific wastes for which other countries are unlikely to develop appropriate treatment processes.

5.2 Waste Package Specifications, Post-Closure Safety and Retrievability

The waste package specifications used by the NDA were developed by Nirex and are closely linked to its concept for geological disposal facilities for ILW (Nirex 2007). The post-closure safety cases for these concepts did not take any credit for the waste container or the physical durability of the waste form. However, they assumed cementitious waste forms and took into account a contribution of these to the alkaline environment which would exist within a disposal facility, largely as a result of the cementitious backfill. The package specifications include a target container life (500 years) and target time for the waste form to retain its integrity (200 years) based on storage, emplacement in a GDF and the GDF remaining open for a few hundred years with waste packages readily retrievable (NDA 2008a). Post-closure safety is dealt with in the LoC process by assessing whether the proposed waste form will be compatible with the assumed cementitious backfill (see Section 5.3), rather than by explicit specifications. This lack of a clear link between the safety case and the waste package specifications causes confusion and makes it difficult to specify R&D requirements on the behaviour of waste packages after disposal.

In the IoP Storage meeting (CoRWM doc. 2519) the issue of the impact of the need for retrievability on R&D programmes was emphasised. Like the issue of the store lifetime, a lack of clarity makes defining R&D programmes difficult for those in the industry. In its 2006 recommendations CoRWM made it clear that it did not see retrievability as a necessary prerequisite of any geological disposal concept for the UK's higher activity wastes. However, Government decided that host communities should have a role in deciding on the time for which a GDF is designed to remain open, with waste packages retrievable.

The NDA waste package specifications are now based on an assumption that retrievability may be needed for up to 300 years. This leads to a target container life of 500 years. Demonstrating this target could be met would require considerable R&D. It is thus important to clarify the status of the target. This in turn requires an examination of the implications of retrievability, and a revisiting of the issue of the timing of a decision on retrievability. In addition, earlier waste packages have been prepared to different, less stringent specifications, and it is uncertain whether these will comply with the newer, more demanding specifications.

5.3 Letter of Compliance (LoC) Process

The Letter of Compliance (LoC) process is described in CoRWM's Interim Storage report (CoRWM doc 2500). It is a process designed to make sure that, as far as practicable, waste conditioning methods will produce waste packages that can be safely stored, transported and disposed of. The system was started by Nirex and was originally called the Letter of Comfort (because it was designed to give comfort to waste producers that Nirex would accept their packages for geological disposal). It is now operated by NDA RWMD.

In order to obtain a LoC, the waste owner has to provide evidence that the waste package will be compliant with the NDA specifications (Nirex 2007). This often requires the owner to conduct R&D. For a typical cemented waste, factors such as the rate of setting, amount of free water, mechanical strength, heat production and fracturing are taken into account. The size of the R&D programmes required to develop and implement conditioning and packaging processes can be substantial in money and time (from hundreds of thousands to millions of pounds and over many years) for difficult wastes. NDA has agreed to allow CoRWM to investigate the R&D underpinning some example LoC applications in order to explore this area more fully.

Nirex/NDA waste package specifications have changed with time and it is possible that they will change again. Thus by the time a geological disposal facility comes into operation, the UK will have several categories of ILW packages: older packages that were prepared to meet the earlier specifications, newer packages designed to meet the current specifications and possibly also packages designed to meet future, different specifications.

The NDA is undertaking a review of earlier LoCs and this will either provide reassurance that "old specification" waste packages will meet the more recent standards, or will identify the need for remedial action to ensure that packages

will meet these standards. R&D will be necessary to determine the types of remedial actions required.

5.4 Current and Planned R&D for ILW

In CoRWM's meetings with NDA, NNL, SLCs, other waste producers, regulators and others we have been made aware of key topics which are, or we believe should be, the focus of significant R&D programmes and these are discussed in this section. CoRWM has some concerns the 2006 NDA Needs, Risks and Opportunities in R&D document does not address storage issues to the extent which is now appropriate and we hope the version currently in preparation will cover these issues in more detail. Useful documents in preparing this section include the NDA's Review of UK Storage Related R&D (draft seen by CoRWM) and Nexia Solutions (now NNL) Review of the Current Status of Underpinning R&D Relating to ILW Package Longevity (Nexia 2007a). The latter report is based on a meeting of interested groups including EA, SEPA, Nirex, UKAEA, BNGSL, Magnox SLC and Nexia Solutions which was chaired by the NDA and is an example of good practice in terms of bringing all stakeholders together.

A comment made to us on many occasions in meetings with those in the nuclear industry is that the continual changes that have been made to the industry over the last 10 years have meant that SLCs' R&D programmes on storage have not been high on their agendas.

5.4.1 ILW Containing Reactive Metals

After about 15 years of storage localised surface bulges have been observed on Magnox Encapsulation Plant (MEP) drums containing reactive metals (EA 2008a). Since these anomalies were discovered, the regulators have required Sellafield Ltd. to conduct R&D to find what caused them to appear, as input to determine whether remedial action is required. The original LoC for the MEP drums attempted to take full account of the likely corrosion of Magnox metal in the drums during storage and contained a caveat about the uranium content of the drums. The bulges are thought to be a result of the presence of large (kg-sized) pieces of uranium in the drums and operational procedures have been changed to prevent this in future. R&D is continuing to confirm the causes of the bulges and assess their significance (CoRWM doc 2464, NDA 2008a).

Questions of wastefrom durability are reflected in SLC TBUrDs, for example 35185 Encapsulated ILW Drum Storage and 35125 Magnox Waste Encapsulation in the Sellafield TBUrD (Figure 1). It is stated explicitly in the Sellafield TBUrD "This strategy covers encapsulation and safe storage of intermediate level waste (ILW) products produced by consignor plants on the Sellafield site up to the point at which a disposal route becomes available".

In the context of a 500-year target lifetime for the waste container (see Section 5.2), both measurement of "store corrosivity" and quantitative assessment of "waste package degradation" are very challenging, not least

because there is no current consensus on those parameters which need to be measured, and there will be a need to measure very small changes and very slow rates. A required element of the safety cases for storage and disposal will be a well-founded predictive model for waste package behaviour. Due to the long timescales, any such model will need to be derived from a process-based, mechanistic understanding; extrapolation from empirical data is unlikely to be sufficient. Currently, this required level of mechanistic understanding does not exist for UK waste packages.

The resources and timescale for the development of techniques for measuring store corrosivity appear very optimistic although the effort and time to be directed towards assessment of waste package degradation seems more appropriate to the potential scale of the problem.

Figure 1. Excerpts from the Sellafield site TBUrd document. The first table identifies R&D requirements for encapsulated ILW drum storage and the second those for Magnox waste encapsulation.

Technical Need - Task + Gap	Context of why a problem	Target date	Cost range	Needs/Risk/ Opportunity	Site/ Generic/ NDA issue	Key outputs/Actions
Identify technique for the determination of store "corrosivity" in real time	It is currently not possible to demonstrate that store conditions are optimised for product longevity	March 08	<£50k	Need	Generic	Report recommending development of one or more instruments for deployment in active waste stores
Develop techniques for the remote non-destructive examination of waste packages	It is currently not possible to quantitatively assess waste package degradation	March 10	>£100k-£1Mk	Need	Generic	Prototype apparatus for measuring identified key parameters which can be remotely deployed in an ILW plant
Improve understanding of pore water availability in Magnox waste packages	Current lifetime predictions may be overly pessimistic which may lead to unnecessary reworking prior to disposal	March 08	£50k-£100k	Opportunity	Site	Report refining predictions of lifetime to monolith failure of encapsulated Magnox swarf drums

Technical Need - Task + Gap	Context of why a problem	Target date	Cost range	Needs/Risk/ Opportunity	Site/ Generic/ NDA issue	Key outputs/Actions
Develop a better understanding of the behaviour of metallic uranium in cement grout containing Magnox swarf	Recent development work to encapsulate Magnox fuel elements and uranium pennies has revealed unexpectedly high uranium corrosion rates under some conditions. The results may be applicable to encapsulated Magnox swarf	March 08	£50k-£100k	Need	Site	Report or reports from further development trials with findings, identified, mechanism(s) for the observed corrosion and rates of corrosion and anticipated corrosion behaviour of uranium in encapsulated Magnox swarf drum

Assess or re-assess the disposability of non-conforming drums in the light of recent ongoing Nirex guidance	In some or all cases, the assessment of disposability may not be to the standard currently expected by Nirex	March 08	<£50k	Need	Site	Assessment of the disposability of the various classes of non-conforming drum against the current repository concept and current Nirex guidelines
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In the context of the Sellafield site, given the number and diversity of ILW packages which will be produced over the rest of the site's lifetime, and the potential significance of wastefrom performance for transportability and disposability, the amount of effort being devoted to resolving uncertainties over product lifetimes seems to be small and CoRWM believe an increased R&D effort is required. The NDA's UK Storage Review identifies the existence and nature of this problem but gives no indication that there will be substantial further R&D.

5.4.2 Graphite

The UK has a large volume, about 86,300 tonnes of ILW equivalent to a raw volume of about 73,000m³, of graphite that is activated or contaminated. This has implications for the geological disposal programme due the large space the graphite would potentially occupy in any GDF unless waste volume minimisation technology is applied. Options for graphite treatment, reuse and disposal have been discussed at several recent workshops (Norris *et al.* 2007, NDA 2006b). Apart from its volume a key concern with this waste is that it contains significant quantities of the long-lived and potentially mobile radionuclides ¹⁴C and ³⁶Cl. Since geological disposal of the current volume of graphite may not be the optimal route R&D is being undertaken to identify the optimal solution. The options being considered for bulk reactor graphite are:

- Treat all graphite waste as ILW and ensure the GDF caters for the large volumes of material. This is the baseline option.
- Condition graphite waste to remove the longest-lived radioisotopes and dispose of the residual graphite in a low level waste repository or an alternative near-surface disposal facility.
- Condition LLW and/or ILW graphite waste to remove most of the contamination and free release or reuse the graphite where possible.
- Separate repository (or repositories) for graphitic wastes, including a near-surface disposal option.
- Interim store ILW graphitic wastes and condition for either LLW disposal or free release.

Current graphite R&D is being carried out under the 4-year EC Carbowaste programme. The NDA is taking the lead in UK strategy development for graphite, with support from its Magnox SLCs who are optioneering potential treatment and disposal options for irradiated graphite for the NDA. This would appear to be a good example of working with the international R&D community on a common issue which is highly relevant to the UK and

CoRWM encourages the NDA and others in the UK research community to develop similar programmes appropriate to other significant UK waste issues.

5.4.3 Other Planned ILW R&D

The NDA's 2006 Needs, Risks and Opportunities document (NDA 2006a) identified some key issues for R&D. For ILW these included increasing the ratio of waste to cement, improving grout percolation through waste and reducing the difficulties of reactive metals. Other needs highlighted included alternative (but cheap and room temperature) matrices for ILW wastes that currently are reacting with cement, an understanding of the long-term behaviour of stored wastes so minimising degradation, and remedial action on stored sea dump drums. In addition the Review of the Current Status of Underpinning R&D Relating to ILW Package Longevity (Nexia 2007) identified issues including: failure criteria, wastefrom integrity at end of storage period, overpack strategy and reworking, reactive metals, alternative options to encapsulation and alternative containers (materials/design).

CoRWM believes that R&D into remedial action on failed or out of specification packages should be addressed as a priority in the R&D strategy. Options have been examined in a review by the Environment Agency (EA 2005). NDA has also carried out some work on overpacking (NDA 2008a), as has Magnox SLC (McHugh 2008).

5.4.4 Steel Corrosion

A recent review of the long-term behaviour of the steels used for ILW storage containers (Lyon 2008) supports the general assertion that the current container materials (typically 316L and some 304 austenitic stainless steels although some early drums were mild steel) will last for suitable (500 year) timescales if manufactured appropriately and stored in controlled atmospheric conditions. However, there were concerns that limited overall confidence including: container materials, manufacture and failure criteria; aspects of internal and external corrosion; and the nature of the desired storage atmosphere. A specific concern is the ability of current steels to resist atmosphere assisted stress corrosion cracking (ASCC) which is exacerbated by the salty atmospheres prevalent at many UK storage locations. Current research is focussed on using high performance duplex alloy (mixed austenite and ferrite) stainless steels which are more resistant to ASCC. Currently, there is no national programme of developing a single best (in terms of corrosion resistance, cost and ease of fabrication) container material and different nuclear site licensees use different steels. Other key drivers in container development (CoRWM doc 2386) are to match the container to the wastefrom it contains (so high risk wastes can be packaged in a higher quality container), matching containers to the store and eventual GDF environment and standardising and simplifying container design.

5.4.5 High Temperature Conditioning Processes

To date, high temperature conditioning processes have not been used in the UK for ILW. They are used in Europe and have the advantage of producing durable waste forms with low volumes. Interest in such processes has increased recently. For example, BE is considering hot pressing for the Sizewell B ion exchange resins (CoRWM docs 2419 and 2489), and Sellafield is considering thermal treatment for SIXEP sand, clinoptilolite and sludge (NDA 2008a). These investigations of alternatives to encapsulation in cement are timely.

5.5 Storage Systems

An issue in storage systems is the balance between the contribution of the store building and that of the container. Some stores (e.g. the EPS1 store at Sellafield) are massive and provide the radiation shielding for the packages they hold but are expensive. Alternatives are simpler weatherproof store buildings with self-shielded containers, such as mini store systems inside. The mini store concept in which ILW waste is stored in robust, thick-walled, self-shielding cast iron containers is one of several which may offer more flexibility in terms of storage and disposal options but it is at an early stage of development in the UK context. Other research and development issues for storage systems brought to our attention in meetings with NDA, SLCs, BE and at the IoP Storage R&D meeting (CoRWM doc. 2519) include:

- Especially for older existing stores, how do we make better predictions of their lifetimes, how can ventilation systems be improved, how can conditions in the store be better monitored and better arrangements be introduced for inspecting waste packages?
- For future stores, who is performing R&D on the newer mini-store concept now being considered?
- If Scotland plans extended near-site near-surface storage as an option in its own right, with no foreseeable endpoint, rather than interim storage with an endpoint, then R&D will be needed to develop appropriate concepts and detailed designs.

The first point is highlighted in paragraphs 3.36-3.38 of the CoRWM Storage report (CoRWM doc. 2500) which covers the lack of suitable atmosphere control in some older stores. This has led to waste container corrosion that is faster than that envisaged when the LoC was issued, due in large part to salty coastal atmospheres (section 5.4.4). As a result it is more likely that remedial action (e.g. overpacking, section 5.4.3) will eventually be needed prior to waste transport and disposal. There is a need to assess options for improving ventilation systems and for monitoring atmospheric conditions in stores where such conditions exist or could occur in future. It is also essential that new storage systems are designed with appropriate ventilation and atmosphere monitoring provisions. Some of these points are recognised in the NDA UK storage review (NDA, 2009d).

Further R&D is needed to demonstrate that existing stores will achieve the design lives claimed for them and to assess whether these lives can be extended, and if so by how much. If controlled atmosphere stores are to be required for many decades, R&D into atmosphere independent packages (such as ceramic overpacks) may be needed. The option of using of such packages could then be compared with the controlled atmosphere option.

5.6 Management of Spent Fuels

The existing and committed UK inventory of spent or used nuclear fuels (SF) can be divided into categories depending on type and source; these being Magnox, AGR, PWR, Exotic and MoD. The current management strategy for each is summarised below along with the related current and planned R&D and areas in which further R&D is likely to be needed are highlighted. An option related to the long-term management of SF that is rapidly gaining favour is dry storage and R&D issues connected to this are also identified below. CoRWM plan to address SF from new build reactors in future.

5.6.1 Magnox Fuel

Magnox fuel consists of uranium metal in a magnesium-alloy cladding and the NDA's current strategy, as outlined in the Magnox Operating Plan, MOP8 (NDA 2007) is to reprocess all spent Magnox fuel. Around 5,800 tHM of Magnox fuel remains to be reprocessed (Defra/NDA, 2008b). Some of it is in operating reactors, some in temporary dry storage in shut down reactors and in the Wylfa dry store, and the rest is stored under water, mainly at Sellafield. The reprocessing strategy is contingent upon the Sellafield Magnox Reprocessing Plant (MRP) continuing to operate until all Magnox spent fuel that can be reprocessed has been. Given the elderly nature of the MRP, considerable effort and resource is being expended into keeping it operating but the possibility of chronic or acute failure before reprocessing is completed (currently projected as 2016) must be considered (CoRWM doc. 2520).

Accordingly, contingency plans for any un-reprocessed Magnox fuel are required (CoRWM doc. 2520) and the NDA is investigating these (NDA 2008d; CoRWM docs. 2418; 2500) along three principal lines, namely:

- Reprocessing through THORP with the recovered U and Pu and the associated HLW being managed in the same way as other THORP products. This would be difficult and costly entailing modification to the THORP head end, and would require significant R&D for the necessary adaptations of the THORP process. It would also disrupt and prolong the THORP programme, and for these reasons this option is currently 'shelved' by the NDA.
- Dry storage followed by geological disposal. This necessitates drying the SF before placing it in one of the preferred forms of dry storage (see section 5.6.6). An issue is how dry to make the fuel. There is at present no capability in the UK for drying SF of any kind on a large scale. However, there is considerable experience in other countries. The work at Hanford in the US, where metal fuels have been successfully dried as a prelude to

- Encapsulation in preparation for interim storage and geological disposal. Experience with encapsulation of relatively small amounts of reactive metals such as uranium has shown that existing cement formulations would not be suitable for uranium metal fuels (see section 5.4.1). It would thus be necessary to carry out a substantial (and successful) programme of R&D into new encapsulants, such as polymers, glasses and alternative cements, before this option could be pursued. This would need to include R&D to demonstrate that the selected encapsulation system was suitable for geological disposal.

Even in the event that the reprocessing strategy proceeds to 'completion', it is inevitable that there will be some spent Magnox fuel that cannot be reprocessed (Defra/NDA 2008a). In particular, the corroded and degraded fuel from the legacy ponds and silos at Sellafield (CoRWM docs. 2418, 2520), will have to be treated as waste. R&D is in progress on suitable conditioning and packaging options for legacy ponds and silos waste, in parallel with the development of methods to retrieve it (CoRWM doc 2520, NDA 2008a). Reducing the hazards associated with the Sellafield legacy ponds and silos has been identified as a matter of urgency by the regulators (HSE 2008e) and our understanding is that the NDA has prioritised funding to undertake the necessary work as quickly as possible (NDA 2008e).

5.6.2 AGR Fuel

AGR fuel consists of low-enriched uranium oxide pellets in stainless steel cladding with graphite sleeves. For management purposes it is divided into two tranches, referred to as "historic" and "new" (CoRWM doc. 2419). The former includes all AGR fuel loaded into reactors on and before January 14th 2005 and the latter all fuel loaded after that date. The historic SF is the property of BE and about three quarters of it is contracted for reprocessing through THORP with the rest contracted to the NDA to store or reprocess at their discretion. The new AGR fuel, including any arising from extensions of AGR lifetimes, is contracted to the NDA to manage as they see fit.

For economic reasons, it is unlikely that THORP will continue operation beyond its baseload reprocessing (due by 2015) and it is predicted that between 5,500 (Defra/NDA 2008b) and 7,000 (CoRWM doc. 2520) tHM of AGR SF will remain in storage at Sellafield. The current plan for AGR spent fuel is essentially for this to remain in pond storage. Apart from capacity issues, this is not a satisfactory long-term strategy and it is incumbent upon the NDA to develop an alternative.

AGR SF is stored in ponds at Sellafield. Some of it is in the THORP Receipt and Storage pond alongside (overseas owned) LWR SF and a large number of empty multi-element bottles. The pond water chemistry cannot be kept sufficiently alkaline to prevent corrosion of the steel cladding on the AGR SF and there is a risk of leakages into the pond water. Sellafield Ltd. has introduced short-term measures to manage the situation, including the prioritisation of reprocessing for corroded AGR SF (CoRWM docs. 2386, 2520) and work is in progress to find a longer-term solution.

In response to the regulators, the NDA is developing an "oxide fuels reference strategy" (NDA 2008d; CoRWM docs. 2418, 2520) in which it will set targets for how much of the remaining AGR SF will be reprocessed and how and where the rest will be stored. The baseline plan, is wet storage pending conditioning for disposal, with dry storage being looked at as an option (section 5.6.6). However, this would require drying of the fuel which has been stored under water. As with Magnox SF, no capability exists in the UK for doing this and a substantial programme of R&D will be needed in order to pursue the dry storage option.

There has been much R&D in other countries on the conditioning and packaging of PWR and BWR SF for geological disposal but there are significant differences between these fuels and AGR SF (CoRWM docs. 2480, 2520 and 2533). It is of some concern (e.g., CoRWM doc. 2520) that relatively little R&D has been undertaken into the conditioning and packaging of AGR SF for geological disposal, beyond suggestions that the Swedish KBS-3 concept might be adapted for this purpose. One possibility worth investigating would be the encapsulation of AGR fuel pins in lead, as has been proposed (Gibb *et al.* 2008) as a prelude to the geological disposal of LWR spent fuel pins. Other issues likely to be important include the type of canister to be used and the leaching behaviour of the fuel once it comes into contact with groundwater. Without demonstrating that geological disposal of AGR SF is feasible, AGR fuel strategies are incomplete. Given the amount of spent AGR fuel likely to require disposal and the fact that it is almost unique to the UK, it would be sensible to give AGR fuel priority in any NDA/RWMD R&D programme into the geological disposal of SF, including transport to the GDF.

5.6.3 PWR Fuel

PWR fuel consists of low-enriched uranium oxide pellets in a zircaloy cladding and, at present is used in the UK only at Sizewell B where the spent fuel is stored in the fuel pond. Over the scheduled 40-year lifetime of the reactor it is expected to generate around 1,200 tHM of SF (Defra/NDA 2008b), which

remains the responsibility of BE. BE have no plans to reprocess Sizewell B SF (CoRWM doc. 2489). BE are currently seeking to increase the approved capacity of the Sizewell storage pond by re-racking but the potential for further increase is limited. BE are currently investigating dry storage (CoRWM docs. 2419 and 2489) with a view to having "dry cask" storage (see Section 5.6.6) on site at Sizewell by 2015. Drying of PWR SF is much simpler than drying Magnox or AGR fuel because of its robust zircaloy cladding. PWR SF is dry stored in several other countries, particularly the US, and BE see an opportunity to buy into 'off the shelf' technology. A further issue relates to the fate of the stored SF. There will need to be R&D on conditioning and packaging Sizewell B SF for geological disposal, and this should take into account the extensive research carried out in other countries on geological disposal of PWR fuels.

5.6.4 Exotic Fuels

Metal, oxide and carbide fuels from a number of experimental and other reactors such as the Windscale piles and the Dounreay prototype and fast reactors are grouped together as 'exotic' fuels. Baseline plans for the management of these exist but are poorly underpinned by R&D (CoRWM doc. 2520) and the NDA is now developing an exotic fuels strategy. Dealing with such a wide range of materials is a complex problem and it is a matter of some urgency to identify the preferred options for some of them, such as the Dounreay Fast Reactor SF, because they could involve utilising the Magnox Reprocessing Plant and THORP, both of which have limited life expectancy. DFR breeder fuel has been used as an example of the approach to be followed and the reference strategy for it is now reprocessing in the Magnox plant at Sellafield (CoRWM doc 2523). At present it is unclear which of the other exotic fuels can be recycled and which will have to be declared as waste (some, such as the Windscale SF, already have (Defra/NDA 2008a)).

CoRWM agrees with the NDA that it is important to have plans for dealing with exotic fuels, so that plant, infrastructure and R&D requirements are clear (CoRWM doc. 2500).

5.6.5 MoD Used Fuel

Naval PWR fuel consists of Zr-clad highly enriched uranium. The used fuel is stored under water at Sellafield on behalf of MoD, which regards it as an asset, but has no current plans for reprocessing or anything beyond the status quo. Reprocessing of such highly enriched fuel could prove difficult and could not be undertaken without a programme of R&D. The stored fuel is showing no evidence of corrosion so there is less urgency for decisions to be made compared to other forms of nuclear fuel; but it cannot remain in storage indefinitely. It is encouraging that the MoD is joining the NDA groups (such as the Strategy Development and Delivery Group and the Spent Fuel and Nuclear Materials Topic Overview Group) on spent fuel management (CoRWM docs 2523 and 2500).

5.6.6 Dry Storage of Spent Fuels

Magnox and AGR fuels are designed for use in dry environments. They can only be stored underwater for limited periods because of the risk of corrosion and degradation (see sections 5.6.1 and 5.6.2). Control of the water chemistry can reduce these effects but is complex, especially where different types of fuel and other materials are present in the same pond. Dry storage is an alternative that is in use for SF in a number of countries, especially for LWR fuels. It has also been used in the UK but only on a very limited scale and mostly for fuels that have not been previously stored in ponds (CoRWM doc 2480). It is potentially cheaper than pond storage, minimises degradation and would be an appropriate precursor to emplacement in a GDF.

The spent fuel is dried, usually with hot air, and sealed into steel containers under an inert atmosphere (e.g., helium, nitrogen). The containers are then stored either in modular concrete vaults (called 'silos' in the USA) or in free-standing casks of concrete, steel or other materials. Vault systems are substantial buildings, often partly below ground, in which the containers are stored in vertical tubes cooled by passive buoyant advecting air that does not come into contact with the spent fuel. These can be constructed in 2-3 years. An example of such a system is the Paks MVDS project in Hungary. Casks are large cylinders, usually of concrete and steel, and can be designed for vertical (more usual) or horizontal storage. They are cooled by convection and heat radiation from their outer surface and may be stood on outdoor dispersal pads (similar to a fenced car park) exposed to the elements in remote areas or inside a simple purpose built building. The former is common in the USA but the latter would be more appropriate for the UK.

Although much of the dry storage technology could be bought 'off the shelf', especially from the USA or Germany, there are a number of significant R&D issues that would need to be addressed before it could be used in the UK for Magnox and AGR spent fuels. For AGR fuel, foremost among these are studies related to how dry the fuel needs to be in order to avoid corrosion of its steel cladding during storage and so be safely stored (and subsequently disposed of), and to potential drying processes (CoRWM docs. 2480, 2500, 2520 and 2533). The former include studies of the fuel clad corrosion processes in the presence of residual moisture and under different 'inert' gases. US experience of drying metal fuels (see Section 5.6.1) and worldwide experience of drying LWR fuels is valuable but R&D specific to the UK's fuels is required. Considerable R&D is needed before a safety case could be made for the use of the Hanford process to dry Magnox fuel and to show that dried Magnox fuel is a suitable waste form for disposal (CoRWM doc. 2500).

5.6.7 National Spent Fuel Strategy

While the NDA has made a good start with its strategy management system a more holistic approach is needed with appropriate and developed contingency strategies for each fuel type and at site level. It would be necessary for Government to delegate the lead since NDA do not have control over, or responsibility for, non-NDA sites and fuels. We agree with the regulators

(CoRWM doc. 2520) on the need for a national spent fuel strategy covering all current types of fuels.

5.7 Management of Plutonium

R&D into management of the UK's civil Pu stockpile has been an NDA priority since its inception and has, we believe, been an example of good practice which could be used as a model for future R&D programmes. It has involved close collaboration between the NDA, NNL, universities and learned societies in a coordinated manner. The strong input from the Royal Society (Royal Society 2007, CoRWM doc 2374) has lent credibility to the programme as has participation in the Euratom funded EU programme entitled Red Impact (Red Impact 2007).

In 2008 the NDA issued a consultation paper on options for the management of plutonium and held two stakeholder workshops (NDA 2008f). It used the results of the consultation and the workshops in preparing a paper on "credible options" for plutonium management that was submitted to Government, with a supporting technical report (NDA 2009a, b, c). The 2009 NDA documents identify four high level strategy options for managing the UK's separated plutonium:

- i) continued storage until 2120, then immobilise the plutonium in a suitable waste form and dispose of the waste in a geological facility
- ii) immobilise the plutonium as soon as practicable, store the resulting waste, then dispose of it in a GDF when one is available
- iii) sell or lease the plutonium for recycling, then dispose of the resulting spent fuel
- iv) some combination of the above.

The NDA proposed that option (i) be adopted as the reference strategy for planning purposes, while further work is carried out to develop and assess the other options (NDA 2009a).

To date the NDA has considered several immobilisation options for plutonium. These are: use of a cement composite, use of a glass composite, use of a ceramic composite made via hot isostatic pressing, and making the plutonium into low specification MOX (either in a new plant that would make MOX assemblies or by modifying the Sellafield MOX plant to produce MOX in cans). The cement option is the most expensive but also the one with the largest variations in cost, depending on how much plutonium there is in each waste package. The NDA proposes to carry out a programme of work to assess the possible waste forms in more detail, particularly from the point of view of their suitability for geological disposal (NDA 2009b, c).

So far, the NDA has not considered the option of recycling plutonium in UK reactors (either existing or new build). This is because a further "justification" exercise would be required to allow MOX fuel to be used in this country. The NDA has assumed in its analyses that recycling would occur in another country, either in an LWR or in a CANDU reactor. (Use of fast reactors was

not considered “credible” at present, because of the long lead time.) The NDA proposes to undertake market engagement to gauge the level of interest in recycling plutonium. If the option seems viable, the NDA would then need to discuss with Government the type of commercial arrangement that would be acceptable (NDA, 2009b, c). There would also need to be R&D on interim storage and geological disposal of MOX fuel. This R&D would be carried out by the countries using the MOX fuel.

NDA technical work on management options for plutonium is continuing. Government is considering the type of decision-making process required to select a future plutonium management strategy. It is clear that this process will involve a public consultation.

5.8 Management of Uranium

The total UK civil holdings of uranium were 96,400 tonnes at the end of 2007. Almost all of this is depleted, natural and low enriched uranium. Less than 1.5 tonnes is highly enriched uranium (i.e. with 20% or more ²³⁵U). Future arisings are estimated to be about 90,000 tonnes of depleted, natural and low enriched uranium (Defra/NDA 2008b). Uranium is stored in various locations and in many forms including as oxides, hexafluoride, nitrates, carbides and metal. The NDA is developing a strategy for managing its uranic materials and is considering both re-use and disposal options (CoRWM doc 2418). It has R&D in progress for immobilisation options for separated uranium.

“Hex tails” are uranium hexafluoride residue from the production of enriched uranium. The tails are depleted in uranium-235 to levels well below the 0.72 wt% of natural uranium, usually about 0.2 wt%. Uranium hexafluoride is a stable solid at room temperature and pressure but sublimates to a vapour at 56.5 °C. It also gives off hydrogen fluoride, which is hazardous, in contact with water or water vapour. Most of the UK’s holdings of Hex tails are at Urenco UK Ltd., Capenhurst site. Urenco plans to “deconvert” the Hex tails back to uranium oxide (U₃O₈), which is a stable solid, and store it pending a decision on its long-term management. The technology for deconversion has been established in other countries. Urenco aims to build a Tails Management Facility (TMF) at Capenhurst, consisting of a deconversion plant for Hex tails and a uranium oxide store. The planning application has been submitted and it is hoped that the TMF will start operations in 2014.

The uranium oxide could be reconverted to UF₆ if it became attractive to re-enrich it and sell it. Another option is to condition and package the oxide and dispose of it in a geological facility in the UK. CoRWM has been told that Urenco has applied for an LoC as part of the demonstration that such an option would be practicable. This will entail providing evidence that its proposed waste form would be suitable for both storage and disposal. Urenco is also supporting international work that is investigating the possibility of sending the uranium oxide back to the original producers of the ore, for disposal in exhausted uranium mines. This would require an international agreement on the transport of uranium oxide waste from the countries where it is held to the countries where ore is produced.

The Encapsulation of Metallic Uranium Steering (EMUS) Group predates NWRF (section 3.1) and was established by Sellafield Ltd. although many other SLCs participate. Its purpose is to ensure that current and future operations, which require metallic uranium conditioning for treatment, storage and disposal, have a sound technical foundation and to facilitate timely delivery of the plans of the SLCs for site clean-up. It shares information through NWRF, but it is not an official sub group.

There is a need for a UK uranium R&D strategy to include U held by organisations other than the NDA (CoRWM doc. 2520) such as the MoD and Urenco.

5.9 Management of Thorium

There are small amounts of thorium at various NDA sites (eg Dounreay, Winfrith). There is no market for thorium and the current strategy is to treat it as waste for geological disposal. This strategy is straightforward if the thorium is in oxide form (because the oxide is stable and insoluble). However some forms of thorium can be pyrophoric and may require conversion to a more stable form, such as the oxide for their long-term management. It is for the NDA sites to carry out R&D on the management of their thorium holdings (CoRWM doc 2418). Winfrith plans to complete immobilisation of its thorium metal in 2009/10 (NDA, 2009a). Dounreay has liquid thorium nitrate, which will need to be converted to a solid for long-term storage or disposal. The site holds an LoC for the material and plans further R&D prior to its solidification.

6 EMERGING CONCLUSIONS

The NDA has made considerable progress in co-ordinating R&D on conditioning, packaging and storage of higher activity wastes and the management of spent fuels, plutonium and uranium. Its NWRF, which involves all its SLCs and other waste producers, is an appropriate mechanism for determining the topics on which R&D related to waste conditioning, packaging and storage is required. Its R&D programme on plutonium management is a good example of co-ordination between the NDA, the NNL, universities and other organisations. However, these are bottom-up approaches and need to be supplemented by mechanisms to produce prioritised R&D strategies within the NDA and for the UK as a whole.

The NDA's mechanisms for developing high level R&D strategy are evolving but at an early stage. We do not understand how the approach of the NWRF and the SLCs feeds into the RWMD R&D strategy or how this feeds into the NDA's overall R&D strategy. There is no obvious mechanism for coordinating the NDA's R&D strategy with those of MoD, BE, the regulators and others, nor is there a means of setting national R&D priorities at the strategic level.

A clear process is needed for checking that there is a suitable balance between strategic/fundamental research and short-term needs driven R&D, that the R&D is funded in a timely manner, that it is done to acceptable

standards and that it has led to improvements in the UK's radioactive waste management programmes. A procedure should be in place to close the R&D loop. This scheme needs to be open, transparent, wide ranging and industrially relevant and should involve all relevant stakeholders (NDA, Government, regulators, MoD, and all the nuclear site licensees).

Recommendations from these conclusions and additional recommendations will be made in our report to Government on R&D, due in October 2009.

7 REFERENCES

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2464	Note of meeting with EA and SEPA on waste conditioning, packaging and storage, 17 October 2008
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2488	Report of 30 October 2008 PSE event
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2500	Report to Government on Interim Storage of Higher Activity Wastes and the Management of Spent Fuels, Plutonium and Uranium, March 2009
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2519	Note of Institute of Physics / CoRWM Interim Storage Meeting, 26 November 2008
2520	Note of meeting with HSE and EA on spent fuels, plutonium and uranium, 9 December 2008

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2523	Note of meeting with NDA on spent fuels, plutonium and uranium, 11 December 2008
2524	Note of meeting with RCUK, Swindon, Dec 3 rd 2008
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8 ACRONYMS

AGR	Advanced Gas cooled Reactor (A type of reactor with a graphite core, and uranium oxide fuel in steel cladding with a graphite sleeve.)
AWE	Atomic Weapons Establishment (at Aldermaston). (AWE plc is the company that runs Aldermaston and Burghfield under contract to the Ministry of Defence.)
ASCC	Atmosphere assisted Stress Corrosion Cracking
BE	British Energy (now owned by Electricite de France, EdF)
BNFL	British Nuclear Fuels Limited
BNG	British Nuclear Group
BNGSL	BNG Sellafield Ltd.
BWR	Boiling Water Reactor
CANDU	CANada Deuterium Uranium (a reactor with natural uranium fuel and heavy water (deuterium oxide) as the moderator and coolant)
COGER	Coordinating Group on Environmental Radioactivity (informal NERC advisory group)
COMARE	Committee on Medical Aspects of Radiation in the Environment (government advisory committee)
CoRWM	Committee on Radioactive Waste Management
Defra	Department for Environment, Food and Rural Affairs
DIAMOND	Decommissioning, Immobilisation And Management Of Nuclear wastes for Disposal (RCUK funded university R&D nuclear waste consortium)

DFR	Dounreay Fast Reactor
DfT	Department for Transport
DRP	Direct Research Portfolio (NDA-funded research programme)
EA	Environment Agency (for England and Wales)
EMUS	Encapsulation of Metallic Uranium Steering group (established by Sellafield Ltd)
EPS	Encapsulated Product Store (at Sellafield, there are three stores: EPS1, EPS2 and EPS3)
EPSRC	Engineering and Physical Sciences research Council
EU	European Union
FHP	Fuel Handling Plant (at Sellafield)
GBq	gigabecquerel (a unit of radioactivity)
GBq/t	gigabecquerels per tonne
GDF	Geological Disposal Facility
GOCO	Government Owned Contractor Operated
HAWS	Higher Activity Wastes Strategy
HLW	High Level Waste
HPA	Health and Protection Agency
HSE	Health and Safety Executive
IAEA	International Atomic Energy Agency (a United Nations agency)
ILW	Intermediate Level Waste
KNOO	Keeping the Nuclear Option Open, RCUK funded university research consortium
KTA	Knowledge Transfer Account (EPSRC funding scheme to encourage knowledge transfer from universities to industry)
LoA	Letter of Arrangement group (EPSRC group with industry, regulator representatives advising on nuclear research activities)
LoC	Letter of Comfort (or Compliance)
LTP	LifeTime Plan
LWR	Light Water Reactor
m	Metre
m ³	cubic metre
MEP	Magnox Encapsulation Plant (at Sellafield)
MoD	Ministry of Defence
MOP	Magnox Operating Plan (the current plan is the eighth, MOP8)
MOX	Mixed OXide fuel (contains uranium and plutonium oxides)
MRC	Medical Research Council
MRP	Magnox Reprocessing Plant
MRWS	Managing Radioactive Waste Safely (Government programme to find a safe solution to managing UKs higher activity wastes)
NDA	Nuclear Decommissioning Authority
NDARB	NDA Research Board on Nuclear Decommissioning and Waste Clean Up
NEA	Nuclear Energy Agency (specialised agency within the Organisation for Economic Cooperation and Development (OECD))
NERC	Natural Environment Research Council
NII	Nuclear Installations Inspectorate (part of HSE)
NNL	National Nuclear Laboratory (was Nexia Solutions)

NuSAC	Nuclear Safety Advisory Committee (now disbanded, advised HSE)
NRI	Nuclear Research Index (HSE scheme)
NWAT	Nuclear Waste Assessment Team (part of the EA)
NWRF	Nuclear Waste Research Forum (a group convened by the NDA)
OCNS	Office of Civil Nuclear Security (part of HSE)
PSE	Public and Stakeholder Engagement
PWR	Pressurised Water Reactor
R&D	Research and Development
RCUK	Research Councils UK (coordinating body for the Government's research councils who fund university research)
RWMD	Radioactive Waste Management Directorate (of the NDA)
SEPA	Scottish Environment Protection Agency
SIXEP	Sellafield Ion Exchange Effluent Plant
SF	Spent nuclear Fuel
SLC	Site Licence Company (a company that runs an NDA site, under contract to the NDA, and holds the nuclear site licence)
SMS	Strategy Management System
SNIFFER	Scotland and Northern Ireland Forum for Environmental Research
TBuRDS	Technical Baseline and underpinning R&D Documents
tHM	Metric tonnes of Heavy Metal (uranium and plutonium)
THORP	Thermal Oxide Reprocessing Plant (at Sellafield)
TMF	Tails Management Facility (to be built at Urenco's Capenhurst site)
UCL	Urenco Capenhurst Ltd
UKAEA	United Kingdom Atomic Energy Authority