Nuclear Decommissioning Authority

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Position Paper of NDA Research Board NDARB016

Review of NDA's Spent Fuels R&D Programme Issue 1

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About the Independent NDA Research Board

Despite its title, the Research Board has terms of reference which cover the Research and Development (R&D) interests for waste management and decommissioning of the UK, not just the that of the NDA. Given the scale of the NDA's work in this sphere however, much of its time is dedicated to the NDA's own programme. Although the Board works cooperatively with the NDA, which provides the secretariat, it is independent. Neither its programme of work or published opinions have to be agreed with the NDA. Its membership comprises experts in the field and senior representatives of key stakeholder organisations such as Government departments and regulatory bodies. Its role is advisory only, reporting to the main NDA Board and to Government departments via their Chief Scientific Advisors. Further information on the Research Board can be found on the NDA website (www.nda.gov.uk).

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Contents

1 Introduction

The reader is asked to note that this Position Statement is based on information provided to the independent Research Board, up to the date of its meeting in October 2014. Any R&D developments after that date are not part of the considerations presented here.

This review is intended to cover only Nuclear Decommissioning Authority (NDA) stocks of currently existing or committed spent fuel. Hence issues not covered here are any future potential fuels from the new nuclear build programme in England and Wales or potential fuels containing plutonium from future reuse of separated plutonium stocks. Neither is any fuel owned by the Ministry of Defence considered or fuel bearing materials currently present in Sellafield legacy ponds and silos.

Information on the UK's stocks of currently existing and committed spent fuels is given in NDARB012. NDA categorises its spent fuel into three groups, Oxide, Magnox and Exotics. This review has been conducted for each of these three groups against a series of questions as detailed in the following text. Radioactive Waste Management Ltd's (RWM) Research and Development (R&D) on spent fuel disposal is treated separately in Section 7, as much of it applies to all three fuel groups.

In summary, the NDA's process for establishing and monitoring its R&D programmes for spent fuels is:

- Establish a clear strategy (having explored a full range of practicable options).
- Establish the major risks to this strategy and the fall back option(s) to address the risks.
- Develop Technology Roadmaps and supporting R&D tables, which identify key milestones and decision points and how R&D feeds into these at appropriate times.
- Review the Technology Roadmaps on at least an annual basis.
- For Advanced Gas-Cooled Reactor (AGR) fuel, monitor progress via the AGR Technical Forum and, at a higher level, via the Independent Research Board.
- For other fuel streams, monitor the progress at high level via the Independent Research Board. Consider a future expanded role for the Technical Forum for more detailed level reviews.

2 Question 1

On the basis of the evidence available to the Research Board, does the Board consider the process for developing the R&D programme is soundly based?

2.1 Oxide Fuels

- NDA owns all spent AGR fuel (including any future arisings) from January 14th 2005 onwards (the British Energy restructuring date) but is also contracted to manage all AGR spent fuel generated in advance of this date. NDA is also contracted to reprocess a much smaller amount of foreign oxide Light Water Reactor (LWR) fuel, see 2.1.2.
- Most of NDA's directly funded R&D on spent fuels of all types in recent years has focused on AGR fuel. This level of R&D activity reflects the fact that a major strategic change, from reprocessing to long-term storage, is planned to occur before the end of this decade.
- The strategy is:
    - Reprocess existing contract commitments (i.e. including LWR fuel) as soon as reasonably practicable, expected to be by 2018.

- Thereafter close the Thermal Oxide Reprocessing Plant (THORP) and wet store AGR fuel for an extended period.
- Monitor the fuel condition and, as a contingency, move to dry store if necessary.
- Eventually direct dispose of the unreprocessed AGR spent fuel to a Geological Disposal Facility (GDF)[1], expected to start around 2075.

The option to reprocess in future is not completely foreclosed, should this subsequently prove to be the more attractive route (but note that this would, of course, need the construction of a new reprocessing plant at that time or contracting to purchase a reprocessing service elsewhere; either of these would be an expensive option).

2.1.1 AGR Fuels

- AGR station ponds are small and not capable of holding large quantities of fuel. The 2018 target for THORP closure is driven by the need to have reprocessed sufficient fuel to have the pond space for lifetime arisings from the AGRs, including life extension, and concerns about the need for a major THORP refurbishment should the life extend much beyond this point.
- The Technology Roadmap for AGR fuel is well developed and shows the timeline for the future management of spent AGR fuel, key milestones and decision points in the management strategy for the fuel, and how R&D work feeds into these at appropriate times.
- Current experience of pond storage times is around 10 years at Sellafield, although some fuel has been stored for around 25 years. A key milestone is expected to be about 2038, when all spent AGR fuel will have been received onto the Sellafield site and marshalled into the THORP Receipt and Storage (TR&S) pond. At that point spent AGR fuel will have been stored in the TR&S pond for about 20 years, which is within the period covered by current experience. Assuming that a period of about 10 years would be needed to design, build and commission contingency facilities and infrastructure, a decision to adopt an alternative to extended wet storage would need to be taken by 2028.
- On the basis of these revised intentions, pond storage will be in use until 2038 and probably until around 2085. Hence the 25 years of current storage experience is in comparison to the 70 years or so that will be required on the revised strategy.
- Sellafield Ltd has conducted a study to select the best interim storage method, which the NDA arranged to have independently assessed. This independent assessment concurred with the NDA view that dry storage must be maintained as a fallback.
- The South of Scotland Electricity Board and, to a more limited extent, the Central Electricity Generating Board and their successors conducted a great of work on drying and then dry storage facilities for AGR fuel. NDA has had access to all of this work. Some members of the teams that worked on these technologies have also been interviewed.
- Shorter term milestones feed into the intention to implement caustic dosing in the TR&S in 2018, and to have the interim storage and monitoring regime established and underpinned by 2019.

[1] Note that, while the policy in England and Wales is to proceed with the development of a deep geological disposal facility for higher activity wastes, the policy of the Scottish government is for near surface storage near to the sites where waste is generated.

NDA recognises the following themes for supporting R&D:

- Understanding the impact of design and irradiation changes on the characteristics of the spent AGR fuel that will be committed to interim storage (The AGR fuel design and burn-up have evolved over time).
- Developing plans for how spent AGR fuel will be interim stored in the TR&S pond.
- Developing plans for how spent AGR fuel and its storage environment will be monitored during interim storage (including potential introduction of innovative techniques).
- Improving the fundamental understanding of how spent AGR fuel behaves in wet and dry storage.
- Increasing knowledge and experience of fuel drying and dry storage systems as an alternative to pond storage.
- Developing the understanding of the interface with the requirements for spent AGR fuel disposal in the GDF.

These are being explored in a cooperative programme by both Sellafield Ltd and the NDA.

NDA also recognises in its work:

- The need to capture and build on the 80s & 90s work on cladding corrosion.
- The need to maintain skills in the wet storage/AGR fuel corrosion area. In part the AGR programme is designed to develop the next generation of experts in this topic. The NDA has also been contributing to the sponsorship of some international programmes (ACSEPT, ASGARD and SACSESS) with a view to maintaining high level skills in nuclear fuel technology.

2.1.2 LWR Fuels

The position with respect to LWR fuel is simpler. At present only EDF's Sizewell B is generating spent LWR fuel in the UK. The EDF strategy for spent fuel is on site storage pending subsequent direct disposal in the long term; NDA has no responsibility for any of this fuel. There are relatively small volumes of foreign "conventional" spent LWR fuel, which the NDA is contracted to reprocess. The intention is that this will all be reprocessed in THORP. There is also a much smaller quantity of other foreign LWR fuel that cannot be reprocessed at Sellafield (*e.g.* mixed oxide fuel), which will need to be treated in the Exotic Fuels group. In the event (e.g. failure of THORP) that these LWR fuels need long term storage, there is very significant world experience of wet storage of such zircalloy clad fuels, which are highly robust against corrosion.

2.1.3 Research Board's Position

- The strategy is clear and a credible fall back option in well advanced.
- The AGR Technology Roadmap is well established and the milestones and decision points identified.
- The programme for the under-pinning R&D is established and credible.
- The intention to monitor the Technology Roadmap at least annually and to monitor the progress of delivery via the AGR Technical Forum is sound.

Recommendation: The intention to move to caustic dosing of the storage pond in 2018 is near term and critical. Although there is good experience of this regime on the Sellafield site it is imperative that the R&D work to underpin this change is completed as soon as possible. The Board also recommends a thorough peer review of the evidence before such a change is implemented.

Recommendation: The NDA has already made efforts to collect the earlier R&D on fuel drying and dry storage conducted by the former electricity utilities in the UK; there should be effort to ensure this earlier work is not lost.

2.2 Magnox Fuels

The key issue for Magnox fuel is that long-term pond storage is very difficult compared to oxide fuel. The cladding and metallic fuel itself are more chemically reactive and the experience is that significant and severe corrosion can occur.

- The Strategy is:
    - Reprocess the whole of the Magnox inventory in the Sellafield Magnox reprocessing plant. However, this plant is now very elderly (it began operation in 1963) and there is a risk that it will not remain operable until all the spent fuel has been reprocessed. The current estimated time for completion is 2018-2020.
    - Establish the contingency option of dry storage (either in reactor if, at some reactor sites, defueling has not been completed or in purpose designed dry storage facilities) in the event of either sudden irreversible loss of reprocessing capability or more gradual loss of capability. This needs to be implementable on a timescale commensurate with the satisfactory pond storage time of the fuel.
    - This contingency only maintains the fuel in a safe condition which minimises deterioration. Once the fuel is in dry storage there is a longer term need to develop the capability for direct disposal.
    - As with AGR fuel, the option to return to reprocessing is not fully foreclosed.
- The fundamental elements of R&D have therefore been directed at:
    - Developing drying technology such that wet stored fuel can be retrieved, dried and put into long term dry storage while direct disposal capability is fully developed.
    - Exploring, as a back up and alleviating technology, continued wet storage for extended periods of around 10 years or more.
    - Exploring continued in reactor storage for those cases where fuel has not been discharged.
    - On a less urgent timescale, developing the capability for direct disposal of Magnox spent fuel.
- There is high confidence that both the vacuum drying and the in reactor storage contingencies are deployable. Supporting elements have been to accelerate the deployment timescale of the vacuum drying contingency.
- However, it is believed that some 2% of the fuel inventory cannot be successfully dried. Deterioration of such fuel in the event of forced long term storage could present a difficult and expensive problem.
- Other R&D work in this area is focused on understanding the resilience of Magnox reprocessing plant and associated infrastructure. Sellafield Ltd has a Magnox Throughput Improvement Programme (MTIP) the intention of which is to maximise the reprocessing throughput, therefore allowing the Magnox Operating Programme to finish as soon as possible.
- There is also the issue of the “end game” for the reprocessing plant which, to a more limited extent, also applies to THORP. These plants were designed for bulk reprocessing and will be

difficult and expensive to use for "tail end" small quantities. The intention to reprocess "all" Magnox or AGR fuel through these plants may therefore need to be tempered with a degree of practicality. The closure of these plants is not many years away. If there is a need to leave some Magnox spent fuel unreprocessed, there is an advantage for this being Wylfa fuel because the fuel discharge route and storage provisions at this site are dry; the fuel is not wetted until flask dispatch to Sellafield. Hence there is the potential for a drying stage to be avoided.

2.2.1 Research Board's Position

- The strategy is clear and a credible fall back option is under development.
- Whilst the Magnox technical baseline is well developed, a Magnox Technology Roadmap document has not been prepared but there is a clear intention to progress this.
- The risks to the basic strategy (*i.e.* reprocess all fuel) have been thought through and the R&D to establish the contingent approach appears to be addressing all the right issues, with the above noted exceptions (2% difficult to dry fuel and tail end quantities). The intention to monitor the Technology Roadmap annually is sound.
- The Research Board accept the argument that development of direct disposal capability for Magnox fuel (some research for which is ongoing) is not an urgent matter although it is probably a difficult issue to resolve.

Recommendation: The Magnox Throughput Improvement Programme should be approached with caution; the objective should be for the plant to last until all the fuel has been reprocessed. If this takes a little longer, is it worth a small time extension to avoid stranded fuel.

Recommendation: Consideration should be given to small tail end quantities of Magnox (and perhaps also to AGR) fuel. R&D may be needed to assess the practicalities of using the reprocessing plants for these or for how they can be otherwise addressed.

Recommendation: The Magnox Operating Programme should consider the merits of leaving some Wylfa fuel until last if there is an acute risk that the reprocessing plant will be unable to complete all fuel. Similarly there are advantages to any "tail end" fuel being that from Wylfa.

2.3 Exotic Fuels

- Spent fuels have arisen from numerous research and prototype reactors that are now shut down and being decommissioned. These Exotic (or non-standard) Fuels comprise relatively small amounts, but of a diverse range of prototype and experimental fuels of variable enrichment (uranium and plutonium) including:
    - Dounreay Fast Reactor (DFR) breeder; lightly-irradiated metallic uranium.
    - Prototype Fast Reactor (PFR); very high burn-up irradiated oxide and carbide fuel, clad in stainless-steel.
    - Windscale Advanced Gas-Cooled Reactor (WAGR); the predecessor of commercial AGR fuel, but including some higher enrichment fuel.
    - Steam Generating Heavy Water Reactor (SGHWR).
    - Post Irradiation Examination (PIE) materials and experimental fuels.
    - Highly Enriched Uranium (HEU) fuels.

- Due to the diverse nature of the fuels, management routes for Exotic fuels necessarily have to be dealt with on a case-by-case basis, albeit with an aspiration to use existing management routes. The intention is to take advantage of THORP and Magnox reprocessing facilities to manage Exotics whenever possible.
- Spent fuel from WAGR and SGHWR is stored at Sellafield pending reprocessing.
- Small quantities of relatively low irradiation spent fuel that are not planned to be reprocessed have already been designated as waste and are reported as such in the UK radioactive waste inventory. These comprise spent fuels from the Windscale Piles, Graphite Low Energy Experimental Pile (GLEEP), Dragon and Zenith reactors, plus small quantities of mainly prototype commercial fuels.
- Development has been focused on four objectives:
    - Reprocessing of DFR breeder fuel in the Magnox reprocessing infrastructure at Sellafield.
    - Encapsulation in cement of Dragon fuel in the Magnox Encapsulation Plant at Sellafield.
    - The consolidation of fuel at a reducing number of storage sites, as facilities permit, to improve the economy of longer term management.
    - Identification and confirmation of the population of extant Exotic fuels, requiring future management.
- NDA has funded some R&D on Exotics recently, although to a fairly small extent. A moderate increase in R&D on Exotics is expected over the next few years, reflecting the fact that management options for these fuels have to be developed. It is likely in the longer term that a flexible, small scale advanced reprocessing/treatment plant will be needed.
- This is a complicated area in that there are so many different fuels to take into account. In as much as there is a strategy it is that in the coming years NDA plans the following R&D work on Exotic fuels:
    - Confirming and aligning research reactor review data against the site licence companies' stockholding records to produce a definitive database of Exotic fuels, in order to underpin future management options.
    - Justification for the long-term storage of Exotic fuels; this may include synergies (on monitoring and inspection) with AGR and other oxide fuels.
    - Preliminary assessment of the storage/packaging options and potential treatment routes for the Exotic fuels which are anticipated to challenge standard methods of long term storage or disposal in a GDF.

2.3.1 Research Board's Position

- The Board supports the need for this work, the first two points of which it regards as urgent. In comparison to the amount of work on AGR spent fuel storage, the current Exotic fuels position seems too underdeveloped. The focus on the large quantities of AGR fuel that need to be managed is understandable, but work on the Exotics should not be allowed to lag too far behind.
- The Board encourages the NDA in its intention to produce the Technology Roadmap and supporting R&D tables for Exotic fuels.

Recommendation: While the NDA believes that the Exotic fuels are generally stable from a corrosion perspective (most of them having been stored at various locations within the UK for many years) it seems to the Board urgent to confirm both the overall inventory characteristics and that the current storage conditions are appropriate.

Recommendation: If the intention is to use the THORP and the Magnox reprocessing plants whenever possible for these materials, both are closing in significantly less than a decade. It must therefore be an urgent matter to identify those Exotic fuels for which there is a possibility to process by these two routes.

Recommendation: As R&D programmes are developed to deal with treatment of the more difficult Exotic fuels it would be appropriate to have close liaison with the Nuclear Innovation and Research Advisory Board (NIRAB). It may be that such R&D (for example pyro-processing) would have similar interests as those of NIRAB for advanced fuel cycles.

3 Question 2

Does the Research Board consider the mechanisms for review of the R&D programme are appropriate and effective? (They could be more than adequate if the programme is subject to excessive review from too many directions.)

3.1 Overview

Spent Fuel is a topic with more security and commercial aspects than most others; the Board recognises that these make sharing of information more difficult. The information provided by the NDA is as follows:

Higher Level and More General Reviews

- The Strategy Development and Implementation Group (SDIG), cover all NDA's strategy areas, at which NDA has provided updates on R&D activities having a key impact on strategic issues.
- The NDA Research Board reviews the R&D programmes associated with NDA strategic themes (*e.g.* this review) and makes recommendations to the NDA Board on the appropriateness of the programmes.
- Relevant R&D which directly connects with strategic issues is shared at Site Strategy Committee meetings, with separate meetings between NDA and the SLCs *e.g.* Sellafield Ltd and Dounreay Site Restoration Ltd. Such meetings take place approximately six times per year with each SLC.

More Specific Spent Fuel Reviews

- The scope of R&D commissioned via Lot 4 of NDA Direct Research Portfolio (Spent Fuels and Nuclear Materials) is reviewed by NDA's Internal R&D Board, which meets monthly.
- NDA meets with regulators (Office of Nuclear Regulation, Environment Agency, Scottish Environment Protection Agency) at the Spent Fuels and Nuclear Materials Topic Overview Group (TOG) at least four times per year. Although these strategy meetings are not dedicated to R&D, NDA does update this group on relevant R&D activities.
- On AGR fuel: NDA, EDF Energy, Sellafield Ltd and International Nuclear Services Ltd meet at the AGR Operating Plan Working Group, at least six times per year. Relevant R&D pertaining to AGR fuel is discussed at this meeting, which is focused on the transfer of fuel from the AGR stations to Sellafield.
- Regarding storage of AGR fuel at Sellafield, the AGR Pond Management Meeting, led by Sellafield Ltd, and attended by NDA and regulators discusses relevant R&D issues.

- There is also an 'Oxide Operations Strategic Regulatory Forum' at least three times per year, with a similar audience.
- Over the past three years NDA has also held a 'Spent Fuel Technical Forum'; representatives from NDA, RWM Ltd, Sellafield Ltd, and NDA's Lot 4 supply chain organisations (Amec, Cavendish Nuclear and NNL) attend this meeting. The purpose of the meeting is for the attendees to give an overview of spent fuel-related work they have been involved in recently, in order to stimulate discussion and sharing of ideas, and to suggest further areas/ideas for work. The most recent such meeting, focusing on AGR fuel, was held in February 2014.
- The NDA has also established an AGR Technical Forum and intends to extend this forum to cover R&D on all spent fuels. On the related issues of spent fuel disposal to a GDF, RWM Ltd is considering setting up an advisory panel of international fuel experts.
- There is currently no direct equivalent of the Nuclear Waste Research Forum (NWRF) Working Groups for R&D on spent fuels.

3.2 Research Board's Position

- The development of the Technology Roadmaps and supporting R&D tables for all spent fuel types is an important step in facilitating appropriate review of the spent fuels R&D programme.
- There are numerous meetings in which such R&D is currently discussed, with the prospect that more may be added. There is a danger that the NDA's limited spent fuel expertise is largely consumed by providing information to and attending these meetings.
- The Board has previously discussed a possible NWRF group on spent fuel. There are a limited number of sites for which spent fuel R&D issues are relevant. The proposal for expansion of the AGR R&D Forum seems the much more attractive approach. The Forum could then be in an analogous position to that of the Technical Assurance Panel which advises RWM Ltd on the GDF programme.

Observation: In principle, the intention of expanding the AGR Technical Forum to cover R&D of all spent fuels appears attractive; monitoring of storage conditions, for example, is a topic which extends across all spent fuel types. However, before this forum's remit is expanded it seems highly desirable that the terms of reference and membership of the numerous existing groups are reviewed and rationalised, with a view to appropriately minimising the meetings at which spent fuel R&D issues are discussed. Consideration should also be given to avoiding the need for separate NDA and RWM groups.

4 Question 3

Recognising the work of others (e.g. the Technical Assessment Panel, CoRWM, regulators, the NWRF etc), are there still areas where the Research Board believes there could be gaps in the R&D programme or where it would like to test for gaps?

The Board notes the reawakened UK interest in advanced nuclear systems following the publication of "The Nuclear Industrial Strategy – The UK's Nuclear Future" (BIS/13/627). There may therefore be future R&D value in some samples of the currently stored spent fuel from earlier research programmes, for example fast reactor fuels and Dragon fuel, both of which may have some potential R&D value for Generation IV advanced systems. It would be disappointing if these fuels were reprocessed or otherwise prepared for disposal without consideration of whether limited quantities should be archived. Which of these fuels would be of value, how and where they would be stored and from where funding

for this would come are matters that would need to be resolved. Although this is strictly outside of its terms of reference, the Board would like to see NDA engaging with the Nuclear Innovation and Research Advisory Board to see whether there is value in the latter developing an archiving strategy. There is currently a programme for encapsulating spent Dragon fuel (of potential value for Gen IV High Temperature Reactor Systems R&D) which presents the most urgent case in which the archiving opportunity might be lost.

4.1 Research Board's Position

Observation: There may be merit in NIRAB sponsoring an archiving strategy for limited quantities of spent fuel from earlier R&D programmes. NDA should open discussions with NIRAB before the opportunity is lost.

Recommendation: As discussed earlier in this document, the Board would like to see:

- Appropriate R&D to resolve the issue of the 2% of the Magnox fuel inventory, for which it is believed drying cannot be achieved in order to satisfactorily dry store the fuel. Further investigation, for example, of the US work to dry store the Hanford K basin fuel may be appropriate, much of which was in extremely poor condition.
- Early resolution of the total Exotics inventory characteristics and confirmation of, or work to establish appropriate long term storage.
- Early R&D to identify those Exotics for which use of THORP and the Magnox reprocessing plants may be appropriate, before the opportunity is lost.

Recommendation: In its earlier review of the RWMD R&D programme, the Board were pleased to see RWMD's efforts with respect to the establishment of a Knowledge Base and long term data management. While the timescales for spent fuel management and disposal are not as lengthy, they do extend over many decades. The Board would like to see that the good practices being adopted elsewhere are also being employed for the long-term in the field of spent fuel management.

5 Question 4

Does the Research Board consider the R&D programme is adequately communicated to the NDA's stakeholders?

5.1 Research Board's Position

- The Board considers that the communication issues for spent fuel management are not as demanding as those for development of a geological disposal facility, the R&D programme for which it recently reviewed. Nevertheless this is an important area for which stakeholder communication needs to be carefully considered.

Observation: As discussed above in the response to second question, there are numerous meetings at which many of the key stakeholders are present. The Board believes there is a need to consider a rationalisation of these meetings. The opportunity to do so would be facilitated if the AGR Technical Forum is expanded to embrace other spent fuel streams, at which many of the key stakeholders are likely to be in attendance.

Observation: The Board also notes that, over the past three years NDA has also held a 'Spent Fuel Technical Forum' with a wide range of stakeholder attendees. The Board supports this as a good practice which should continue in the future.

6 Question 5

Is the R&D programme robust to change?

6.1 Research Board's Position

- The Board notes and supports the intentions to develop the Technology Roadmaps and supporting R&D tables for all spent fuel streams and to review these on an annual basis. Once these intentions have been fulfilled the associated key milestones and decision dates can be regularly reviewed to ensure the strategies continue to be robust.
- The Board is pleased to note that the strategies for AGR and Magnox fuels already address the risks that the main strategic approach proves not to be implementable and are hence robust to change.

Recommendation: As noted above, the strategic approach for Exotic fuels is under-developed at present. In particular, the assumption that current storage arrangements for all such fuels are appropriate seems unproven. While work is intended in this area, currently the programme for Exotic fuels is not robust to change and, as indicated earlier, in the Research Board's view some aspects need more urgent attention.

Recommendation: The NDA is dependent on a singleton in house expert in this area. Given the importance of the topic NDA does not appear to be robust against the potential risk from the loss of this expert. The NDA should review its response to this potential risk.

7 RWM's R&D on Spent Fuel Disposal

Research work relevant to the disposal of spent fuel includes consideration of the aspects of container evolution, waste form evolution, criticality safety and issues associated with the disposal of high heat generating wastes. Concepts for the disposal of spent fuel are generally based on:

- Long containment periods in the engineered barrier system (EBS) (of the order of 10,000s of years or significantly longer), achieved through the combination of the properties of suitably designed waste containers (typically copper or carbon steel) and surrounding buffer materials (typically clays).
- Relatively slow radionuclide release rate from the waste form (i.e. the spent fuel if disposed without further treatment) once containment in the EBS has been breached;
- Long transport periods of any radioactive isotopes (and other chemotoxic species) released from the waste form through the host rock (either in the groundwater or in any gas phase).

7.1 Container Evolution

The high level objective of the current research programme in this area is to understand the likely durability of a variety of candidate container materials in relevant scenarios and the potential effect of pre-closure periods on the behaviour during the GDF post-closure period.

Work on the durability of waste containers for the disposal of spent fuel is important in order to develop a general understanding of the evolution of a GDF as well as to evaluate the containment function provided by the EBS. This is a key safety function in most disposal concepts for spent fuel. A minimum

durability of the order of 1,000 years is generally required from the waste container to physically contain radionuclides during the 'thermal period', a period in which the radiotoxicity is highest and the temperature of the environment is such that it may result in higher transport rates away from the EBS, should any radionuclide be released from the waste.

Additional research is focusing on understanding the effect that water entrained in storage / disposal containers due to previous pond storage operations would have on the potential for internal pressurisation and structural damage of waste containers. Initial work focusing on disposal of waterlogged spent AGR fuel has been completed. Overall, at completion, this research will inform requirements on the levels of dryness of spent fuel upon containerisation, on the maximum amount of waterlogged fuel that may be acceptable in a disposal container, and on changes in container design (*e.g.* to increase gas expansion volumes) that may mitigate relevant effects.

7.2 Waste Form Evolution

Work on the dissolution and leaching behaviour of spent fuel is important to develop a general understanding of the evolution of a GDF containing spent fuel. In particular, it is important to quantify the likely release of radionuclides in the geological barrier at late times in the expected evolution of the disposal system (*e.g.* 10,000-100,000s of years, the time at which, depending on the disposal concept, perforation of the waste container is expected). Given the relatively high impact of this research, the limited amount of work carried out to date in the UK, and the unique nature of some key fuel streams to the UK, this area is considered of high priority within the RWM generic research programme.

Current research effort focuses on spent AGR fuel which, according to the current strategy, may require disposal in relatively large amounts. This fuel is unique to the UK and hence, from a disposal point view, has been less studied internationally. Future plans include work on spent Pressurised Water Reactor (PWR) fuel (for which a large amount of relevant information is available internationally) and, depending on strategic developments and the outcome of disposability assessments, on Mixed Oxide (MOX) fuel, Magnox fuel and Exotic fuels.

The high level objective of the current research programme in this area is to compare the leaching characteristics of spent AGR fuel with that of fuels which have been better studied internationally (LWR fuels). A strong similarity in the behaviour of these fuel types would give the opportunity to capitalise on existing information.

In parallel with such work RWM are exploring the possibility of carrying out leaching /characterisation measurements on legacy WAGR fuel being retrieved as part of ongoing decommissioning projects at Sellafield. A key objective of this work will be to evaluate chemical changes which have occurred in the fuel as a result of prolonged exposure to pond water (the pond contains fuel elements which have been punctured or cut as part of PIE operations and subsequently exposed to pond water for about forty to fifty years). This could provide significant confidence in the understanding of evolution / leaching processes over longer timescales than those generally accessible experimentally.

Additional exploratory work (co-funded by the Engineering and Physical Sciences Research Council (EPSRC)) is being carried out in UK Universities (Cambridge, Imperial College and Lancaster, with support from the National Nuclear Laboratory (NNL) to evaluate the benefits of employing spent fuel simulants to develop a better mechanistic understanding of the characteristics and leaching behaviour of AGR fuel.

7.3 Criticality Safety

A GDF will include disposal of fissile materials which could hypothetically, under certain conditions, lead to a nuclear criticality. Because of this, demonstration of criticality safety forms an important part of the GDF safety case. In particular the Environment Agency Guidance on Requirements for Authorisation

(GRA) for a GDF requires a demonstration that "the possibility of a local accumulation of fissile material such as to produce a neutron chain reaction is not a significant concern". In addition, the GRA states that the "environmental safety case should also investigate, as a 'what-if' scenario, the impact of a postulated criticality event on the performance of the disposal system".

RWM need to be able to underpin the assertion that post closure criticality is a low likelihood and low consequence event. It has recently (2011- 2014) completed two research contracts 'Likelihood of Criticality' and 'Modelling of Consequences of Hypothetical Criticality', which confirm both the low likelihood and low consequence claims.

7.4 Heat Generating Waste

In the context of waste disposal, high heat generating wastes are materials whose radiogenic heat at the time of disposal is likely to be sufficiently high to require specific consideration in the development of suitable disposal concepts and engineered barrier system designs. These include spent fuels even after significant periods of cooling in storage.

For these materials, disposal concepts usually envisage designs in which long periods of radionuclide containment are achieved through suitable combinations of container and buffer materials. High temperatures can be detrimental to important properties of typical buffer materials, particularly clays (but potentially also cements).

In order to identify potential solutions for the disposal of fuel, RWM has been integrating information from relevant technical areas as well as initiating new work. These new tasks include specific R&D aimed at:

- Refining estimates of the thermal output of the spent fuel and waste packages.
- Exploring options for managing GDF temperature through suitable design (including consideration on 'mixing/matching' of fuel types in a waste packages and GDF spacings/layout).
- Evaluating the likely impact of higher temperatures on candidate EBS components (particularly buffer materials).

7.5 Research Board's Earlier Position Statement on RWMD's Overall R&D Programme[2]

In summary, the response to the Board's standard questions was as follows:

- The process for developing the R&D programme was soundly based.
- The mechanisms for review were adequate.
- It was unlikely that there were any significant gaps.
- Communication to the non-specialist stakeholders could be improved.

[2] See Position Paper of NDA Research Board, NDARB011, "Review of Radioactive Waste Management Directorate's (RWMD) R&D Programme."

The fifth question on robustness to change was not addressed a that point. In view of the fact that no spent fuel will be disposed to a GDF for many decades, it is clear that the programme is robust to change. While no category of spent fuel has a completed disposability assessment at present, the Board regards the current R&D programme as appropriate to address the future needs.

8 Short Concluding Summary

This short summary of the Board's conclusions on a complex topic can only address the findings at a high level; interested readers are directed to the full text and recommendations. The Board has reviewed the NDA's R&D programme on spent fuel against a set of standard questions.

Q1. On the basis of the evidence available to the Research Board, does the Board consider the process for developing the R&D programme is soundly based?

- Oxide fuel (i.e. AGR and LWR): Yes. The Technology Roadmap for AGR is well developed and shows the timeline for the future management, key milestones and decision points and how R&D feeds into this. Given the significant amount of world experience, the position for the much smaller quantity of LWR fuel for which NDA is responsible is much simpler, with the exception of the even smaller quantities that cannot be reprocessed via THORP (and are hence treated in the Exotics categorisation).
- Magnox Fuel: Progressing.
    - The strategy is clear and a credible fall back option is under development. The Technology Roadmap is not as well developed as that for AGR fuel but there is a clear intention to progress it.
    - Consideration should be given to small tail end quantities of Magnox (and perhaps also to AGR) fuel. R&D may be needed to assess the practicalities of using the reprocessing plants for these or for how they can be otherwise addressed.
- Exotics: No:
    - The Board encourages the NDA in its intention to produce the Technology Roadmap and supporting R&D tables for Exotic fuels.
    - As R&D programmes are developed to deal with treatment of the more difficult Exotic fuels it would be appropriate to have close liaison with NIRAB. It may be that such R&D (for example pyro-processing) would have similar interests as those of NIRAB for advanced fuel cycles.

Q2. Does the Research Board consider the mechanisms for review of the R&D programme are appropriate and effective? (They could be more than adequate if the programme is subject to excessive review from too many directions.)

- The development of the Technology Roadmaps and supporting R&D tables for all spent fuel types is an important step in facilitating appropriate review of the spent fuels R&D programme.
- In principle, the intention of expanding the AGR Technical Forum to cover R&D of all spent fuels appears attractive. However, before this forum's remit is expanded it seems highly desirable that the terms of reference and membership of the numerous existing groups are reviewed and rationalised, with a view to appropriately minimising the venues at which spent fuel R&D issues are discussed.

Q3. Recognising the work of others (e.g. the Technical Assessment Panel, CoRWM, regulators, the NWRF etc), are there still areas where the Research Board believes there could be gaps in the R&D programme or where it would like to test for gaps?

The Board would like to see:

- Appropriate R&D to resolve the issue of the 2% of the Magnox fuel inventory, for which it is believed drying cannot be achieved in order to satisfactorily dry store the fuel.
- Early resolution of the total Exotics inventory and confirmation of, or work to establish appropriate long term storage.
- Early R&D to identify those Exotics for which use of THORP and the Magnox reprocessing plants may be appropriate, before the opportunity is lost.
- As indicated in the response to Q1, liaison with NIRAB should advanced reprocessing technologies be needed for this fuel category.

Q4. Does the Research Board consider the R&D programme is adequately communicated to the NDA's stakeholders?

- As discussed above in the response to second question, there are numerous meetings at which many of the key stakeholders are present. The Board believes there is a need to consider a rationalisation of these meetings. The opportunity to do so would be facilitated if the AGR Technical Forum is expanded to embrace other spent fuel steams, at which many of the key stakeholders are likely to be in attendance.
- The Board also notes that, over the past three years, NDA has held a 'Spent Fuel Technical Forum' with a wide range of stakeholder attendees. The Board supports this as a good practice which should continue in the future.

Q5. Is the R&D programme robust to change?

- The Board notes and supports the intentions to develop the Technology Roadmaps and supporting R&D tables for all spent fuel streams and to review these on an annual basis. Once these intentions have been fulfilled the associated key milestones and decision dates can be regularly reviewed to ensure the strategies continue to be robust.
- As noted above, the strategic approach for Exotic fuels is under-developed at present. While work is intended in this area, currently the programme for Exotic fuels is not robust to change.
- The NDA is dependent on a singleton in house expert in this area. Given the importance of the topic NDA does not appear to be robust against the potential risk from the loss of this expert. The NDA should review its response to this potential risk.