



PROGRESS ON PLUTONIUM CONSOLIDATION, STORAGE AND DISPOSITION

March 2019



BACKGROUND

OVERVIEW OF THE MANAGEMENT AND DISPOSITION OF PLUTONIUM IN THE UK

One of the most complex challenges facing the NDA in dealing with the UK's nuclear legacy is the management and, ultimately, disposition of the inventory of separated plutonium held in the UK (*ref. 1*). The inventory has arisen from large-scale reprocessing of spent fuel from both UK Magnox and AGR power stations but also from overseas energy utilities under historical commercial agreements.

The safe and secure management of civil separated plutonium is a UK government priority. Continued, indefinite, long-term storage leaves a burden of security risks and proliferation sensitivities for future generations to manage. The UK government, working with the NDA, aims to identify a solution that puts the UK's civil plutonium beyond reach. This could be reuse as Mixed Oxide Fuel (MOX) in nuclear reactors or as an immobilised product. This would put the material in a form which both reduces the long-term security burden during storage and ensures it is suitable for disposal in a Geological Disposal Facility (GDF). Implementing a long-term solution for plutonium is essential to dealing with the UK's nuclear legacy.

This paper provides an update on the NDA's progress on developing and implementing the UK's plutonium management strategy in line with UK government policy.

This work covers three distinct areas of focus: Consolidation, Safe and Secure Storage and Disposition.

- **Consolidation:**

The NDA has taken the strategic decision to consolidate the Dounreay plutonium inventory at Sellafield, the UK's centre of excellence for plutonium management, where it can be better managed, and enable progress towards decommissioning and remediation of the Dounreay site.

- **Safe and Secure Storage:**

The NDA is ensuring the continued safe and secure storage of plutonium in the UK by repacking the material for placement in a suite of modern stores, allowing time to develop and implement the right long-term disposition solution.

- **Disposition:**

The NDA is supporting the UK government in the development of a long-term disposition solution to put separated plutonium beyond reach.



PLUTONIUM MANAGEMENT AND DISPOSITION PROGRAMME

CONSOLIDATION

Objective: Ensure all separated plutonium is stored on one site, in a small number of facilities where it can be better managed

Activities: Transfer all of our plutonium stocks to Sellafield

SAFE AND SECURE STORAGE

Objective: Ensure the safe and secure storage of plutonium in stores with enhanced resilience measures

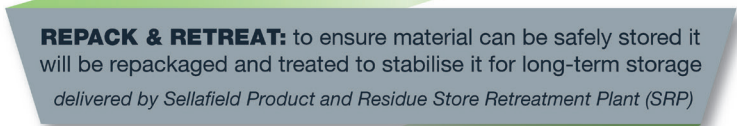
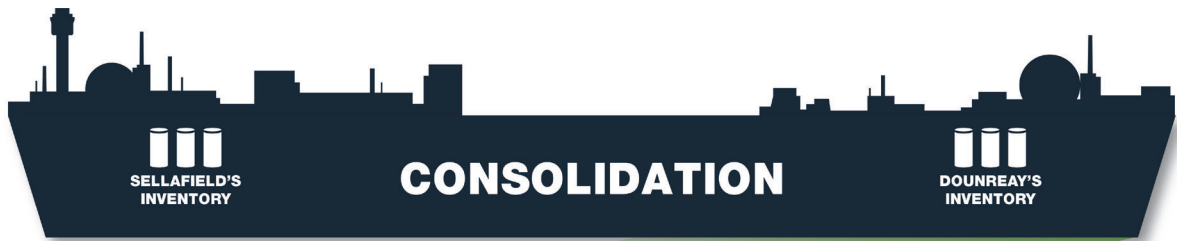
Activities: Repack and retreat plutonium packages to allow time to implement the right long-term solution

DISPOSITION: THE LONG-TERM SOLUTION

Objective: Support government in developing a long-term solution to put separated plutonium beyond reach

Activities: Work with government, developers and technology suppliers on reuse and immobilisation options

The inventory of plutonium in the UK has arisen from the large-scale reprocessing of spent fuel. Reprocessing separates spent fuel into uranium, plutonium and waste products.



CONSOLIDATION

THE CONSOLIDATION OF THE UK'S CIVIL SEPARATED PLUTONIUM INVENTORY AT SELLAFIELD

Reprocessing separates spent nuclear fuel into uranium, plutonium and waste products. The end of spent nuclear fuel reprocessing at Sellafield began with the completion of the THORP reprocessing programme in 2018 and will be followed by the closure of Magnox reprocessing in 2020. The NDA will hold an inventory of around 140 tonnes of separated plutonium by the time reprocessing finishes (*ref.2*). Nearly all of this is held at Sellafield, with a relatively small amount at Dounreay. About 23 tonnes is foreign-owned, largely but not exclusively by Japanese utilities, and is managed under long-term contracts.

Due to the radioactive and fissile nature of the material, plutonium handling and storage requires specialised facilities and stringent management arrangements. The independent Office for Nuclear Regulation (ONR) is responsible for regulating nuclear safety and security across the UK and its inspectors ensure that site licensees (Sellafield Ltd and Dounreay Site Restoration Ltd) meet these stringent requirements. The plutonium inventory held by NDA is stored in line with the requirements of the International Convention on the Physical Protection of Nuclear Materials.

The stored plutonium can only be used for peaceful purposes, and is managed in strict accordance with the UK's voluntary International Safeguards agreements with the International Atomic Energy Agency (IAEA) (*ref.2*). The inventory is closely monitored by EURATOM

and the IAEA. Following the UK's exit from the European Union, the ONR will take over responsibility for ensuring UK compliance with these agreements (*ref.3 and ref.4*).

Following engagement and consultation in 2012, the NDA took the decision to transfer the plutonium inventory currently held at Dounreay to Sellafield (*ref.5*). This means that all significant stocks will ultimately be stored at Sellafield, the UK's centre of excellence for plutonium management. It also enables progress towards the decommissioning and remediation of the Dounreay site.

The NDA initially proposed construction of a specialised facility at Dounreay to package materials for transport to Sellafield. Recently, under a modified approach, material is instead being shipped directly to Sellafield, for treatment and repackaging, before transfer to the modern Sellafield Product and Residue Store (SPRS) for long-term storage. This avoids the requirement for a specialised facility at Dounreay and makes best use of the Sellafield expertise in managing plutonium.

We consider that this new approach offers the best balance of safety and delivery and allows the packages to be treated where there is the greatest expertise and management experience. Sellafield Ltd has already developed a number of facilities for handling this material and is in the process of further developing these capabilities to enable the delivery of the mission. The NDA will prioritise the management and treatment of these materials when they are consolidated at Sellafield.

It will take several decades to implement a solution for plutonium. In the meantime, therefore, we have decided to consolidate all of the inventory on one site.

STORAGE

UNDERPINNING LONG-TERM SAFE AND SECURE STORAGE

Due to the size of the plutonium inventory, any long-term disposition solution will take many decades to implement. In the meantime, the NDA strategy is continued storage in a suite of custom-built facilities that ensure its safety and security in line with regulatory requirements.

There are a number of plutonium stores on the Sellafield site. Over the past decade, materials have continued to be retrieved from older stores and consolidated in more modern state-of-the-art facilities such as the Sellafield Product and Residue Store (SPRS). The aim is to transfer all plutonium into the SPRS store and its extensions over the next few decades. To ensure that the plutonium packages can be safely stored in SPRS, they will be repackaged and, where appropriate, some plutonium will be treated to be made compatible with long-term storage. In some cases treatment is necessary to remove contaminants which can reduce the lifetime of the packages.

A major, new specialised facility to repackage materials is required to support this strategy. Known as the Sellafield Product and Residues

Store Retreatment Plant, abbreviated to SRP, this facility will repackage, and where appropriate, retreat, all of the plutonium packages.

Based on current estimates this facility is expected to become operational in less than 10 years and to operate for nearly 40 years.

The NDA has evaluated the need for the new repackaging plant, SRP, in the context of the long-term plutonium disposition options under development and concluded that, irrespective of which option is chosen, this new capability is required to ensure continued safe and secure storage.

MANAGEMENT OF LEGACY PLUTONIUM FACILITIES AND PACKAGES

The first-generation plutonium plants and stores at Sellafield were built in the 1950s to support reprocessing operations. The NDA considers some of the older plutonium facilities used for manufacturing and storage to be amongst the highest hazards on the Sellafield site, comparable with the legacy ponds and silos facilities (*ref. 6 and 7*).

The condition of some of these plutonium facilities and some of the packages held within, is such



STORAGE

that urgent action is required to reduce the risk with them.

A programme of work was therefore instigated to retrieve these materials from older stores and consolidate them in more modern stores, and is now largely complete.

A major programme of asset care has also been undertaken at these legacy facilities to support operation until they can be taken out of service and decommissioned. Sellafield Ltd has introduced enhanced package inspections programmes and identified categories of containers, in particular some of the oldest ones, which are not suitable for extended storage and should be promptly repackaged.

Due to the requirement to reduce risk, and to ensure their continued safe management most of these containers will be repackaged in existing plants. When the new SRP plant becomes available the contents of these containers will be treated and then repackaged into containers suitable for long-term storage in the modern SPRS store.

This programme of work is receiving enhanced regulatory oversight, and Sellafield Ltd is working with the ONR to complete this work promptly.

The NDA strategy is continued storage in a suite of custom-built facilities that ensure its safety and security in line with regulatory requirements.



DISPOSITION

DEVELOPING A LONG-TERM SOLUTION FOR PLUTONIUM: PROGRESS ON DISPOSITION. THE CREDIBLE OPTIONS FOR PUTTING PLUTONIUM BEYOND REACH

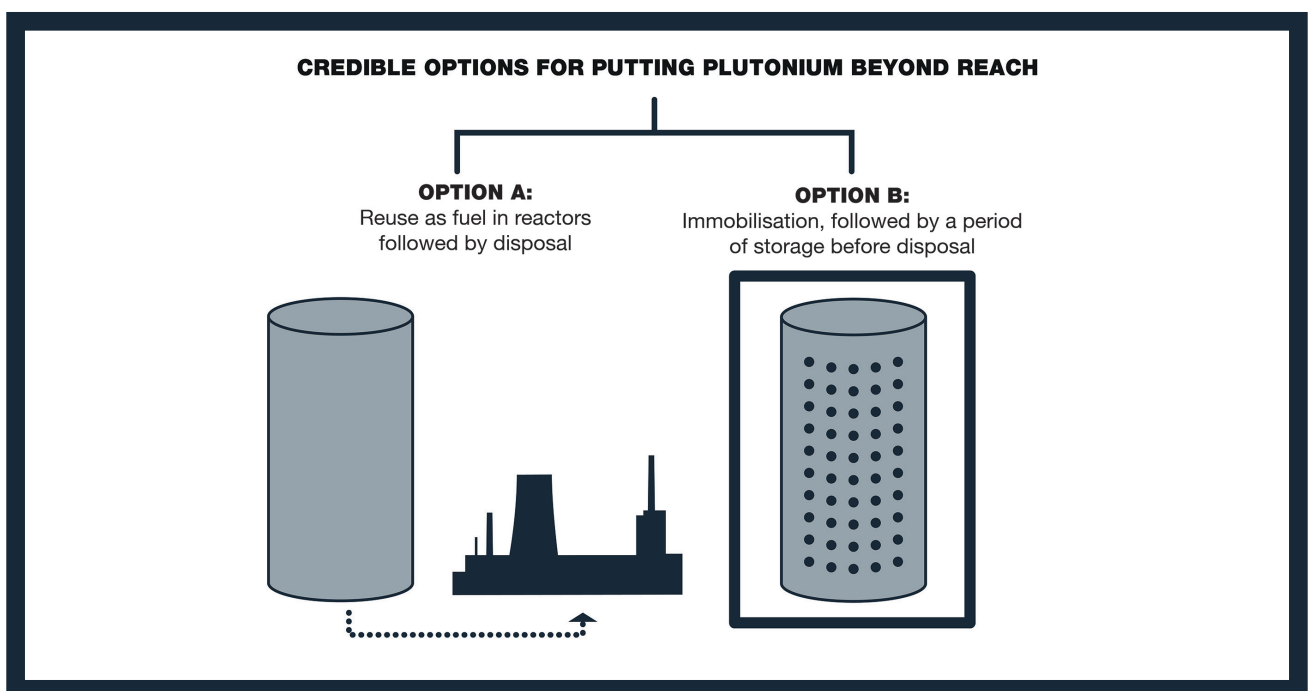
Implementing a long-term solution is essential to enable delivery of the NDA's nuclear clean-up and decommissioning mission. Indefinite continued long-term storage of plutonium leaves a burden of security risks and proliferation sensitivities for future generations to manage. The UK government, working with the NDA, aims to identify a solution that puts the UK's plutonium beyond reach. This could be reuse as Mixed Oxide Fuel (MOX) in nuclear reactors or as an immobilised product. Both approaches would put the plutonium in a form which reduces the long-term security burden during storage as well as ensuring it is suitable for disposal in a Geological Disposal Facility (GDF). In the meantime, the material will remain in safe and secure indefinite long-term storage pending decisions on the disposition route.

At a high level, two distinct options can broadly be described as:

A. Reuse as fuel in reactors followed by disposal in a GDF.

B. Immobilisation, followed by disposal in a GDF. In December 2011, informed by NDA work on strategic options and following a public consultation, the UK government concluded that its preferred policy for managing the vast majority of UK plutonium was to reuse it as MOX in nuclear reactors (*ref.8*). Any remaining plutonium unsuitable for conversion into MOX would be immobilised and subsequently treated as a waste for disposal. The policy position recognises that not all the inventory could be reused; therefore, any strategy will also require the development of approaches to immobilise plutonium for storage pending disposal. It was emphasised at the time that, while UK government believed it had sufficient information to set a direction, it did not have sufficient confidence to progress into implementation. The government would only proceed when it was confident that its preferred option could be implemented safely and securely, was affordable, deliverable and offered value for money.

In addition to setting out a position on UK-owned plutonium, the government decided that overseas-owned plutonium in the UK, which remains the responsibility of the owners, could be managed alongside UK plutonium or transferred to UK



DISPOSITION

ownership subject to acceptable commercial terms, (see ref.8) Since then, the NDA, on behalf of the UK government has reached commercial settlements with a number of customers who have transferred ownership of their plutonium to the NDA. In the long term, this approach will help to simplify the implementation of the government's plutonium management policy by reducing uncertainty for both the UK and the overseas owners. (For further details on these transfers see ref.9)

Since 2011, the NDA has been working with commercial developers, technology suppliers, and other R&D organisations to develop the potential options that could be deployed. In particular this has focused on gaining a sufficient understanding of the technical and commercial risks with each option to allow a decision to be made with a higher degree of confidence. In 2014, the NDA provided an update on the progress made, outlining work with technology suppliers on developing an understanding of their proposals (ref. 10).

Since this 2014 update, the NDA has continued work with suppliers to develop a much improved understanding of the technical issues relating to all aspects of the lifecycle, along with likely costs and timeframes for each option¹. This work also included a joint review by the ONR and Environment Agency (EA) of the alignment of each option with the current UK regulatory framework. The options evaluated included multiple reuse and immobilisation options.

The NDA has advised the government that there is insufficient understanding for each of the options to move confidently to implementation. The different technologies have varying degrees of maturity, and further work is required to enable the government to both make a decision, and establish a timeframe for a decision to be taken. The NDA is working with the government on an agreed multi-year phase of work which covers both reuse and immobilisation options.

The following pages provide an update on work, both ongoing and completed, with suppliers of technologies for both reuse and immobilisation.



¹A prudent estimate of £10.0 billion (discounted) has been included within the NDA's Nuclear Provision based on a review of the potential costs of the reuse and immobilisation options. The estimate is revised annually reflecting any changes in the UK government's treatment of long-term financial uncertainties (ref 11).

DISPOSITION

A. REUSE

I REUSE AS MOX IN LIGHT WATER REACTORS (LWR)

Mixed Oxide (MOX) fuel is a type of nuclear fuel manufactured using a blend of plutonium and uranium oxides. This would require building a MOX plant, to convert the separated plutonium into nuclear fuel, for supply to nuclear power stations which use Light Water Reactors (LWR)

Lifecycle implementation scenarios have been formulated along with the associated cost and schedule estimates for the plants and processes needed to deliver this approach. Given the range of material and the time elapsed since it was produced, assessments have also been made of the UK-held plutonium inventory that would still be suitable for reuse as MOX fuel. This option could manage the majority of the stockpile, possibly as much as 95%, and has the most underpinned cost and schedule estimates of the reuse options. A regulatory review provided good confidence that this approach could be licensed in the UK.

However, this option carries significant risks and uncertainties since it is fundamentally dependent on the availability of suitable new reactors in the UK and the operators' willingness to use MOX fuel. As the overall design of a MOX plant depends on a number of reactor-specific factors, commitments from operators under suitable terms would be a pre-requisite to reaching a decision on this option.

FORWARD LOOK

The NDA is continuing to work with Orano (formerly Areva) on potential approaches to implementing this option. Orano has designed, built and operated a MOX plant in France which has supplied over 2,500 tonnes of MOX fuel to customers including utilities in France and other European countries. To increase confidence in how much of the UK's inventory could be reused as MOX fuel, a series of fuel pellet manufacturing trials are being jointly undertaken at Orano's demonstration facility in France. These trials are scheduled to complete in 2020 and are using actual samples of UK-produced plutonium from the Magnox and THORP reprocessing

plants at Sellafield. This aims to demonstrate that the Orano process for making MOX fuel, commonly referred to as the MIMAS process, can be successfully applied to the UK inventory of plutonium. Orano is also completing further, more detailed work on developing an understanding of the conceptual design and operation of a new UK MOX facility within the UK regulatory framework. The work will, in due course, be peer-reviewed by the UK regulators. Taken together, this will provide increasing confidence in the design, build, and operation with the associated cost estimates and schedule of a Orano-designed MOX plant in the UK.

At this time, and given the current status of the UK's nuclear new build programme, work is focused on generic LWR-type fuels rather than specific fuels from reactors in the UK's new build programme.

II REUSE IN CANDU REACTORS

The CANMOX solution was offered by a consortium led by SNC Lavalin. This approach would involve the building of a CANMOX fuel plant and at least two CANDU EC-6 reactors in the UK to irradiate the fuel.

Potential implementation scenarios were formulated and assessed, showing that reuse as CANMOX is credible. However, no discernible evidence was offered that this approach would be significantly simpler or more cost-effective than reuse as MOX in LWRs. The cost estimate for the CANMOX fuel fabrication plant is in line with the estimate for an LWR MOX plant but with greater technical and implementation risks. This is largely due to the fact that production of CANMOX fuel has not been demonstrated on an industrial-scale. In addition, there are currently no CANDU reactors in operation which achieve the levels of fuel irradiation proposed by SNC Lavalin for this option.

FORWARD LOOK

A limited programme of work has been developed between the NDA and a consortium of companies led by SNC Lavalin to progress the CANMOX option. Building on previous findings, this work is focused on applying and integrating the proven Orano MOX fuel fabrication process to CANMOX fuel production

DISPOSITION

developed with BWXT. Orano has expertise in MOX fuel design and production and is supporting SNC Lavalin with BWXT in developing the process. As there are some notable differences in the CANMOX fuel design, a programme of pellet production and testing is planned to demonstrate that the SNC Lavalin, BWXT and Orano technologies can be successfully integrated.

REUSE IN PRISM REACTORS

The NDA considered a proposal by GE Hitachi Nuclear Energy (GEH) to build a fuel fabrication plant and two PRISM reactors to irradiate a plutonium alloy fuel. No PRISM reactors or fuel plants have ever been built, and the proposal considered by NDA therefore envisaged both the reactors and fuel plant being first of a kind.

This approach had some theoretical benefits compared to the MOX options. PRISM fast reactors were put forward by GEH as commercially viable, “ready to deploy” and capable of quickly dispositioning the complete plutonium stockpile. However, the studies undertaken by NDA with GEH over the past few years have shown that a major research and development programme would be required, indicating a low level of technical maturity for the option with no guarantee of success.

Whilst these R&D requirements are extensive, they are also reasonably well understood. However, the work needed for the fuel fabrication facility is considered preliminary and the proposal was based on not requiring further plutonium-active testing prior to scale-up and industrialisation. This major technical risk, based on GEH’s proposal, would also be borne by the NDA. In addition, the regulatory review by the ONR and EA highlighted this approach as carrying significant licensing risks in all areas. Implementation scenarios were assessed as economically unfavourable compared to other options reflecting, in part, the technical and licensing uncertainties in the proposal.

FORWARD LOOK

At this time, it is noted that the cost, scope and extent of work required to progress Fast Reactor options, such as the GEH PRISM, as well as the timeframe for these options to become available, means it is not credible for the NDA to develop these options, or have them

available for implementation within the next 20 years. Therefore no further work with GEH has been funded by NDA. However, given the very long-term nature of any disposition programme, the NDA will continue to monitor Fast Reactor developments world-wide and assess levels of maturity and potential benefits

B. IMMOBILISATION

The UK civil plutonium inventory is diverse, including historic scraps, residues and other contaminated materials. Regardless of the overall solution, a proportion of the plutonium would be unsuitable for use as a fuel and will have to be disposed of. The NDA is working to better understand the proportion that will need to be immobilised, and also continues to develop approaches that could immobilise and dispose of the entire inventory.

Given the diverse nature of the inventory, a number of different approaches are being investigated so that parts or all of the inventory can be immobilised in a form suitable for ultimate disposal in a GDF.

The three main options being examined are;

- I Hot isostatic pressing (HIP) to produce a monolithic ceramic product.
- II Pressing and sintering process similar to MOX manufacturing to produce pellets.
- III Encapsulation in cement-based matrices as used in the UK for Intermediate Level Wastes.

The NDA also continues to monitor technology developments within and outside the nuclear sector to determine whether they offer any benefits for possible immobilisation processes.

DISPOSITION

IMMOBILISATION AS A CERAMIC PRODUCT (OPTIONS B.I AND B.II)

Immobilisation of plutonium as a ceramic product, manufactured as monolithic blocks, is predicted to produce a highly durable product, suitable for disposal in a GDF. This approach is currently understood to be suitable for immobilisation of plutonium oxide powder, but can also incorporate some of the more difficult residues.

Work funded by NDA over the last decade has shown that immobilisation of plutonium using a technology called Hot Isostatic Pressing (HIP), essentially mixing plutonium with an inorganic precursor and then subjecting it to a combination of high heat and pressure to produce a rock-like plutonium product, is credible. However, this technology is at a relatively low level of technical maturity, compared to reuse as MOX, although there is confidence that the product could be disposed of in a GDF.

Immobilisation of plutonium as a ceramic product would require new industrial-scale facilities, of a similar scale to those required for reuse. Specially designed stores would also be required to store the immobilised waste packages, potentially for at least several decades until a GDF is available. This approach could be implemented at the Sellafield site, with the waste then transported to a GDF.

FORWARD LOOK

NDA has assessed what work is needed to raise the maturity of this technology and has recommended to government that further work is undertaken. The NDA has engaged National Nuclear Laboratory (NNL) to install a pilot test facility for the HIP process in its laboratories at Sellafield. The intention is to manufacture small-scale plutonium-active products in the early 2020s as a demonstration of the technology using UK materials. Alongside this, work to industrialise the process has started which could result in the deployment of an immobilisation demonstrator at Sellafield capable of immobilising plutonium materials not suitable for reuse. This work is supported by further R&D work to develop the maturity of the underpinning process operations, to

explore the options for interim storage prior to disposal and inform the likely requirements relating to disposal in a GDF. In the event the HIP technology cannot be developed, an alternative immobilisation approach is being pursued which involves a manufacturing process similar to making MOX. This process can also produce a ceramic product but in a pelleted form.

IMMOBILISATION BY ENCAPSULATION (OPTION B.III)

For a small part of the inventory, including some residues, encapsulation in a cement-based matrix is being considered. This approach is already used at Sellafield for immobilising 'plutonium contaminated materials' arising from some processing operations. Due to the large volumes of waste that would need to be stored and then disposed of in a GDF, this approach is not considered suitable for bulk plutonium oxide powder.

FORWARD LOOK

Currently this approach is applied to immobilising wastes where typically tens of grammes of plutonium are present, but has been applied on a scale up to a few hundred grammes. If successful, this opens up the possibility of using existing encapsulation plants at Sellafield to immobilise these materials over the next decade.

The NDA will continue to monitor technology developments outside the nuclear sector to determine potential benefits

NEXT STEPS

OUTLINE

The NDA continues to make progress on this important issue, working with technology suppliers, developers and the UK government to establish how each option could be secured and implemented. A balanced programme of activities has been established on both reuse and immobilisation options to provide further informed advice to the government during 2020. The government will then consider the NDA's advice and determine the next steps for the disposition programme.

The work is focused on technical and implementation aspects enabling development of a fuller understanding of potential approaches that would meet government policy requirements and deliver the best value for money. This work also supports the UK's ability to retain the skills platform for managing plutonium and the capability to implement a long-term disposition solution.

The NDA also continues to monitor technology developments within and outside of the nuclear sector to determine whether they offer any benefits. Work is also under way with other international organisations in the US, France and Japan to understand and learn from their experience.

Any decision on plutonium disposition should not be made in isolation due to potential interdependencies with the UK's wider nuclear programmes including new nuclear build, geological disposal and national security.

A programme to implement a long-term solution for the disposition of separated plutonium will be complex, incorporating significant technical challenges and uncertainties, and will take many decades to complete.

For these reasons, the UK government has been clear that a decision cannot be taken quickly and, when taken, must be underpinned by the right evidence.

The NDA continues to work with the UK government to understand the conditions that need to be met so a decision, and the timetable for making such a decision, can be made with confidence. Further updates will be provided on this work in line with UK government expectations.





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