

# Exotic Fuels – Dounreay Fast Reactor (DFR) Breeder

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## Credible & Preferred Options

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July 2011

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# Exotic Fuels – Dounreay Fast Reactor (DFR) Breeder Credible & Preferred Options July 2011

## Executive Summary

NDA has studied the high level options associated with the management of DFR breeder material, currently stored at Dounreay. This paper describes and discusses the relevant factors associated with each high level option, and draws conclusions based on the analysis.

This consideration has shown that there is a clear and compelling strategic case for the NDA management option for DFR breeder material to be changed from immobilization, at Dounreay, to management with spent Magnox fuel at Sellafield, the reference strategy for which is reprocessing.

Work still needs to be completed by the SLCs to deliver the final business case to the NDA to confirm this view, or otherwise, so a decision can be made to implement the selected strategy for management of DFR breeder material.

In preparing the final business case, the SLCs and NDA will need to engage with regulators, stakeholders and local communities to gain their view of the proposed strategy for management of this material.

It is anticipated that the final business case will be presented in early autumn 2011 and that a decision by NDA will follow within 2 months of receipt. Should management of DFR breeder material at Sellafield become the approved strategy, transportation will commence in 2012.

	Name	Signature	Date
AUTHOR:	Dr Paul Gilchrist		
CHECKED:	Clive Nixon		
APPROVED:	Dr Adrian Simper		

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## **1 Background**

### **1.1 The Dounreay Fast Reactor (DFR)**

The Dounreay Fast Reactor (DFR) was an experimental nuclear reactor developed in the 1950s at Dounreay in Caithness, Scotland. The reactor had a power rating of 60MW (thermal) and was designed as a fast breeder, which means it used an inner reactor core operating at high temperature and an outer ring (known as breeder material) of uranium metal which captured neutrons from the inner core and produced plutonium which could be removed and converted to new fuel.

In the 1950s and 1960s, fast breeder reactors were considered to be “the solution” to the UK’s long term energy challenge, as they could generate electricity (from the inner core) and produce nuclear materials for new fuel (from the outer ring of uranium metal). The DFR started operations in 1959.

The DFR was relatively successful, which created the optimism in the UK to build a more advanced fast reactor (the Prototype Fast Reactor, PFR) which opened in 1974. Following the successful commissioning of the PFR, the DFR stopped operating in 1977.

### **1.2 What is DFR Breeder Material?**

DFR breeder material comprises cylinders of uranium metal, about 150mm long and 35mm diameter (known as “pucks”), of which 14 are stacked end-to-end in a stainless steel tube, with each tube positioned vertically around the reactor core. There are 44 tonnes of breeder material at the Dounreay site, but because of the very high density of uranium metal (around 19 kilograms per litre), it has a small volume of around 2.5m<sup>3</sup>.

During reactor operation, only a small amount of the uranium is converted into plutonium as a result of exposure to neutrons.

The breeder material is not classified as a fuel, as it does not take part in the nuclear “core” reaction and is not converted into fission products but neither is it waste. This is why, to avoid confusion, it is referred to as “material”.

The breeder material is radioactive, but much less so than fuel since it does not contain large amounts of fission products, and it has also been cooled since 1977.

### **1.3 How Has DFR Breeder Material Been Managed So Far?**

Originally, the breeder material was stored under a metal alloy of potassium and sodium, (“NaK”). Of the 44 tonnes of breeder material at Dounreay, some has already been removed from DFR, has been cleaned of any adhering NaK and is currently safely and securely stored out of the reactor elsewhere on the site. The remaining material remains in the reactor under NaK. There is a detailed plan being implemented for the extraction of the fuel from the core and cleaning off of any excess NaK, which is scheduled to be complete around 2015/16.

Dounreay does not have any operational reprocessing facilities and so chemical reprocessing of the breeder material at Dounreay is not possible.

The original plan for management of DFR breeder material was to reprocess it at Sellafield, where the plutonium and uranium could be recovered and potentially converted into fresh

fuel. Indeed, around 30 tonnes of breeder material between 1967 and 1972 was sent to Sellafield for reprocessing in the Magnox reprocessing plants.

In 2006, the Dounreay lifetime plan inherited by the NDA had a baseline in which the DFR breeder material would be encapsulated, probably using grout. This was consistent with thinking at that time, especially given that the anticipated end date of Magnox Reprocessing at Sellafield, derived from the Magnox Operating Programme (MOP), was 2012. In addition, fuel was not anticipated to be available to be removed from the DFR until 2011 at best, which did not give enough time for fuel transport and processing at Sellafield. The LTPO7 for Dounreay maintained that approach although the technical underpinning and R&D of the grout option was immature. To this end, Dounreay put forward a proposal that polymer encapsulation might be considered for the fuel, along the lines of that for the Pile 1 fuel at Windscale, although this too was acknowledged to be a long way from being technically mature.

In late 2007, it emerged that the MOP end date was unlikely to be 2012 with around 2016 becoming more likely. As a result, NDA sought to validate this position and then published “MOP 8” in January 2008, which had an anticipated end date of around 2016. As a result of this extension to Magnox reprocessing operations, NDA reopened a study, in parallel to the MOP considerations, to evaluate the opportunity of sending the DFR breeder material for reprocessing at Sellafield – i.e. a reversion to the original plan.

That study commenced in 2008, and initially focused on technical and logistical issues prior to an examination of the commercial, stakeholder and economic issues. NDA also sought to further understand the technical options, before discussing in any detail with regulators, to properly inform the preferred option decision. Once the preferred option was identified, it was considered that enough information was available to have informative discussions with stakeholders about the options, and their impact, prior to NDA making a formal strategic decision.

## **2 Strategic Case**

### **2.1 Existing Situation**

The remaining 44 tonnes of DFR breeder material represent approximately 40% of the total inventory of nuclear materials on the site, with a quantity stored away from the reactor and the remainder within the reactor and inaccessible until the bulk of the NaK coolant has been removed.

The material is uranium metal that has been lightly irradiated within the breeder blanket of the reactor and contains small quantities of plutonium. These factors make the material of interest from a security perspective as well as possibly presenting increased uncertainties around its ultimate disposal, if it were to be disposed of directly to a geological disposal facility.

In terms of reprocessing technology, the chemical, physical, and radiological properties of DFR material are sufficiently close to spent Magnox fuel to allow the material to be managed using the same facilities. Thus it appears rational that the strategy for the management of DFR material and Magnox fuel be the same.

## **2.2 Business Needs**

The quantity and nature of the breeder material, means it is one of the major work streams that must be addressed for Dounreay to reach its interim end-state and is also key in determining the long-term security arrangements for the site. Without a secure disposition route for this material the site cannot properly plan for the interim end-state.

## **2.3 Investment Objectives**

The long term business objectives are:

- to reduce the overall hazard on the Dounreay site and get the site into its interim end-state on acceptable timescales
- to expedite the reduction of the security classification of the Dounreay site
- to remove from the Dounreay site the liability posed by the DFR breeder material and reduce the risks associated with its long-term management
- to reduce the security classification of the DFR material from a Category A material
- to manage the DFR breeder material in line with UK Government's current non-proliferation agenda
- to utilize existing facilities and infrastructure effectively

## **2.4 Dependencies**

There are three key dependencies associated with this work programme:

- reducing long-term security costs at the Dounreay Site, by transferring higher category materials off site, is dependent on other materials being removed from the site as well
- the material must be integrated into the Magnox Operating Programme (MOP) and blended with high burn-up fuel from the Magnox reactors. Current estimates for completion of the MOP are 2016/2017, although these are still under review
- the 'in-reactor' material cannot be accessed until the bulk of the NaK has been removed from the reactor. Removal of the bulk NaK is programmed to be complete by March 2013.

## **2.5 Credible Options**

An initial options assessment was carried out and the high-level options that were examined can be summarised as follows:

- A. reprocess at Dounreay
- B. transport to Sellafield and manage with Magnox fuel (for which the reference strategy is reprocessing)
- C. reprocess overseas
- D. immobilise in grout or polymer at Dounreay and store the product prior to disposal (the current LTP Baseline)
- E. immobilise in grout or polymer at Sellafield and store the product prior to disposal in a GDF

It was clear from an early stage that options A and C were not credible.

For option A, there are no reprocessing facilities at Dounreay and there would be very significant regulatory issues to overcome and Government policy statements to reverse prior to even considering this option, without looking at the economic and logistical components of such a case.

For option C, there are no known overseas commercial metal reprocessing facilities that could manage the DFR breeder material. Additionally, should one become available, the requirements of international sea transportation of breeder material are likely to be prohibitive. In any event it is extremely likely that this option would require the return of products and wastes and this would require the design and implementation of these import routes as well as the export route for the DFR breeder material.

For option E, given that there are some grout facilities already at Dounreay and their design would be amenable with some modifications to DFR breeder material, there are no additional direct cost benefits for DFR if the breeder material were to be treated by immobilisation at Sellafield.

Hence, at the credible options stage, only options B and D were selected for further investigation.

It was evident that, while technically possible at a high level, there was a lot of theoretical work and regulatory discussions required to establish if option B could be realised. However, because of the nature of the material, the difficulties were predominantly logistical rather than technical.

The immaturity of the immobilisation option indicated that an extensive R&D programme would be required to underpin option D. Such an R&D programme was underway to support work in other areas of the NDA estate, but was not anticipated to mature in-line with the decision timeframe associated with the DFR material. The nuclear sector has historically found it difficult to develop immobilisation options for bulk quantities of uranium metal, but there may be value in maintaining a watching brief on these activities and continuing some development work as a contingency.

## **2.6 Preferred Option**

Following on from the credible options work, it was clear that there were two realistic high level options remaining:

- D immobilise in grout or polymer at Dounreay and store the product prior to disposal (the current LTP Baseline)
- B transport to Sellafield and manage with Magnox fuel (for which the reference strategy is reprocessing)

Both options have been evaluated as costing similar amounts to implement (see economic case), and both also have some large risks and uncertainties associated with them. However, the Sellafield option addresses safeguards and non-proliferation issues, removes the material from the Dounreay site making long-term savings in security costs more accessible, and increases the number of options available for managing the uncertainties associated with long-term disposability of products. In addition, reprocessing is an established, technically mature treatment process. Also, the quantities of material involved will have only a very minor impact on the costs of addressing the products and wastes arising given the overall quantities that arise from the Magnox fuel management (reprocessing) programme.

Reprocessing the material and treating it as fuel also recognises Scottish policy on higher activity wastes and does not materially alter the hazard profiles for the Sellafield site.

A more detailed examination of the Sellafield option needed to focus on five key areas of uncertainty:

- i) could the fuel be removed from the reactor in time to meet the window of opportunity in the Magnox reprocessing programme?
- ii) could the breeder material be transported to Sellafield in a reasonable timescale with a reasonable amount of journeys?
- iii) could the Sellafield reprocessing plant be used, or easily modified, to accept and manage the breeder material?
- iv) could the requirements of the nuclear regulators be met?
- v) In the event that the Magnox reprocessing programme cannot be completed, can the material be managed safely using the non-reprocessing options being developed for spent Magnox fuel or processed along with other feeds located at Sellafield?

For question i, there is still a degree of programme uncertainty that makes addressing this issue difficult. From the expected completion dates of both breeder material removal and MOP it is still expected that the programmes should be complementary.

For question ii, it has been established with specialist transportation companies, flask owners and regulators that a limited number of journeys over a 3 - 4 year period would be required. To this end Dounreay would be treated as a 'Magnox' station as it has material to transport to Sellafield for reprocessing. The flasks are available and there is confidence that transport regulations can be met.



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For question iii, there are some modifications to procedures and monitoring equipment required in the Magnox reprocessing facilities at Sellafield to enable the safe management of the breeder material. This is because the isotopic composition of the plutonium in the breeder material differs from that in spent Magnox fuel. These are all considered by the Sellafield SLC to be implementable.

For question iv, there are many requirements that regulators put on such operations. In order to help with their considerations, two workshops have been held to discuss the technical detail of this programme of work and allow regulators to be informed and seek clarification in areas of potential concern. At this time, and subject to more formal regulatory processes, there appear to be no principle concerns about the proposed reprocessing of breeder material, although there will be future requirement for the SLCs to submit more formal detailed safety case submissions for regulatory approval.

The environmental aspects of the DFR breeder material transfer to Sellafield for reprocessing has been considered with the following findings:

- Dounreay – Hazard reduced. No additional environmental aspects introduced during processing and loading
- Sellafield – Insignificant impact as facilities already operational over the period concerned. No new chemicals etc introduced by process or in the DFR material
- Transport – This is the only real environmental impact but this too is minimal as there is proposed to be *circa*. 50 rail movements over 4-5 years (compared to 5460 rail journeys from Thurso to Inverness over the same time period).

For question v the current work on non-reprocessing options for spent Magnox fuel may need to be adjusted slightly to understand whether DFR breeder material could be incorporated, if required.

For the immobilisation options, there has been some further R&D completed, but not enough to consider these options as mature at this time although they are still credible.

Taking all the above into account, from a strategic case perspective, managing DFR breeder material with spent Magnox fuel by reprocessing at Sellafield is considered the preferred option.

## 3 Economic Case

In order to validate the preferred option a number of critical success factors have been considered in the economic case as follows:

- must not significantly extend the duration of the MOP
- must not compromise the ability to reduce long-term security costs at the Dounreay site
- must reduce risks associated with long-term management
- must significantly reduce the security risks
- must meet nuclear material accountancy requirements with respect to separation of out-of-reactor material and in reactor material during reprocessing

### 3.1 Reprocessing at Sellafield

The differentiating factors in the reprocessing route are the transportation to Sellafield and the cost of reprocessing.

There are two modes of transport considered – road and rail. Analysis has determined that rail transport is less costly (circa £10M) and eliminates some process risks associated with one of the Sellafield receiving plants. The total cost to prepare and transport material using rail as the preferred option has an estimated cost of *circa*. £30M.

It has been demonstrated by Sellafield that reprocessing breeder material requires additional processing time which incurs additional cost to the MOP. This has been calculated to be an equivalent direct cost of *circa*. £30M undiscounted.

### 3.2 Immobilisation at Dounreay

The alternative to not reprocessing DFR breeder material involves retention of the material at Dounreay, condition, store and ultimately dispose of. The most recent Dounreay provision allowed *circa*. £65M for this option.

### 3.3 Reprocessing vs Immobilisation Economic Summary

Several factors have been considered in the development of the economic case, including security, hazard reduction, safety, environment, socio-economic and costs. These are summarized in the table below:

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Factor	Reprocessing	Immobilisation
Security	<ul style="list-style-type: none"> <li>Material is mixed with spent Magnox</li> <li>Breeder material removed from Dounreay and product stored with similar protected material at Sellafield</li> <li>Criticality constraints mean that shipments are at reduced security category</li> </ul>	<ul style="list-style-type: none"> <li>Material, whether encapsulated in resin or cement, is considered as being recoverable</li> <li>Security Category 1 material remains on the Dounreay site and security is required up to point of disposal</li> <li>No guarantee that waste form can be justified without significant rework</li> <li>Scottish waste policy means this may not be an exit strategy thereby resulting in an open ended commitment on security</li> </ul>
Hazard reduction	<ul style="list-style-type: none"> <li>Provides earlier remediation of the residual NaK compared to encapsulation as no requirement to construct additional storage</li> </ul>	<ul style="list-style-type: none"> <li>Residual NaK, which is one of the highest hazards on the Dounreay site, cannot be addressed until the DFR material has been removed. The requirement for new stores will delay this</li> </ul>
Safety	<ul style="list-style-type: none"> <li>Reprocessing route well proven and breeder material has been reprocessed in the past</li> <li>Flask transport safety record well proven.</li> <li>Dose rate on de-clad material much lower than normal Magnox</li> </ul>	<ul style="list-style-type: none"> <li>Retention at Dounreay would result in need for new store which would extend time to remove residual NaK from reactor, a major hazard reduction objective</li> <li>Material would need to be de-clad and washed for safe storage so no reduction in dose uptake</li> </ul>
Environment	<ul style="list-style-type: none"> <li>Transportation to Sellafield results on all movements by rail. Total of circa 50 rail movements.</li> <li>There would be a minor increase in product arisings at Sellafield but well within current storage capacity</li> <li>Minor discharges but very low fission product loading means minimal HA stream impact</li> <li>In line with waste hierarchy objectives</li> </ul>	<ul style="list-style-type: none"> <li>Transport and material requirement to build new facilities</li> <li>No disposal facility yet defined and hence no waste form requirements.</li> <li>Material is prone to corrosion and waste form could be difficult to develop and justify</li> </ul>
Socio-economic	<ul style="list-style-type: none"> <li>Maintains employment at Sellafield but reduces employment at Dounreay arising from construction of new buildings</li> </ul>	<ul style="list-style-type: none"> <li>Creates short-term jobs at Dounreay arising from construction of new buildings</li> </ul>
Costs	<ul style="list-style-type: none"> <li><i>circa.</i> £60M including reprocessing fixed costs</li> </ul>	<ul style="list-style-type: none"> <li>Basic direct costs of <i>circa.</i> £65M</li> </ul>

## **4 Commercial Case**

Delivery of the work scope will be through the Dounreay and Sellafield contracts but will also require support from flask design authorities who are located in other SLCs and INS / DRS to support flask transfers.

Dounreay and Sellafield will own the work scope and will co-operate on a shared endeavour to deliver the overall work programme. Magnox Ltd as the MOP lead SLC will integrate and co-ordinate shipments within the overall MOP requirements.

To deliver the above requires Dounreay and Sellafield to let a number of contracts with other SLCs and third parties. There will be three single source contracts due to monopoly positions such as design authorities and supply of unique services. All other packages for design of equipment, manufacture and testing will be sourced in line with current procurement procedures though the overall value is anticipated to be small.

## **5 Financial Case**

A full financial case has been prepared and the impact on site funding is well understood. This is a contractual matter for the SLCs and NDA and will not be published here.

A more detailed financial case will be delivered in the presentation of the final business case by the SLCs to NDA.

## **6 Management Case**

The programme and project management arrangements have been considered. The successful delivery of the project requires close working between Dounreay and Sellafield and management of the interfaces with DRS and MOP.

To ensure success, clear accountabilities and interface arrangements have been identified:

- A joint Project Board has been established with senior representatives from Sellafield and Dounreay. NDA will be represented on the board
- A single point of accountability (SPA) has been identified for each site reporting to the Project Board
- There will be site specific project teams for Sellafield and Dounreay. These teams will report to the site SPA
- Dounreay accountability is up to delivery of loaded cuboid flasks to Sellafield including leading the interface with INS, DRS, the MOP, Magnox North and DFT
- Sellafield accountability is from receipt of loaded flasks to export of empty flasks loaded with appropriate skips and furniture.
- Magnox will act as design authority as owner of the fuel flasks and be accountable for integration within the overall MOP



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The work programme will be managed in three phases:

### Phase 1 - Preparatory Phase

Completion of the commissioning of the DFR in-reactor material retrieval and treatment route, development and preparation of the transfer route from storage to DFR for the out-of-reactor material, modifications, test rigs, testing and security enhancements at Fuel Handling Plant, preparation of the five cuboid flasks with skips and skip furniture and development of the appropriate safety cases.

### Phase 2 – Out-of-Reactor Fuel

Preparation, transportation and reprocessing the out-of-reactor material. Wash-out of the reprocessing plant. The scheduled break between out-of-reactor and in-reactor material does not coincide with any planned plant washout hence an additional one is required.

### Phase 3 – In-Reactor Material

Recovery, decanning, treatment, re-sleeving, transportation and reprocessing of the in-reactor material.

Should management with spent Magnox fuel at Sellafield become the approved management strategy for this material, then movements between Dounreay and Sellafield are likely to commence in the first half of 2012.

## 7 Summary and Conclusions

NDA has studied the high level options associated with the management of DFR breeder material, currently stored at Dounreay. This paper describes and discusses the relevant factors associated with each high-level option, and draws conclusions based on the analysis.

This consideration has shown that there is a clear and compelling strategic case for the NDA management option for DFR breeder material to be changed from immobilization, at Dounreay, to management with spent Magnox fuel at Sellafield, the reference strategy for which is reprocessing.

Work still needs to be completed by the SLCs to deliver the final business case to the NDA to confirm this view, or otherwise, so a decision can be made to implement the selected strategy for management of DFR breeder material.

In preparing the final business case, the SLCs and NDA will need to engage with regulators, stakeholders and local communities to gain their view of the proposed strategy for management of this material.

It is anticipated that the final business case will be presented in early autumn 2011 and that a decision by NDA will follow within 2 months of receipt. Should management of DFR breeder material at Sellafield become the approved strategy, transportation will commence in 2012.