ICEM'09/DECOM'09

Contingency Options for the Drying, Conditioning and Packaging of Magnox Spent Fuel in the UK

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Outline

- **Contingency Options for the Management of Magnox Spent Fuel**
  - Options for drying, conditioning and packaging
  - Options for dry storage – earlier talk
- **Background**
- **Current Magnox Spent Fuel Inventory**
- **Drying Options**
- **Conditioning and Packaging Options**
- **Summary**

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Magnox Spent Fuel Contingency Options

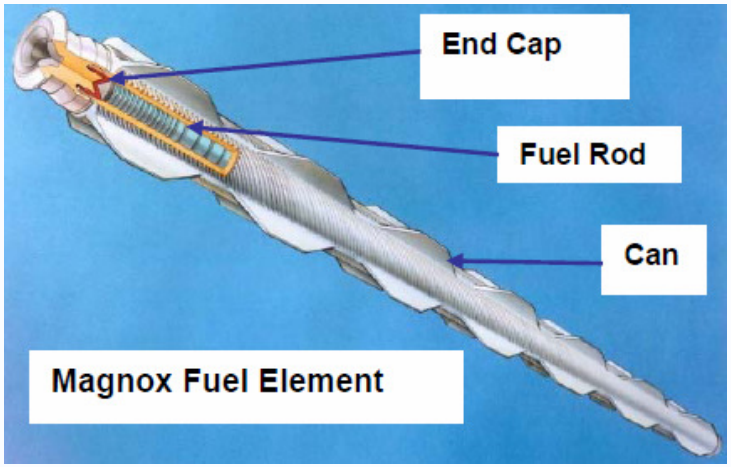
- **Objective**
  - To consider potential alternative management options for Magnox spent fuel in the UK
  - Focus on drying and dry storage of formerly wetted fuel, as an alternative to reprocessing
  - International literature review and expert workshops
- **Funding**
  - NDA Direct Research Portfolio (DRP) – Lot 4 (Actinide and Strategic Materials)
  - Project let to a UKAEA-led consortium in July 2008
- **Contributors**
  - Technical lead - Galson Sciences Ltd. (GSL)
  - UKAEA Ltd. (supporting role – part of DRP consortium)
  - Various associates (ex-Magnox)

Background – Magnox fuel

- **Magnox fuel**
  - Uranium metal clad in magnesium (>99%) alloy
  - Not suitable for extended wet storage, as both uranium and magnesium react with water
  - Delays to reprocessing or implementation of dry storage have resulted in extended periods of unplanned wet storage, causing:
    - Cladding corrosion
    - Hydrogen gas generation

$$U + H_2O \longrightarrow UO_2 + 2H_2$$

    - Potential production of uranium hydride



NDA Springfields Fuel Ltd, 2008

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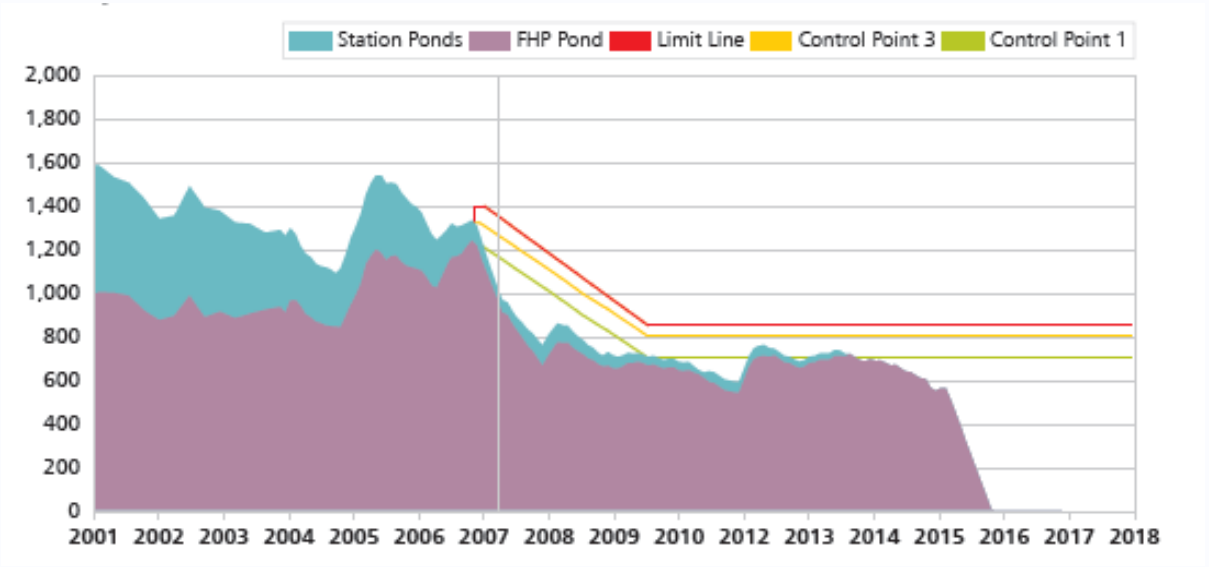
Background – NDA Strategy

- **Current NDA strategy**
  - Magnox Operating Programme (MOP8) - aims for all Magnox spent fuel to be reprocessed by January 2016
  - Short term wet storage (mostly) in FHP pond prior to reprocessing at Sellafield
  - Other fuel in operating and shut down reactors and some reactor ponds



NDA , 2007

Current Magnox Spent Fuel Inventory

Location	Quantity	Condition	MOP8 Schedule
Sellafield FHP Pond	~800 tonnes (wet)	Variable (about 300 tonnes of older, legacy fuel in poor condition)	2009 to 2016 (reprocessing)
Other Sellafield Legacy Facilities	Not available	Variable, mostly poor	Not included
Calder Hall	~450 tonnes (dry)	In reactor	9/12 to 5/15 (defuelling)
Chapelcross	~440 tonnes (dry)	In reactor	4/08 to 8/11 (defuelling)
Dungeness A	~660 tonnes (mostly dry)	In reactor and on-site ponds	4/08 to 3/11 (defuelling)
Oldbury†	~700 tonnes (mostly dry)	In reactor and on-site ponds	4/11 to 9/13 (defuelling)
Sizewell A	~680 tonnes (mostly dry)	In reactor and on-site ponds	7/09 to 6/12 (defuelling)
Wylfa†	~1,100 tonnes (all dry)	In reactor and on-site dry storage cells	8/11 to 1/15 (defuelling)

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NDA, 2008

Drying Options

- **Relevant Spent Fuels**
  - Hanford N-Reactor fuel (Zircaloy clad)
  - UNGG (Uranium Naturel Graphite Gaz) fuel (magnesium clad)
  - Canadian legacy metallic uranium fuels (aluminium clad)
- **Relevant Programmes**
  - Hanford (US)
  - Chalk River (Canada)
  - Idaho / INEEL (US)
  - CEA Cadarache (France)
  - PIE (UK)

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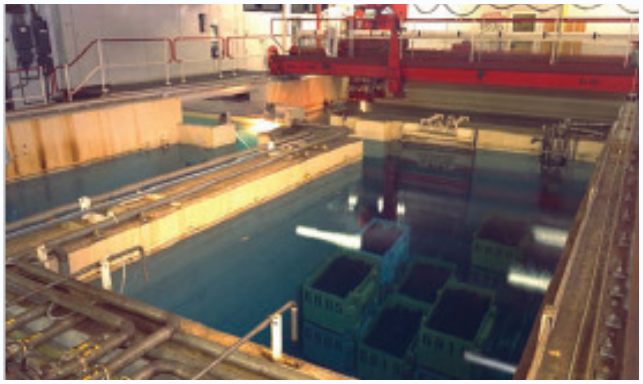
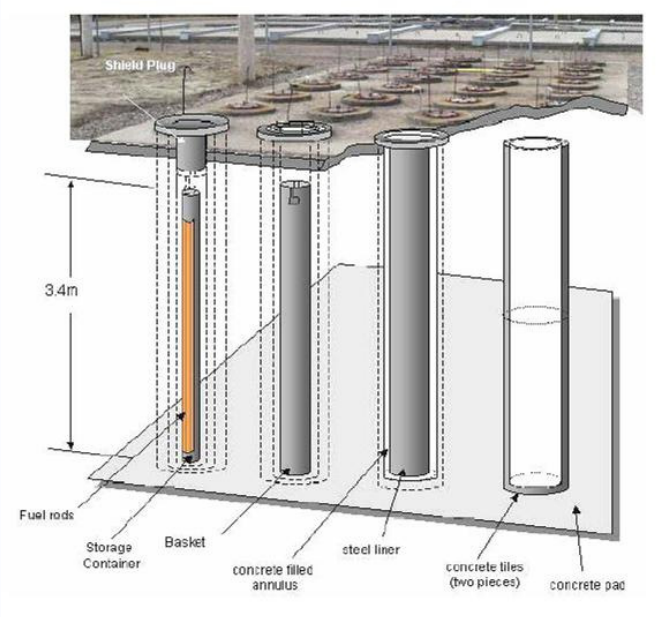


NDA, 2008



Cox *et al.*, 2005

Drying Techniques

- **Vacuum Drying**
  - **Cold Vacuum Drying** – Spent fuel is placed under vacuum and heated to below 100 ℃, removing bulk and free water, not physically and chemically bound water
  - **Hot Vacuum Drying** – Involves a heating step above 100 ℃. This can also remove physically and some chemically bound water
  - The fuel is considered to be ‘dry’ when the system is isolated and the pressure remains constant for a specified period
- **Hot Gas Drying**
  - Spent fuel is uniformly heated to 90 – 150 ℃ in an inert gas flow at or greater than atmospheric pressure
  - The fuel is considered to be dry when the moisture content of the exhaust air matches that of the inlet air
- **Conditioning**
  - Both vacuum and hot gas drying can be followed by a conditioning and passivation step

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Cold Vacuum Drying – Chalk River

Legacy containers removed from tile holes and placed in transfer flask.

↓

Legacy containers transferred to new **vented** stainless steel canister.

↓

Canister placed in vacuum vessel, heated to < 100 ℃ and pressurised to 1 atm. with Ar or He.

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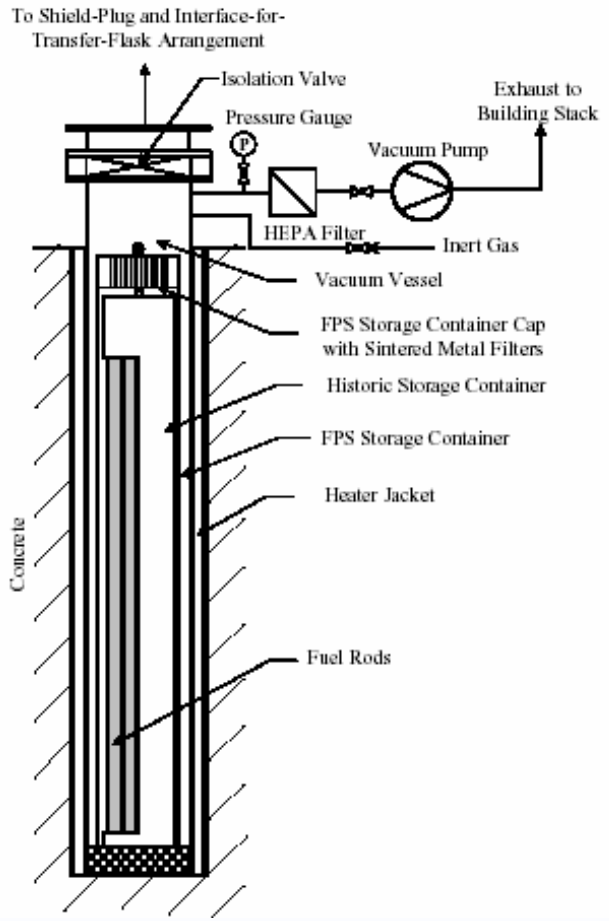
Applied a series of vacuum and heating cycles.

↓

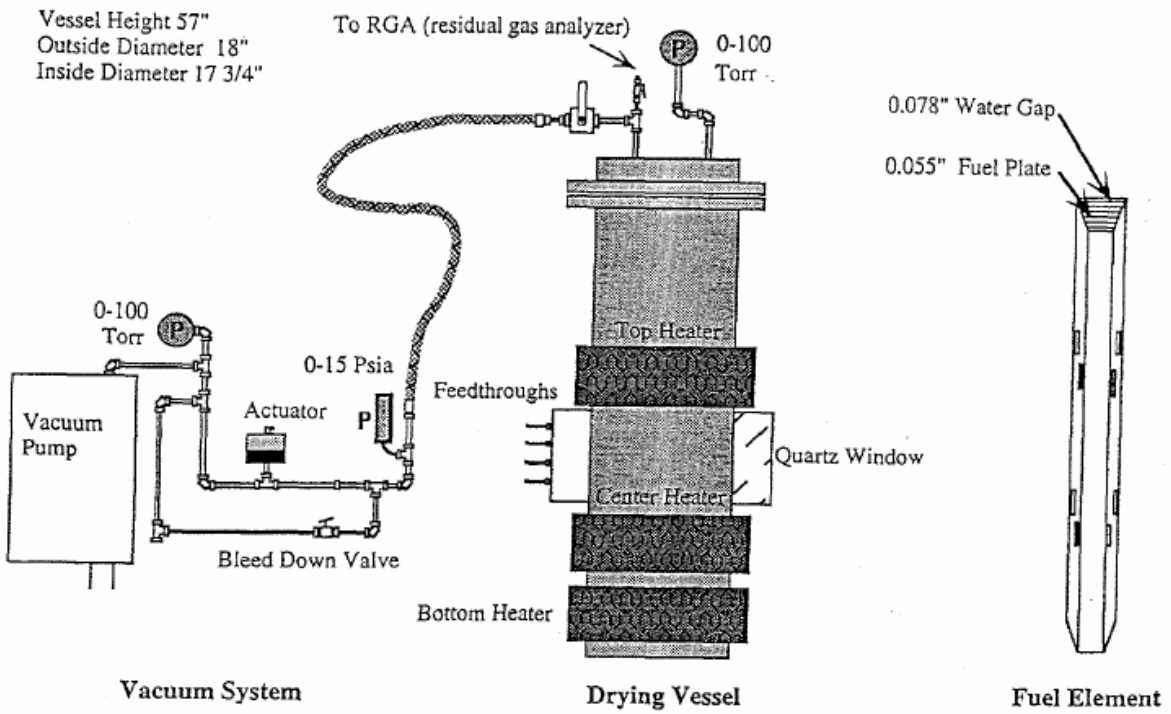
Pressure rebound test measurement to verify the removal of free water from the legacy containers.

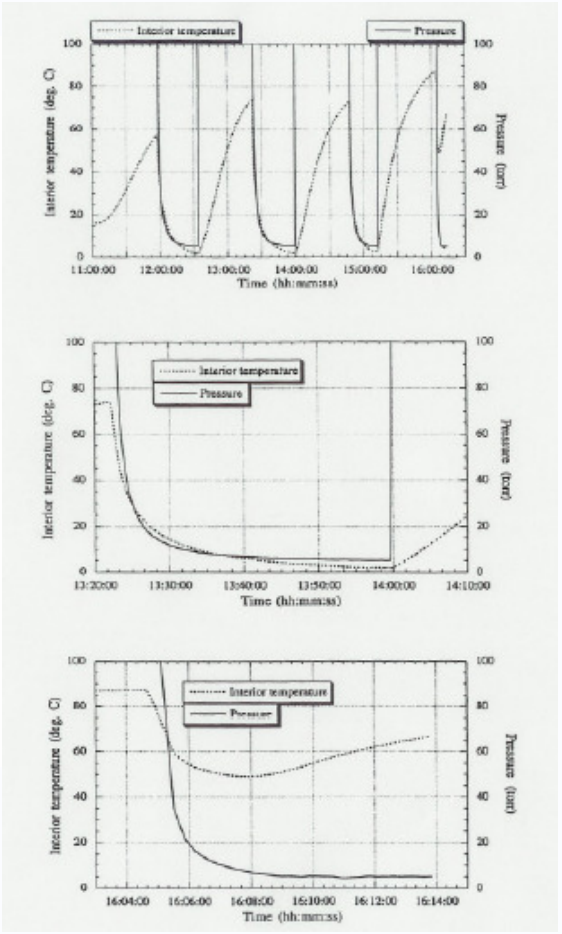


Rodrigo et al., 2005

Hot Vacuum Drying - INEEL

- **Experimental trials performed in development of Fuel Canning Station process**





Lords et al.,1996

Crepeau et al.,1998

Hot Gas Drying – CEA Cadarache

Spent fuel was retrieved from INB 56 Ponds in original canisters, which were monitored and assessed.

↓

The legacy canisters were placed into a transfer container under an inert gas and packaged for transport to STAR facility.

The legacy canisters were opened and the magnesium cladding removed.

↓

Magnesium cladding removed and uranium metal heated in argon at 100 ℃.

↓

Uranium heated to 430 ℃ to pyrolyse uranium hydride.

Uranium metal surface partially oxidised at 250 ℃ with oxygen concentrations from 5 – 20 % in argon.

↓

Uranium placed in welded stainless steel containers with an inert cover gas for storage at CASCAD.

After CEA (2008)

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Drying Options - Summary

Drying Method	Process	Fuel Type	Applicability to Magnox Spent Fuel
Cold Vacuum Drying (<100 °C)	Hanford (US)	**Zircaloy** clad uranium metal fuels	Industrial scale process. Able to handle intact and damaged fuel.
	Chalk River (Canada)	**Aluminium** clad uranium metal fuels	Industrial scale process under development. Aluminium cladding is less reactive than Magnox. Able to handle intact and damaged fuel.
Hot Vacuum Drying (>100 °C)	Idaho INEEL (US)	**Aluminium** clad uranium metal fuels	Industrial scale process. Aluminium cladding is less reactive than Magnox.
Hot Gas Drying	CEA Cadarache STAR Facility (France)	UNGG **magnesium** clad uranium metal fuels	U separated from the Mg cladding. Included drying and conditioning steps Able to handle intact and damaged fuel.

Conditioning Processes

- **UK regulatory requirement that radioactive waste is stored according to the principles of passive safety**
- **Conditioning processes which may be suitable for Magnox spent fuel include:**
  - Inorganic-based encapsulation with cements or geopolymers
  - Organic polymer-based encapsulation
  - Chemical treatment, followed by cementation or vitrification
  - Alternative methods, including electrometallurgical treatment and transmutation

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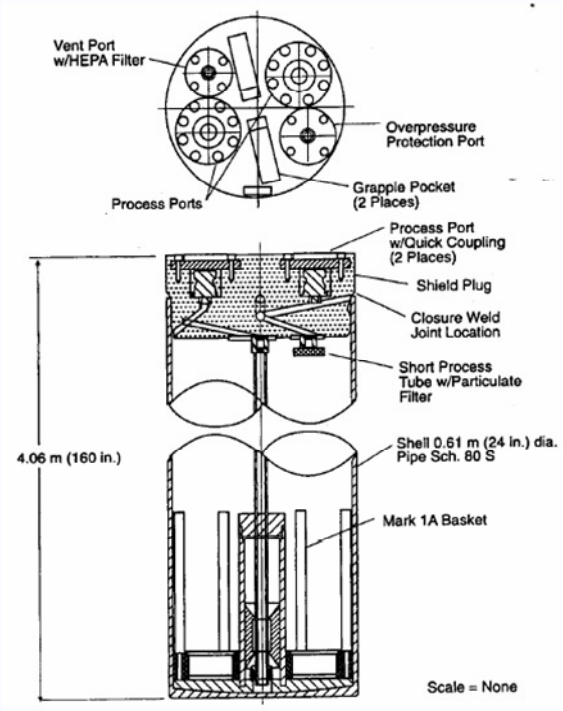
Method	Programme / Process	Encapsulant	Fuel Type / Material	Applicability to Magnox Fuel
Inorganic Encapsulation	Sellafield Magnox Encapsulation Plant (MEP) (UK)	Ordinary Portland Cement (OPC)	Magnox Swarf	Corrosion rate of Magnox metal is dependent on the availability of water at the metal surface.
	ANSTO Research (Australia) / NuCap (US)	Geopolymers	LLW/ILW	Price of raw materials and manufacturing costs are cheaper for geopolymers than OPC, and requires ⅔ of the energy.
Organic Polymer-based Encapsulation	Trawsfynydd Power Station (UK)	VERI (Vinyl Ester Resin In-situ)	Magnox Swarf	Flammability issues. Polymers are expensive and their production uses oil feedstocks.
Dissolution	Sellafield (PUREX process) (UK)	None (further treatment required)	Magnox and Uranium Oxide Fuels	Dissolution is used on an industrial scale in the reprocessing of Magnox spent fuel.
Vitrification	Sellafield Waste Vitrification Plant (WVP)	Glass	Products from Magnox Reprocessing	Uranium and plutonium are currently separated out in the standard PUREX process; development required.

Packaging Options

- **Magnox spent fuel may be:**
  - Packaged in sealed or vented containers
  - Stored bare, following drying, in a suitably designed vault store (as discussed in earlier talk)
- **Containers used with similar fuels:**
  - Hanford multi-canister overpack (sealed)
  - INEEL canister (vented)
  - Aluminium alloy (AG3) canisters
- **Commercially available containers:**
  - CEA spent fuel holder
  - SKB or NAGRA spent fuel canisters



Goldmann et al., 1996

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Summary

- Drying of wetted Magnox spent fuel is complicated by reactivity of Magnox and uranium metal and the potential for generation of pyrophoric corrosion products and hydrogen gas
- The drying methods used internationally for similar fuels could be used to treat intact and broken Magnox spent fuel
- Little operational experience of encapsulation methods for spent fuel, and potential difficulties foreseen if applied to Magnox spent fuel
- Variety of containers could be considered in association with drying and conditioning options

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