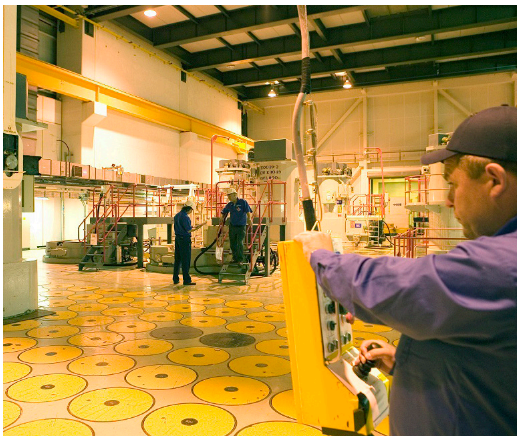
Department for Business, Energy & Industrial Strategy

Nuclear Decommissioning Authority

Radioactive Wastes in the UK:

Radioactive Wastes and Materials not Reported in the 2016 Waste Inventory



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2016 UK RADIOACTIVE WASTE & MATERIALS INVENTORY:
RADIOACTIVE WASTES AND MATERIALS NOT REPORTED IN THE 2016 WASTE INVENTORY

Report prepared for the Department for Business, Energy & Industrial Strategy (BEIS) and the Nuclear Decommissioning Authority (NDA) by Pöyry Energy Limited and Amec Foster Wheeler plc.

PREFACE

The 2016 United Kingdom Radioactive Waste & Materials Inventory (the 2016 Inventory) provides detailed information on radioactive wastes and materials in the United Kingdom (UK). It is produced by the Department for Business, Energy and Industrial Strategy (BEIS) and the Nuclear Decommissioning Authority (NDA).

The 2016 Inventory provides information on radioactive waste stocks (at 1 April 2016) and forecasts of future waste arisings. Information on radioactive materials that may be classed as waste in the future is also presented. The 2016 Inventory aims to provide data in an open and transparent manner for those interested in radioactive wastes and materials.

Information collected for the 2016 Inventory is presented in a suite of five reports:

- Summary Brochure
- Context and Methodology
- UK Radioactive Waste Inventory
- Radioactive Wastes and Materials Not Reported in the Waste Inventory
- Summary for International Reporting

All documents have been prepared using information supplied to the 2016 Inventory contractors, Pöyry Energy and Amec Foster Wheeler. This information was verified in accordance with arrangements established by Pöyry Energy and Amec Foster Wheeler in agreement with NDA.

This report provides a summary of radioactive wastes and materials not reported in the 2016 Radioactive Waste Inventory. This includes nuclear materials not currently deemed to be waste (some spent fuels, uranium and plutonium). It also includes potential radioactively contaminated land and other materials that are not yet sufficiently well characterised to be included in the Radioactive Waste Inventory.

Conditions of Publication

Feedback

We welcome feedback on the content, clarity and presentation of the UK Inventory reports. Please do not hesitate to contact us if you would like to provide feedback or if you would like further information about radioactive waste issues:

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Contents

GLOSSARY

	~	About.
	<	Less than.
A	**AGR**	Advanced Gas-cooled Reactor.
B	**BEIS**	The Department for Business, Energy & Industrial Strategy is a ministerial department that brings together responsibilities for business, industrial strategy, science, innovation, energy, and climate change.
D	**Depleted uranium**	Uranium where the uranium-235 isotope content is below the naturally occurring 0.72% by mass.
	DFR	Dounreay Fast Reactor (shut down in 1977).
	DNLEU	Depleted, Natural and Low Enriched Uranium.
	Dragon	Experimental high temperature reactor project sited at Winfrith (shut down in 1976).
	DU	Depleted Uranium.
E	**Enriched uranium**	Uranium where the uranium-235 isotope content is above the naturally occurring 0.72% by mass.
	Enrichment	The process of increasing the abundance of fissionable atoms in natural uranium.
	Euratom	European Atomic Energy Community.
	Ex situ	'Off the site' (in the context of waste disposal).
G	**GLEEP**	Graphite Low Energy Experimental Pile. Graphite reactor at Harwell site (shut down in 1990).
	Government	A collective term for the central government bodies responsible for setting radioactive waste management policy within the UK. It comprises the UK Government, the Scottish Government and the Devolved Administrations of Wales and Northern Ireland.
H	**HEU**	Highly Enriched Uranium. Uranium where the uranium-235 isotope content is 20% by mass or more.
	HVVLLW	High Volume Very Low Level Waste.
I	**IAEA**	International Atomic Energy Agency.
	ILW	Intermediate Level Waste.
	In situ	'On the site' (in the context of waste disposal).
	Irradiated fuel	Fuel that is being or has been used to power nuclear reactors.
L	**LEU**	Low Enriched Uranium. Uranium enriched in uranium-235 to less than 20% by mass.
	LLW	Low Level Waste.

	LLWR	Low Level Waste Repository. The LLWR, south of Sellafield in Cumbria, has operated as a national disposal facility for LLW since 1959.
	LLW Repository Ltd	*NDA* Site Licence Company that manages the *LLWR* and oversees the National LLW Programme.
	LWR	Light Water Reactor.
M ▸	**Magnox**	An alloy of magnesium used for fuel element cladding in natural uranium fuelled gas-cooled power reactors. Also a generic name for this type of reactor.
	MOD	Ministry of Defence.
	MOX	Mixed Oxide. Refers to nuclear fuel consisting of uranium oxide and plutonium oxide for use in reactors.
N ▸	**NDA**	Nuclear Decommissioning Authority. A non-departmental public body responsible for overseeing the decommissioning and clean-up of 17 of the UK's civil public sector nuclear sites.
	NU	Natural Uranium.
	Nuclear fuel	Fuel used in a nuclear reactor. Most fuel is made of uranium metal or oxide, and produces heat when the uranium atoms split into smaller fragments.
O ▸	**ONR**	Office for Nuclear Regulation (an agency of the Health and Safety Executive).
P ▸	**PIE**	Post-Irradiation Examination, of fuel elements etc.
	PFR	Prototype Fast Reactor (at Dounreay site; shut down in 1994).
	Plutonium	A radioactive element created in nuclear reactors. It can be separated from nuclear fuel by reprocessing. Plutonium is used as a nuclear fuel, in nuclear weapons and as a power source for space probes.
	Pu	Plutonium.
	PuO_2	Plutonium dioxide.
	PWR	Pressurised Water Reactor.
R ▸	**Radionuclide**	A general term for an unstable nuclide that emits ionising radiation (e.g. cobalt-60).
	Reprocessing	The chemical extraction of reusable uranium and plutonium from waste materials in spent nuclear fuel.
S ▸	**SGHWR**	Steam Generating Heavy Water Reactor (at Winfrith site; shut down in 1990).
	Spent fuel	Fuel that has been used (i.e. irradiated) in nuclear reactors that is no longer capable of efficient fission due to the loss of fissile material.

T ▸	**tHM**	Tonnes of heavy metal. A unit of mass used to quantify uranium, plutonium and thorium including mixtures of these elements.
	Thorium	Thorium is a naturally occurring radioactive element that can be mined, extracted and processed to make fuel for certain reactors.
	Thorp	Thermal Oxide Reprocessing Plant (at Sellafield site).
U ▸	**UF_4**	Uranium tetrafluoride.
	UF_6	Uranium hexafluoride.
	U_3O_8	Triuranium octoxide.
	UO_2	Uranium dioxide.
	UO_3	Uranium trioxide.
	Uranium	A radioactive element that occurs in nature. Uranium is used for nuclear fuel and in nuclear weapons.
	Uranium-235	Uranium-235 is the main fissile isotope of uranium. Natural uranium typically contains 0.72% by weight of uranium-235.
	Unirradiated fuel	Fuel that has not yet been used to power nuclear reactors.
V ▸	**VLLW**	Very Low Level Waste.
W ▸	**WAGR**	Windscale Advanced Gas-cooled Reactor (at Sellafield site; shut down in 1981).
Y ▸	**Yellowcake**	Yellowcake is concentrated uranium oxide, obtained through the milling of uranium ore. Yellow cake typically consists of 70-90% U_3O_8 with the remainder consisting of UO_2 and UO_3.
Z ▸	**Zenith reactor**	A research reactor at Winfrith that has been decommissioned.

1 INTRODUCTION

1.1 Radioactive materials

UK legislation [1, 2] defines radioactive material as a substance containing either one or more naturally-occurring or man-made radionuclides at concentrations exceeding those specified in the legislation.

Any radioactive material that has no further use, or a substance that has become contaminated by or incorporates radionuclides exceeding these specified concentrations, is known as radioactive waste.

As one of the pioneers of nuclear technology, the UK has accumulated a substantial legacy of radioactive waste from a variety of different civil and defence-related nuclear programmes. Some of this waste is already in storage, but most of it still forms part of existing facilities, and will only become waste over the next century or so as these plants are shut down, decommissioned and cleaned up.

As well as waste, past and existing nuclear programmes have produced an accumulation of radioactive materials such as spent (i.e. used) nuclear fuel, uranium and plutonium that are not currently designated as waste. In most cases this is because they have potential value. Spent fuel can be reprocessed to separate uranium and plutonium, which in turn can be used to manufacture fresh fuel. However, if it were decided at some point in the future, on the basis of economics, or environmental and safety issues, that these materials had no further use, they may need to be managed as wastes.

1.2 Government policy

Government[1] recognises that its policy for managing radioactive materials should be as comprehensive and forward looking as possible, and that the UK waste management strategy should include a clear idea of those radioactive materials that might come forward as waste. Consequently the UK Government in its framework for the long-term management of higher activity waste is also considering radioactive materials not currently classified as wastes [3].

The long-term management policy of the UK Government and that of the Northern Ireland executive for higher activity waste is geological disposal, preceded by safe and secure interim storage and supported by ongoing research. The Welsh government has also decided to adopt a policy for geological disposal and continues to support the policy of voluntary engagement [4].

The Scottish Government has a different policy for its higher activity waste; this is that long-term management should be in near-surface facilities [5]. Spent nuclear fuel, plutonium, uranium or other such radioactive fuels and materials are not covered by this policy.

With regard to plutonium, the Government's preferred long-term management option is to reuse the UK's civil plutonium stockpile as mixed oxide (MOX) fuel [6, 7].

Government policy for the long-term management of solid Low Level Waste (LLW) in the UK provides a high level framework of principles and outlines priorities for responsible and safe management of LLW [8]. Management of the LLW and Very Low Level Waste (VLLW) reported in this document will be subject to the same criteria as those reported in the

[1] The use of "Government" in this report refers collectively to the UK Government and the devolved administrations for Scotland, Wales and Northern Ireland.

Radioactive Waste Inventory; that is application of the waste hierarchy, making best use of existing LLW assets and the development of new fit-for-purpose waste management routes.

1.3 Nuclear safeguards

Civil nuclear facilities are subject to the UK's safeguards[2] agreements with international bodies - the International Atomic Energy Agency (IAEA) and the European Atomic Energy Community (Euratom) - and to the safeguards provisions of the Euratom treaty. These are designed to detect diversion of nuclear material into clandestine weapons programmes, and involve accounting for nuclear material and submitting to international inspection.

1.4 Government reporting

Government has obligations under the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management to report in these areas. The UK's 5th national report for the Convention was provided in October 2014 [9]. This report contains an inventory of spent nuclear fuel in storage, as well as volumes of radioactive waste in storage and projected in future arisings. National reports are subject to a process of peer review by the Contracting Parties and are updated every three years.

Government also publishes annual figures for the UK's stocks of civil plutonium and uranium, and in accordance with its commitment under the "Guidelines for the Management of Plutonium" provides figures to the IAEA. The latest figures are for 31 December 2015 [10].

1.5 The Inventory

An inventory of radioactive waste in the UK is compiled periodically by the Department for Business, Energy & Industrial Strategy (BEIS) and the Nuclear Decommissioning Authority (NDA).

Information from the Inventory helps the UK to plan safe and effective radioactive waste and material management routes, with high standards of protection for people and the environment. The Inventory:

- Enables the UK to meet international reporting obligations;
- Informs policy and strategy development;
- Aids radioactive waste and material management planning; and
- Supports stakeholder engagement.

The Inventory is used by a wide range of stakeholders, including:

- ***Government Departments and Agencies*** who develop policies and strategies for managing waste and who regulate nuclear operations;
- ***Supply chain organisations*** who process waste and need data to support the planning, operation and performance of their facilities;
- ***Waste planners*** who are responsible for ensuring that waste management facilities meet local and national needs;

[2] Nuclear safeguards are measures to verify that countries abide by their commitments to use nuclear material for declared peaceful purposes.

- ***Researchers and academics*** who are developing innovative technologies and processes for managing our radioactive wastes; and

- ***Members of the public*** who would like to understand more about radioactive waste.

1.6 Inventory documents

The 2016 UK Radioactive Waste & Materials Inventory (the 2016 Inventory) is the latest public record on the sources, quantities and properties of radioactive waste and materials in the UK at 1 April 2016 and predicted to arise after that date.

The 2016 Inventory comprises five reports:

- ***Summary Brochure*** – gives a high level overview of radioactive waste in the UK, waste quantities and waste management;

- ***Context and Methodology*** – provides information on how the Inventory was produced, including the scope of the Inventory and the terms and conventions used in reporting Inventory data;

- ***Radioactive Waste Inventory*** – describes the volume, radioactivity and composition of radioactive waste in the UK;

- ***Radioactive Wastes and Materials Not Reported in the Waste Inventory*** – summarises information on UK civil nuclear materials and other radioactive substances that might have to be managed as waste in the future; and

- ***Summary for International Reporting*** – gives a summary of information to meet the UK's international reporting obligations in the field of radioactive waste.

1.7 This report

This report brings together information about civil nuclear materials in the UK and other radioactive substances that might have to be managed as waste in the future.

It also includes land contamination (e.g. radioactively contaminated soil) that might arise as waste and radioactively contaminated subsurface structures (e.g. building foundations), where significant uncertainty over the management route and/or the waste quantities currently stands in the way of inclusion in the Radioactive Waste Inventory.

2 TYPES OF RADIOACTIVE MATERIAL

There are two types of radioactive material included in this report:

- Civil nuclear materials that are not currently deemed to be waste. This category comprises irradiated fuel, unirradiated fuel, uranium, plutonium and thorium; and
- Land that is potentially contaminated but is yet to be fully characterised, and hence where there is considerable uncertainty in the quantities that might arise. As a consequence some waste producers have chosen not to report current volume estimates in the 2016 Radioactive Waste Inventory.

2.1 Uranium

Uranium is a naturally occurring radioactive element that is the raw material used for making fuel for nuclear reactors. Uranium ore is processed to concentrate the uranium content, which is imported into the UK as triuranium octoxide (U_3O_8) – commonly referred to as yellowcake. This product is then further processed to produce uranium in a physical and chemical form suitable for fabricating into nuclear fuels.

There are different types (or grades) of uranium:

- **Natural Uranium (NU)**

Uranium in nature has a uranium-235 content of about 0.72% by mass. Natural uranium was used in its metallic form in Magnox reactor fuel[3].

- **Low-Enriched Uranium (LEU)**

Uranium enriched in uranium-235 to less than 20% by mass. LEU as uranium dioxide (UO_2) is used in the manufacture of Advanced Gas-cooled Reactor (AGR) and pressurised Water Reactor (PWR) fuels. Power reactor fuels have a typical initial uranium-235 content of between 3 and 5% by mass. LEU (with reduced uranium-235 content) is also a product of reprocessing these fuels. This recycled uranium is stored as uranium trioxide (UO_3).

- **High-Enriched Uranium (HEU)**

Uranium enriched in uranium-235 to 20% or more by mass. HEU is used in the manufacture of specialist nuclear fuels (e.g. for research reactors). In the past it has also been recovered by the reprocessing of these fuels.

- **Depleted Uranium (DU)**

Uranium with uranium-235 content less than in natural uranium. DU is a by-product of the uranium enrichment process used in the manufacture of nuclear fuels for AGR and PWR power stations. This is currently stored as uranium hexafluoride (UF_6). DU is also a product of reprocessing spent Magnox reactor fuel. This is stored as UO_3.

[3] *Some Magnox fuel was slightly enriched (<1% uranium-235) to offset the effects of reactor ageing.*

Yellowcake, the raw material used to manufacture uranium nuclear fuel

Fuel for civil nuclear reactors is manufactured at Springfields in Lancashire. Yellowcake is first converted through chemical processing into uranium tetrafluoride (UF_4). The next process stage depends on the type of fuel to be manufactured. AGR fuel is fabricated from low enriched uranium (UO_2). Here UF_4 is first converted to UF_6, which is enriched at Capenhurst in Cheshire. The enriched UF_6 is then converted to UO_2 at Springfields, which in turn is formed into ceramic pellets.

For Magnox reactor fuel UF_4 was converted to uranium metal: the manufacture of this fuel has now ceased.

Uranium recovered from the reprocessing of spent fuel can be re-enriched and re-utilised in new nuclear fuel. Some reprocessed uranium from the Magnox programme has in the past been used to manufacture new AGR fuel. Depleted uranium UF_6 can be enriched to provide feed stock for new fuel. Depleted uranium can also be mixed with plutonium to make MOX fuel.

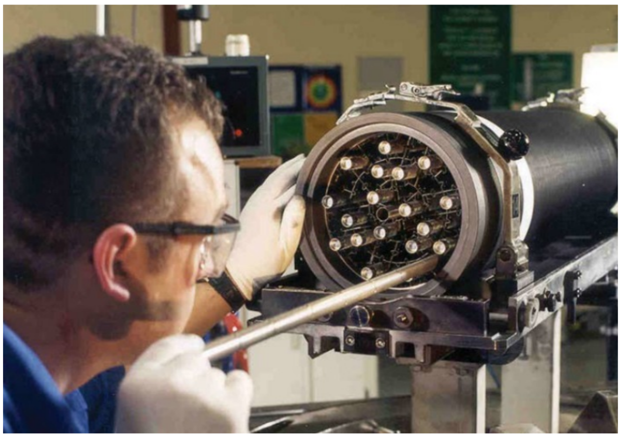
Depleted uranium (UO_3) in storage at Capenhurst

There are some uranium residues at Capenhurst that are not designated as waste. Residues are being processed to recover the uranium.

2.2 Thorium

Thorium is a naturally occurring radioactive element that can be mined, extracted and processed to make fuel for nuclear reactors. In the UK only experimental reactors have used thorium-based fuels. The Dragon high temperature helium-cooled reactor at Winfrith, which operated from 1964 to 1975, used a mix of uranium and thorium fuels. Dragon reactor fuel and unused reactor grade, thorium metal bars have already been designated as waste, and are reported in the 2016 Radioactive Waste Inventory.

2.3 Unirradiated fuel



Unirradiated fuel is nuclear fuel that has not yet been used to power nuclear reactors. It includes fuel at fabrication plants awaiting shipment and fuel at nuclear power stations awaiting loading into reactors.

There are also small quantities of surplus unirradiated research fuels.

Fuel manufacture at Springfields

2.4 Irradiated fuel

Irradiated fuel is nuclear fuel that is being or has been used to power nuclear reactors. When it has reached the end of its life and is no longer capable of efficient fission, it is known as 'spent fuel'. Spent fuel still contains large amounts of uranium (and some plutonium), which can be separated out through reprocessing and used to make new fuel. It is because of the potential value of the uranium and plutonium that it contains that most spent fuel is not classified as radioactive waste.

Civil nuclear power programme

In the UK, nuclear fuels are used in the AGR and PWR power stations[4]. Typically the spent fuel is made up of 96% unreacted uranium, 1% plutonium and 3% waste products, although the precise composition depends on the type of reactor and the amount of power produced by the fuel.

Spent Magnox and AGR fuel is stored at the power station for a short cooling period before transfer to Sellafield in Cumbria. All spent Magnox fuel is reprocessed at Sellafield. Spent AGR fuel is also reprocessed, but after the closure of the Thorp reprocessing plant in 2018 will be stored. Spent PWR fuel from Sizewell is currently stored at the station. Some spent Light Water Reactor (LWR) fuel from overseas is also held and reprocessed at Sellafield[5].

AGR spent fuel storage pond at Sellafield

[4] All Magnox power stations have been shut down; the last operating station at Wylfa was shut down in December 2015.

[5] The UK has contracts with other countries to reprocess their spent fuel. All contracts signed since 1976 provide for the return of recovered uranium and plutonium and associated waste to the country of origin. UK policy allows "waste substitution" arrangements that ensure broad environmental neutrality to the UK.

Other programmes

Until 1996 spent fuel was reprocessed at Dounreay in Caithness in support of the UK fast breeder reactor programme and overseas customers, but on a much smaller scale than at Sellafield. Some spent fuel remains in storage at the site[6].

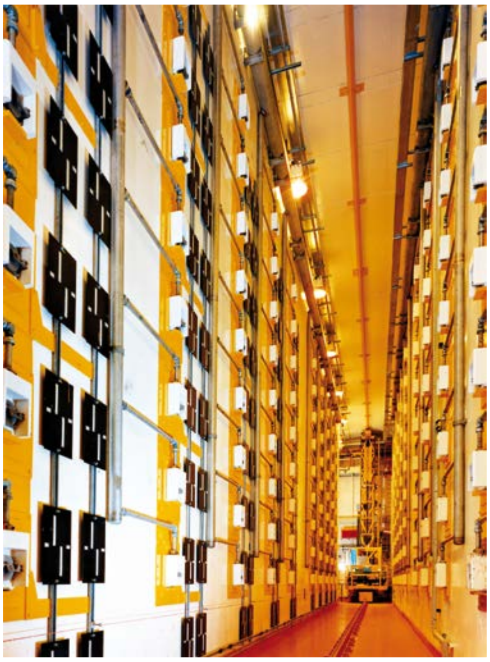
Uranium seperated from spent fuel at Dounreay

Other spent fuels have arisen from research, experimental and prototype reactors that are now shut down and being decommissioned. Spent fuel from the Windscale Advanced Gas-cooled Reactor (WAGR) and the Steam Generating Heavy Water Reactor (SGHWR) is stored at Sellafield; most of this fuel is planned to be reprocessed.

Small quantities of relatively low irradiation spent fuel that are not planned to be reprocessed have already been designated as waste and are reported in the 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.

2.5 Plutonium

Plutonium is a radioactive element that does not occur in nature. Plutonium is created in nuclear reactors as a result of 'burning' (i.e. irradiating) the uranium in nuclear fuel. It is contained within spent nuclear fuel when it is removed from the reactor, but can be extracted by reprocessing the fuel. Separated plutonium is stored as plutonium oxide powder within high integrity containers in purpose-built facilities at reprocessing sites.



Plutonium is a potentially valuable energy source. The original intention of recovering plutonium was to reuse the material in a future fast breeder reactor programme. Fast breeder reactors make more efficient use of nuclear materials – effectively generating more fuel than they consume. It was believed in the 1950s and 1960s that a closed nuclear fuel cycle was the most desirable option for future energy supply in light of the scarcity of uranium at the time. The UK fast breeder reactor programme was cancelled in the early 1990s as the forecast uranium supply shortage did not occur, therefore closing this option for the use of recovered plutonium.

Plutonium store at Sellafield

[6] NDA's nuclear material management strategy includes the transfer of Dounreay Fast Reactor (DFR) Breeder material and so-called "exotics" (various irradiated and unirradiated fuels) from Dounreay to Sellafield. Transports of Breeder material started in December 2012. The strategy also includes the transfer of fuel and nuclear material from Harwell to Sellafield.

However, plutonium can be used as a component of MOX fuel – a mixture of uranium and plutonium[7]. Some countries are using MOX fuel in their reactors, but MOX fuel (and hence UK-owned plutonium) is not currently used in UK reactors[8].

2.6 Radioactive land contamination and subsurface structures

Land (e.g. soil) and building structures that are beneath the surface may become contaminated as a result of lifetime site operations.

Land contamination that is *in situ* is not considered to be waste. It only becomes waste if it is excavated (e.g. for treatment or to access another subsurface structure). Much of the land contamination at nuclear sites is being managed *in situ* at present and may never require excavation.

Radioactively contaminated subsurface structures become waste when they no longer have a purpose, and whether they are disposed of *in situ* or excavated and disposed of *ex situ*. Examples are reactor basements, below ground ponds and radioactive effluent pipelines. The document '*Guidance on Requirements for Release of Nuclear Sites from Radioactive Substances Regulation (GRR)'* [11] from the environmental regulators directs nuclear operators to review their approach to site-wide waste management, to ensure the delivery of an optimised site end state. This may involve options for the *in situ* disposal of existing subsurface structures and the on-site disposal of associated above-ground parts.

There can be significant uncertainty in the quantities of waste from the clean-up of land contamination land and radioactively contaminated structures[9]. This is particularly the case for radioactive wastes at the lower end of the activity range referred to as VLLW. Because of these uncertainties it is likely that the estimated waste volumes in the UK Radioactive Waste Inventory will change.

Where clean-up plans have been confirmed, the waste resulting from radioactive land contamination and radioactively contaminated subsurface structures is reported in the 2016 Radioactive Waste Inventory. However, some waste producers have chosen to include information in this report until site characterisation has been completed and the optimal management or disposal route has been identified.

[7] *The Government's preferred option for long-term management of the UK's plutonium stockpile is reuse as MOX. Proposals on potential alternative approaches to long-term plutonium management have been made, and these are being reviewed by NDA.*

[8] *MOX fuel delivered to overseas reactors only contained plutonium that the overseas customer owned.*

[9] *Because of the uncertainties, potential volumes are not currently considered as part of LLW Repository Ltd's disposal capacity calculations or supply chain waste planning activities.*

3 MATERIAL QUANTITIES

A summary of key points:

- *UK-owned uranium stock is ~ 113,000 tHM*
- *UK-owned plutonium stock is ~103 tHM*
- *UK-owned irradiated fuel in reactor and in storage is ~7,700 tHM*
- *Reprocessing of irradiated fuel at Sellafield continues to 2020*

This chapter presents summary information on the quantities of radioactive materials in the UK. The information has been provided by the NDA and those organisations that operate sites in the UK where radioactive materials are stored and forecast to arise in the future.

Quantities of nuclear materials (uranium, thorium, plutonium, and irradiated and unirradiated nuclear fuels) are given as masses expressed as tonnes of heavy metal (tHM). Quantities of radioactive land contamination and radioactively contaminated subsurface structures are given as volumes expressed as cubic metres.

Appendix A sets out the assumptions used in reporting radioactive materials in the 2016 Inventory. Appendix B gives quantities of miscellaneous materials. Appendix C provides details of land contamination.

3.1 Uranium

Table 1 gives the total masses of UK-owned DNLEU (Depleted, Natural and Low Enriched Uranium) and HEU at 1 April 2016.

Table 1: UK-owned uranium Mass in stocks (tHM)

Location	Description	Stock at 1 April 2016
All UK sites	DNLEU	~113,000 (1)
All UK sites	HEU	<1

(1) The latest figure published by the Office for Nuclear Regulation (ONR is ~127,000 tHM at 31 December 2015 [10]*. This is greater than the figure reported here because it includes DNLEU present in irradiated fuels as well as foreign-owned uranium, both of which are reported separately in the 2016 Inventory (see Table 5 and text below).*

There are about 113,000 tHM of DNLEU in stock. The major components are depleted uranium from enrichment in the form of UF_6, and from reprocessing of Magnox fuel in the form of UO_3. DNLEU stocks are held at Capenhurst, Springfields, Sellafield and Dounreay. Table 4 excludes about 7,900 tHM of overseas-owned material.

Future arisings of UK-owned DNLEU are estimated at about 87,000 tHM. This figure assumes enrichment operations continuing over the next twenty years, and the irradiated fuel management scenario as described in Appendix A. The majority of anticipated future arisings are depleted uranium from enrichment operations.

In addition approximately 63,000 tHM of foreign-owned UF_6 are forecast for enrichment at Capenhurst. Future enrichment may utilise either existing uranium stocks or new uranium depending on the economics. Hence, there is uncertainty in the total quantities of DNLEU that will be produced.

There is currently less than 1 tHM of HEU in stock. This material comprises residues from reprocessing and fuel fabrication. No further arisings are expected.

3.2 Thorium

Table 2 gives the total mass of UK-owned thorium at 1 April 2016. There are no reported future arisings.

Table 2: UK-owned thorium Mass in stocks (tHM)

Location	Description	Stock at 1 April 2016
Springfields	ThO_2	~0.2 (1)

(1) The mass represents a significant reduction from that previously reported. This is due to unused reactor grade thorium metal bars being reported as radioactive waste in the 2016 Inventory.

3.3 Plutonium

Table 3 gives the total masses of UK-owned separated plutonium at 1 April 2016. Separated plutonium is held mainly as plutonium dioxide (PuO_2) from the reprocessing of Magnox and oxide fuel at Sellafield, with a small amount in other forms and fuel residues.

Table 3: UK-owned separated plutonium Mass in stocks (tHM)

Location	Description	Stock at 1 April 2016
All UK sites	PuO_2	~103

There are currently about 103 tHM of UK-owned separated plutonium in stock. Forecast arisings of plutonium from future UK spent fuel reprocessing at Sellafield will see this figure rise to about 114 tHM.

Existing stocks and forecast future arisings of plutonium from reprocessing overseas spent LWR fuel are about 24 tHM.[10]

3.4 Unirradiated fuel

Table 4 gives the masses of UK-owned unirradiated fuel in the UK. The total mass of unirradiated fuel at 1 April 2016 is estimated to be about 160 tHM. There will be future arisings of UK power reactor fuels to meet the fuelling requirements for projected reactor lifetimes, but these are not estimated.

[10] The UK Government has stated that overseas owners of plutonium stored in the UK could have that plutonium managed in line with UK plutonium, subject to commercial terms that are acceptable to the UK Government. In addition, subject to compliance with inter-governmental agreements and acceptable commercial arrangements, the UK is prepared to take ownership of overseas plutonium stored in the UK as a result of which it would be treated in with the same way as UK-owned plutonium. The Government considers that there are advantages to having national control over more of the civil plutonium in the UK, as this gives greater influence over how it is ultimately managed [3].

Table 4: UK-owned unirradiated fuel Mass in stocks (tHM)

Location	Description	Stock at 1 April 2016
Sellafield	Various (1)	~13
Dounreay	Various (2)	~11
Wylfa	Magnox fuel	<0.1
All UK sites	AGR fuel	~100
All UK sites	PWR fuel	~40
Total		**~160**

(1) Includes unirradiated uranium metal, uranium oxide and MOX fuels.

(2) Includes unirradiated PFR, MOX and carbide fuels.

3.5 Irradiated fuel

The UK's current stock of irradiated fuel consists mainly of Magnox, AGR and PWR fuels, but also includes smaller stocks of various irradiated experimental and research fuels.

Table 5 gives the masses of UK-owned irradiated fuel at 1 April 2016 and estimated in future arisings. The total mass of irradiated fuel at 1 April 2016 was about 7,700 tHM, with estimated future arisings of about 2,900 tHM. The figures for irradiated fuel at 1 April 2016 exclude about 0.7 tHM of overseas-owned spent fuel at Dounreay.

It is planned that the remaining Magnox fuel, SGHWR and other spent fuels at Sellafield, and DFR breeder material currently stored at Dounreay, will be reprocessed (apart from small quantities that are unsuitable). A proportion of the fuel produced over the lifetime of the AGR stations will be reprocessed. It is assumed that about 5,500 tHM of spent AGR fuel will remain in long-term storage. Actual quantities of fuel to be reprocessed and/or stored are subject to contractual arrangements to be agreed between NDA and its customers.

The Sizewell B PWR station is expected to generate about 1,000 tHM spent fuel over its 40-year operating lifetime. It is currently assumed that this fuel will be held in long-term storage.

Table 5: UK-owned irradiated fuel Mass in stocks and estimated for future arisings (tHM)

Location	Description	Stock at 1 April 2016 (1)		Estimated future arisings
		In reactor	In storage	
Sellafield	Magnox fuel		750	- (2)
	AGR fuel		~2,400	- (3)
	SGHWR fuel		120	0
	WAGR fuel		31	0
	Other fuels (4)		~850	0
Dounreay	DFR breeder fuel	32	1	0

	PFR		10	0
	Other fuels		<1	0
Magnox power stations (5)	Magnox fuel	~1,200	49	0
AGR power stations	AGR fuel (6)	~1,600	40	~2,500
PWR power station	PWR fuel (6)	90	550	410
Others	Various		~1 (7)	0
Total		**~2,900**	**~4,800**	**~2,900**

(1) Fuel 'In reactor' is that in reactor cores; fuel 'In storage' has been removed from reactor cores to storage facilities.

(2) See Magnox power stations for future transfers of spent fuel to Sellafield.

(3) See AGR power stations for future transfers of spent fuel to Sellafield.

(4) Includes former overseas LWR fuel transferred to UK ownership and 1.6 tHM DFR breeder fuel transferred from Dounreay.

(5) Includes Calder Hall on the Sellafield site.

(6) From data provided by EDF Energy and from best available public domain information.

(7) Comprises low irradiated fuels at Harwell.

3.6 Miscellaneous materials

There are a number of uranic residues at Capenhurst (see Appendix B for a list of streams and quantities). These materials continue to be processed off-site to recover the uranium content. Any radioactive waste from this activity is being disposed of by the processing site and is included in the 2016 Inventory.

3.7 Radioactive land contamination and radioactively contaminated subsurface structures

The estimated volume of radioactive land contamination reported here is about 6,200,000 m^3. Most of this is High Volume VLLW (HVVLLW) and LLW contaminated soil at Sellafield.

The estimate of contaminated soil at Sellafield is less than half that reported in the 2013 Inventory, as the site has introduced an improved analysis methodology that considers variation in the distribution of contamination across the site. Furthermore, the proportion of LLW has increased (and the proportion of VLLW decreased) with the systematic application of national waste management categories to all material under the care of land quality. This includes material that was previously categorised as VLLW for on-site disposal in current facilities, but would require management as LLW if disposal occurred in another facility. Much of the radioactively contaminated soil on site can be managed *in situ* and will not require excavation and treatment as waste (see Appendix C for further information).

The estimate of radioactively contaminated subsurface structures reported here is about 240,000 m^3. This mostly comprises building foundations at Sellafield.

The 2016 Radioactive Waste Inventory itself includes a further 140,000 m^3 of contaminated soil and spoil from radioactive land contamination, principally at Sellafield, Capenhurst, Harwell, Winfrith, Aldermaston and Magnox reactor sites. It also includes radioactively contaminated subsurface structures as a component of site decommissioning waste streams.

4 REFERENCES

[1] “Radioactive Substances Act 1993 (as amended),” 27 May 1993.

[2] “Environmental Permitting (England and Wales) Regulations 2010 (as amended). Statutory Instrument,” 10 March 2010.

[3] Department of Energy & Climate Change, “Implementing Geological Disposal: A Framework for the long-term management of higher activity radioactive waste,” July 2014.

[4] Welsh Government, “Welsh Government Policy on the Management and Disposal of Higher Activity Radioactive Waste,” 2015.

[5] The Scottish Government, “Scotland's Higher Activity Radioactive Waste Policy 2011,” January 2011.

[6] Department of Energy & Climate Change, “Management of the UK's plutonium stocks. A consultation response on the long-term management of UK-owned separated civil plutonium,” URN 11D/819, December 2011.

[7] Department of Energy & Climate Change, “Management of the UK's plutonium stocks. A consultation response on the proposed justification process for the reuse of plutonium,” URN 13D/091, May 2011.

[8] Department for Environment, Food and Rural Affairs, “Policy for the Long Term Management of Solid Low Level Radioactive Waste in the United Kingdom,” March 2007.

[9] Department of Energy & Climate Change, “The United Kingdom's fith national report on cpompliance with the obligations of the Joint Convention on the safety of spent fuel management and on the safety of radioactive waste management,” URN 14D/471, October 2014.

[10] Office for Nuclear Regulation, “Annual Civil Plutonium and Uranium Figures as of 31 December 2015”.

[11] Scottish Environment Protection Agency, Environment Agency, Natural Resources Wales, “Guidance on Requirements for Release of Nuclear Sites from Radioactive Substances Regulation. Consultation Document,” February 2016.

APPENDIX A ASSUMPTIONS USED FOR REPORTING CIVIL NUCLEAR MATERIALS

All assumptions listed below are in line with those used in compiling data for the 2016 Inventory. These assumptions represent the planning positions at 1 April 2016 of the organisations that operate sites where radioactive waste and materials are generated or held. Projections may need to be amended as plans and arrangements are developed or are changed for commercial, policy or funding reasons, or if improved data become available.

Generic assumptions

- Plutonium, uranium and irradiated nuclear fuel from UK civil nuclear power stations have potential value as they can be reused for manufacturing fresh nuclear fuel. These materials are not currently classified as waste.

- Small quantities of relatively low irradiation spent fuel that are not planned to be reprocessed have already been designated as waste and are reported in the 2016 Inventory (i.e. excluded from this report).

- A proportion of irradiated fuel arising from UK gas-cooled reactors is reprocessed (see assumptions below). To report this irradiated fuel as well as the plutonium and uranium that is recovered by reprocessing the fuel would result in double counting of nuclear materials. To prevent double counting, the radioactive materials inventory includes quantities of plutonium, uranium and spent fuel that were held in the UK at 1 April 2016, as well as future arisings of irradiated fuel. The estimated quantities of plutonium and uranium that will be recovered by future fuel reprocessing are given for information.

- The radioactive materials inventory reports UK materials. Quantities of overseas-owned materials currently held in the UK are given for information.

- The radioactive materials inventory does not include nuclear materials owned by the Ministry of Defence (MOD) or ‘small users’ (i.e. universities and research establishments).

- Land contamination is managed *in situ* under existing regulatory requirements. Some of this material may never arise as waste. Volumes estimates are based on the most recent characterisation data and understanding of the site, and are subject to change as knowledge of the site improves. Where land remediation work or other actions will generate waste this is reported in the Radioactive Waste Inventory.

- Radioactively contaminated subsurface structures are likely to be difficult to characterise. The structures reported here are those not sufficiently well characterised to be included in the Radioactive Waste Inventory.

Irradiated fuel arisings

- In addition to the spent fuel already generated from the 11 shutdown Magnox power stations in the UK, irradiated fuel will arise from the operations and final defuelling of the following nuclear power stations:

Table A1: Operating nuclear power stations in the UK

Station	Planned shutdown date
AGR:	
Hinkley Point B	2023
Hunterston B	2023
Hartlepool	2024
Heysham 1	2024
Dungeness B	2028
Heysham 2	2030
Torness	2030
PWR:	
Sizewell B	2035

Note: Arisings from new nuclear power stations are not included in this report.

- No new nuclear power stations are assumed to be constructed in the UK[11].

Irradiated fuel management

- Nuclear fuel manufacturing in the UK is assumed to continue until 2030.
- The following spent fuel that has been produced or is forecast to arise from UK reactors is assumed to be reprocessed at Sellafield:
  - About 55,000 tHM from Magnox reactors, of which over 53,000tHM had been reprocessed by 1 April 2016;
  - About 5,000 tHM from AGRs, of which about 4,100tHM had been reprocessed by 1 April 2016;
  - 9 tHM from WAGR;
  - About 115 tHM from SGHWR;
  - About 44 tHM from DFR, of which 11tHM had been reprocessed by 1 April 2016; and
  - Small amount of Post Irradiation Examination (PIE) type materials.
- Approximately 4,300 tHM of foreign-owned LWR spent fuel has been reprocessed in the UK.

[11] *The UK Government has stated that it supports new nuclear power stations and some operators are planning new stations. However no final investment decisions had been taken at the 2016 Inventory stock date.*

- The following spent fuel that has been produced or is forecast to arise from UK reactors is assumed to be held in long-term storage in the UK (i.e. there are no current plans for reprocessing these fuels)[12]:
  - 5,500 tHM from AGRs;
  - 1,050 tHM from the Sizewell B PWR; and
  - Small quantities of other fuels, including some SGHWR and WAGR fuel.

Separated uranium and plutonium arisings & management

- Separated uranium and plutonium is assumed to arise in the UK from the reprocessing activities listed above. Spent Magnox fuel reprocessing is assumed to be complete by 2020; spent oxide fuel reprocessing in Thorp by the end of 2018; and
- All UK-owned separated uranium and plutonium is assumed to be held in long-term storage in the UK.

[12] *Although plutonium, uranium and spent fuel are not classified as waste, these materials are considered in the inventory for disposal in the Government's 'Implementing Geological Disposal' framework for long-term management of higher activity radioactive waste.*

APPENDIX B MISCELLANEOUS MATERIALS

This appendix gives the quantities of miscellaneous materials. These are uranic residues from uranium enrichment operations at Capenhurst.

Table B1: Miscellaneous materials
Mass at 1 April 2016 and estimated future arisings (tHM)

Site	Stream identifier	Stream description	Stock at 1 April 2016	Future arisings
Capenhurst	8A13	Technetium contaminated uranic residues	0	~16,100 (1)
	8A14	Uranic residues	13.5 (1)	0
	M8A1011	Chemical adsorber trap residues (CATR)	<24.4	<106
	M8A1012	Citric sludge	<0.22	<4.4
	M8A1013	Degreaser sludge	<0.23	<4.5
	M8A1014	Effluents	<79.4	<38
	M8A1015	Uranic residues	<0.65	<0.8

(1) *Volume (m^3) of material.*

APPENDIX C RADIOACTIVELY CONTAMINATED LAND AND SUBSURFACE STRUCTURES

This appendix presents volumes of potential radioactive land contamination and radioactively contaminated subsurface structures. These are not recorded in the 2016 Radioactive Waste Inventory because the waste producers have chosen to include them with radioactive materials until characterisation provides more certainty on their management and disposal route, and the quantities that might come forward as waste. Table C1 lists streams at Sellafield, Springfields, Aldermaston and the LLWR.

Table C1: Potential radioactive land contamination and radioactively contaminated subsurface structures

Site	Stream identifier	Stream description	Estimated volume (m^3) (1)
Sellafield	2D150	Contaminated Soil ILW	1,600
	2D151	Contaminated Soil LLW	2,560,000
	2D152	Contaminated Foundations ILW (2)	2,200
	2D153	Contaminated Foundations LLW (2)	33,000
	2D154	Contaminated Soil from Site Clearance - HVVLLW	3,490,000
	2D155	Contaminated Foundations from Site Clearance – HVVLLW(2)	200,000
Springfields	2E5000	Radioactive Contaminated Land	<32,500 (3)
Aldermaston	7A5000	Radioactive Contaminated Land	~110,000
LLWR	2N101	Vault Profiling Material from PCM Facilities VLLW	10,800
	2N102	Contaminated Land VLLW	3,700
All sites		**Total**	**6,440,000**

(1) *Volumes are currently being managed in situ under existing regulatory requirements for the management of contaminated land and groundwater on nuclear sites. Some of this material may never arise as waste or the optimum management plan may be some form of in situ disposal, particularly for the most lightly contaminated material.*

(2) *Some of this material may be suitable for beneficial reuse or the optimum management plan may be some form of in situ disposal.*

(3) *Volumes are uncertain, but will be established during ongoing land contamination projects.*

The volumes given for Sellafield in Table C1 represent the best estimate of land affected by radioactive contamination in the various waste categories. They are estimates based on the most recent characterisation data and understanding of the site, and are subject to constant review as knowledge of the site improves. The Sellafield strategy is to manage land contamination *in situ* in the short-term. In the longer-term access to the contamination will be possible when extensive decommissioning takes place. It is not envisaged that, on the basis of an overall balance between risk and benefit, all contaminated material will be excavated. In particular, for the most lightly contaminated material within the HVVLLW category the optimum plan may be *in situ* management.

At Springfields the stock volume is based on site investigations and the results of soil samples collected from boreholes. At Aldermaston about 110,000 m^3 of land associated with process buildings have been identified as having the potential to be contaminated. At the LLWR the estimate of land contamination is based on non-targeted ground investigation and therefore has high uncertainty. At all three sites further site investigation work will give clearer information on potential volumes.

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