Department for
Business, Energy
& Industrial Strategy

2019 UK Radioactive Material Inventory

December 2019

2019 UK RADIOACTIVE MATERIAL INVENTORY

Report prepared for the Department for Business, Energy & Industrial Strategy (BEIS)
and the Nuclear Decommissioning Authority (NDA)
by Pöyry Energy Ltd and Wood Nuclear Ltd

PREFACE

The 2019 United Kingdom Radioactive Waste & Materials Inventory (the 2019 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 2019 Inventory provides information on radioactive waste stocks (at 1 April 2019) and forecasts of future waste arisings. Information on radioactive materials that may be classed as waste in the future is also presented. The 2019 Inventory aims to provide data in an open and transparent manner for those interested in radioactive wastes and materials.

Information collected for the 2019 Inventory is presented in a suite of four reports:

- 2019 UK Radioactive Waste Inventory
- 2019 UK Radioactive Material Inventory
- 2019 UK Radioactive Waste Detailed Data
- 2019 Summary of UK Radioactive Waste and Material Inventory for International Reporting.

All documents have been prepared using information supplied by the radioactive waste producers and custodians to the 2019 Inventory contractors, Wood and Pöyry Energy. This information was verified in accordance with arrangements established by Wood and Pöyry Energy in agreement with NDA.

This report provides a summary of radioactive wastes and materials not reported in the 2019 UK 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.

Feedback

We welcome feedback on the content, clarity and presentation of the 2019 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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Uranium hexafluoride cylinders at Capenhurst

1 INTRODUCTION

1.1 The Inventory

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

The inventory provides up-to-date information about radioactive waste to:

- Enable the UK to meet international reporting obligations
- Inform policy and strategy development
- Aid radioactive waste and material management planning
- Support stakeholder engagement.

The inventory is used by a wide range of stakeholders:

Government departments & agencies	Develop policies and strategies for managing UK radioactive waste and regulating nuclear operations
Supply chain organisations	Process waste and use data to support the planning, operation and performance of their facilities
Waste planners	Ensure that radioactive waste management facilities meet local and national needs
Researchers & academics	Develop innovative technologies and processes for managing the range of radioactive waste in the UK
Members of the public	Increase in understanding about the types and quantities of radioactive waste produced in the UK

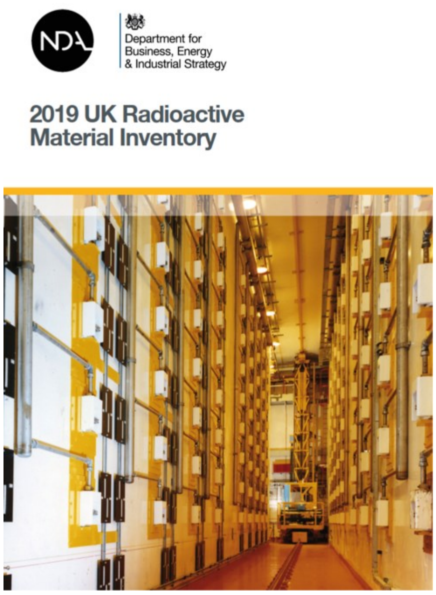
The 2019 UK Radioactive Waste & Materials Inventory (the 2019 Inventory) is the latest public record on the sources, quantities and properties of radioactive waste and materials in the UK at 1 April 2019 and predicted to arise after that date.

1.2 Inventory documents

The 2019 Inventory comprises four reports:

Radioactive Waste Inventory

Describes the sources, volume, composition and activity of radioactive waste in the UK, and a comparison with the previous inventory



Radioactive Material Inventory

Summarises the quantities of UK civil nuclear materials that might have to be managed as waste in the future

Waste Detailed Data

Provides further information on the radioactive waste inventory including a list of waste streams

Summary for International Reporting

Gives information to meet the UK's international reporting obligations in the field of radioactive waste and materials

As part of the commitment to openness, NDA has created a website dedicated to the Inventory, www.nda.gov.uk/ukinventory, where all of the 2019 Inventory reports can be found together with other information about radioactive waste.

1.3 This report

This report brings together information about civil nuclear materials in the UK and other radioactive substances that are not currently classed as waste but that might have to be managed as waste in the future.

Information covers radioactive materials that existed on 1 April 2019 and those forecast to arise in the future. Information is collected about the type and quantity of radioactive materials that exist in operational reactors and stores. Also collected are estimates of future arisings of radioactive materials.

This report 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.

UK defence activities produce irradiated fuel, but this fuel is not included in this report.

AGR fuel flask in Fuel Handling Plant, Sellafield

2 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.

Through past and current nuclear programmes, the UK has accumulated radioactive materials such as spent (i.e. used) nuclear fuel, uranium and plutonium. These materials are not currently designated as radioactive waste by their owners. If it were decided at some point in the future that these materials had no further use, they would need to be managed as wastes.

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

- **Civil nuclear materials and spent fuel** that are not currently deemed to be waste. This category comprises uranium, thorium, plutonium, unirradiated fuel and spent fuel.
- **Land that is potentially contaminated with radioactivity** but is yet to be fully characterised, and therefore has considerable uncertainty in the quantities that may arise. As a consequence these provisional volume estimates are not reported in the 2019 UK Radioactive Waste Inventory.

Excluded are nuclear materials outside safeguards. The UK Safeguards Office defines non-safeguarded nuclear material as "*nuclear material that is excluded from the accountancy and safeguards requirements for reasons of national security and/or defence purposes*"[3]. Also excluded are small quantities of nuclear materials with very low concentrations of activity typically from research establishments, universities and the non-nuclear industry.

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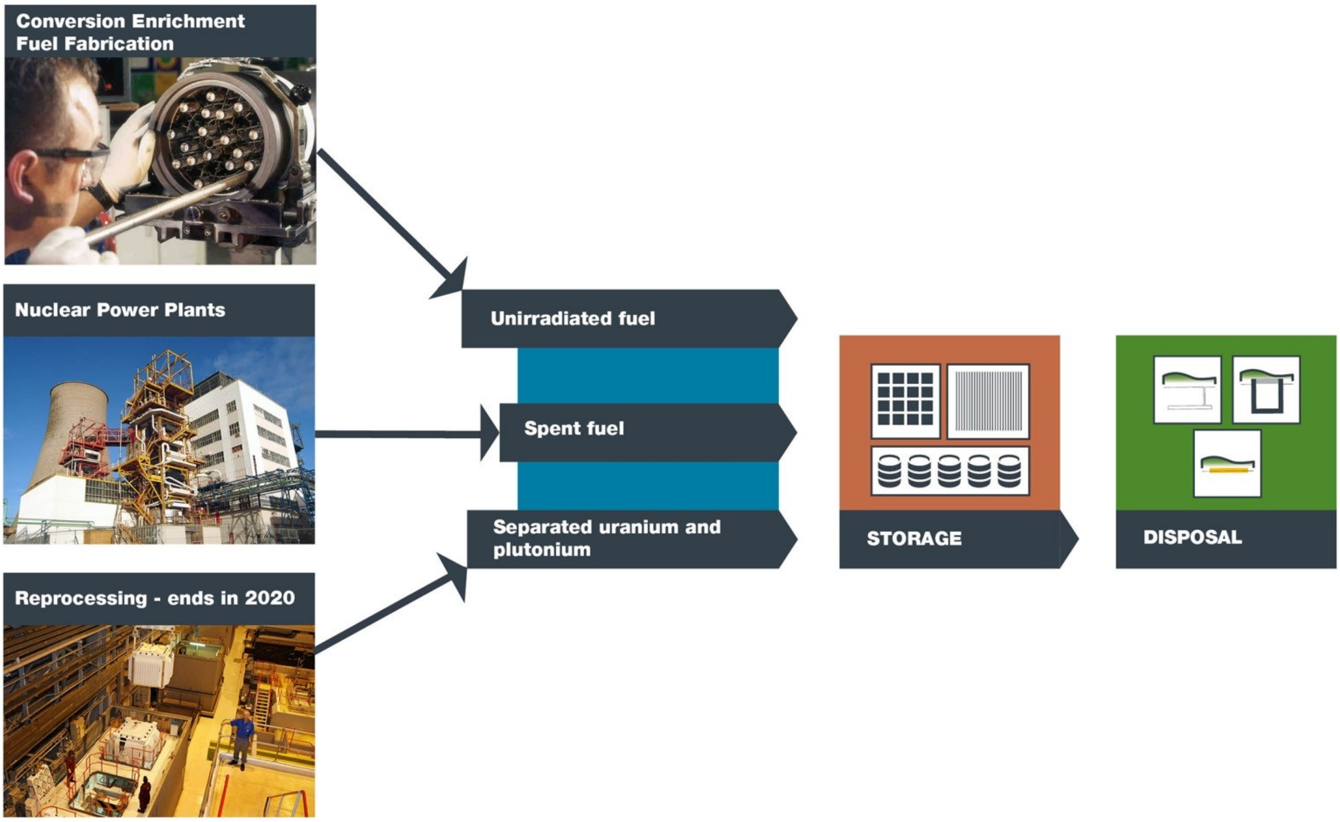
[1] Radioactive Substances Act 1993 (as amended), 27 May 1993.
[2] Environmental Permitting (England and Wales) Regulations 2010 (as amended). Statutory Instrument, 10 March 2010.
[3] Nuclear licensed sites used solely for defence purposes are not subject to safeguards requirements. Nevertheless, it is Ministry of Defence (MOD) policy to have nuclear materials accountancy standards and management arrangements that are, so far as reasonably practicable, at least as good as those required by safeguards legislation. Civil nuclear licensed sites that handle nuclear materials excluded from safeguards for reasons of national security/defence requirements are expected to comply with the MOD requirements.

The diagram below illustrates the 'nuclear fuel cycle', a sequence of industrial activities for processing uranium and manufacturing nuclear fuel to generate electricity by nuclear power. It also includes activities to manage depleted uranium hexafluoride from the uranium enrichment process (storage and deconversion) and spent nuclear fuel (reprocessing[4] and storage). Information on the use of nuclear materials and nuclear fuels in the UK is given on the following pages.



[4] *Spent fuel reprocessing in the UK will come to an end in 2020. The recycling of separated uranium from reprocessing has not been carried out since the mid-1990s.*

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 exported from the mines 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[5].

Highly Enriched Uranium (HEU)

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

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 AGR and 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 in Thorp. This recycled uranium is stored as uranium trioxide (UO_3).

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. DU is a component of MOX fuel.

To manufacture fuel for the current UK civil nuclear reactors, yellowcake is first converted through chemical processing into uranium hexafluoride UF_6, which is enriched to LEU. The enriched UF_6 is then converted to UO_2 and formed into ceramic pellets which are fabricated into fuel pins and assemblies. In the UK, enrichment is carried out at Capenhurst in Cheshire and enriched oxide fuel is fabricated at Springfields in Lancashire.

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 mixed oxide (MOX) fuel.

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 2019 UK Radioactive Waste Inventory.

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

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.

Assembling an AGR fuel element at Springfields

2.4 Spent 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'. 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.

There are three main types of nuclear power reactor that have operated in the UK (Magnox, AGR and PWR), and spent fuel from each is handled differently.

Magnox	Spent fuel from Magnox reactors[6] is currently reprocessed, but this is due to be completed in 2020. Any remaining fuel will be stored pending decisions about its future disposal.
AGR	Reprocessing of spent fuel from AGRs was completed in November 2018. The remaining and future spent fuel from the seven AGR stations will be stored at Sellafield pending decisions about its future disposal.
PWR	Spent fuel from the Sizewell B PWR is stored at the station pending decisions about its future disposal.

[6] *All Magnox power stations are shut down.*

AGR spent fuel flasks at Sellafield

Spent fuel has also arisen from the various test and prototype reactors, both large and small, that have operated in the UK. These include the PFR and DFR at Dounreay, DIDO and PLUTO at Harwell, WAGR at Windscale and SGHWR at Winfrith.[7] Much of the spent fuel from these reactors has been reprocessed, and the remaining fuel will be stored pending decisions about its future disposal.[8]

New nuclear power stations built in the UK will also produce spent fuel. It is not yet clear how many reactors and of what design might be constructed, and it is for these reasons an estimate of spent fuel from nuclear new build is not included in this report. An assumed new build programme is accounted for in Low Level Waste Repository Ltd's (LLWR's) Environmental Safety Case and Radioactive Waste Management's (RWM's) Inventory for Geological Disposal.

Small quantities of relatively low irradiation spent fuel have already been designated as waste and are reported in the 2019 UK Radioactive Waste Inventory. These comprise spent fuels from the Graphite Low Energy Experimental Pile (GLEEP) and the Dragon and Zenith reactors, plus small quantities of Windscale Pile fuel and prototype commercial fuels.

[7] *All of these research reactors, and their associated facilities, are shut down and being decommissioned or have already been decommissioned.*

[8] *NDA's nuclear material management strategy includes the transfer of Dounreay Fast Reactor (DFR) breeder material and so-called "exotics" (various spent 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.*

2.5 Plutonium

Plutonium is a radioactive element that does not occur in nature; it is created in nuclear reactors as a result of 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.

However, plutonium can be used as a component of MOX fuel – a mixture of uranium and plutonium (see section 3.1). Some countries are using MOX fuel in their reactors, but MOX fuel (and hence UK-owned plutonium) is not currently used in UK reactors.

Plutonium store at Sellafield

2.6 Radioactive land contamination

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.[9]

There can be significant uncertainty in the quantities of waste from the clean-up of land contamination and radioactively contaminated structures.[10] 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 2019 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.

Clearing land contamination at Harwell

[9] *The document 'Guidance on Requirements for Release of Nuclear Sites from Radioactive Substances Regulation (GRR)', February 2016, 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.*

[10] *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.*

Aerial view of Capenhurst

3 MATERIALS MANAGEMENT

3.1 Management policy

Government recognises that its policy for managing radioactive materials in the long term 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 through geological disposal is also considering radioactive materials not currently classified as wastes[11].

Spent fuel

Historically the UK's approach has been to reprocess spent nuclear fuel in order to recover the uranium and plutonium content, however, this will cease in 2020. All remaining and future spent fuel arising from nuclear power stations in the UK will be stored pending a future decision on whether to declare them as waste for disposal in a GDF.

Nuclear materials

The strategy for nuclear materials management in the UK is safe and secure storage pending development of cost-effective lifecycle solutions for their management in line with UK Government policy[12].

For plutonium the priority is to provide a solution that puts the UK's civil plutonium beyond reach. This is because continued, indefinite, long-term storage leaves a burden of security risks and proliferation sensitivities for future generations to manage.

In 2011 the UK Government set out its preferred policy for the long-term management of civil separated plutonium – that it should be reused in the form of MOX fuel[13,14]. At that time the Government believed that there was sufficient information to set out a direction, but not to implement a MOX programme. Since then the Government has been working closely with the NDA to develop, assess and ultimately to implement approaches to put the inventory of separated civil plutonium beyond reach. As a proportion of the inventory cannot be reused, both reuse as new nuclear fuel and immobilisation are being considered. Only when the UK Government is confident that a solution can be implemented safely and securely and that it is affordable, deliverable, and offers value for money will any programme proceed.

Uranium has the potential to be reused in nuclear fuel for generating electricity. Uranium stocks are held in safe and secure storage on fuel manufacture, enrichment and reprocessing sites pending the development of disposition options. If it were decided that some of these materials have no future value they may need to be managed as waste.

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

[12] Nuclear Decommissioning Authority, "Strategy Effective from April 2016", March 2016.

[13] 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

[14] 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.

3.2 Nuclear safeguards

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

Civil nuclear facilities are subject to the UK's safeguards 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.

3.3 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 6th national report for the Convention was provided in October 2017[15]. 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 2018[16].

[15] *Department for Business, Energy & Industrial Strategy, "The United Kingdom's Sixth National Report on Compliance with the Obligations of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management," October 2017.*
[16] *Office for Nuclear Regulation http://www.onr.org.uk/safeguards/civilplut18.ttm*

4 MATERIAL QUANTITIES

Key facts:

- UK-owned uranium stock is ~ 99,000 tHM
- UK-owned plutonium stock is ~112 tHM
- UK-owned spent fuel in reactor and in storage is ~6,100 tHM
- Reprocessing of spent fuel at Sellafield ends in 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 spent 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.

The Appendix sets out the assumptions used in reporting radioactive materials in the 2019 Inventory.

4.1 Uranium

Table 1 gives the total masses of UK-owned DNLEU (Depleted, Natural and Low Enriched Uranium) and HEU at 1 April 2019.

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

Location	Description	Stock at 1 April 2019
All UK sites	DNLEU	~99,000 (1)
All UK sites	HEU	<1

(1) The latest figure published by the Office for Nuclear Regulation (ONR) is 111,600 tHM at 31 December 2018. This is greater than the figure reported here because it includes DNLEU present in spent fuels as well as foreign-owned uranium, both of which are reported separately in the 2019 Inventory (see Table 5 and text below).

There are about 99,000 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 1 excludes about 9,300 tHM of overseas-owned material.

Future arisings of UK-owned DNLEU are estimated at about 85,000 tHM. This figure assumes enrichment operations continuing over the next twenty years, and the spent fuel management scenario as described in the Appendix. 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.

4.2 Thorium

Table 2 gives the total mass of UK-owned thorium at 1 April 2019. There are no reported future arisings.

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

Location	Description	Stock at 1 April 2019
Springfields	ThO_2	~0.2

4.3 Plutonium

Table 3 gives the total masses of UK-owned separated plutonium at 1 April 2019. 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 2019
All UK sites	PuO_2	~112

There are currently about 112 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 of plutonium from reprocessing overseas spent LWR fuel are about 24 tHM[17].

[17] *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 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.*

4.4 Unirradiated fuel

Table 4 gives the masses of UK-owned unirradiated fuel in the UK. The total mass of unirradiated fuel at 1 April 2019 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.

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

Location	Description	Stock at 1 April 2019
Sellafield	Various (1)	~19
Dounreay	Various (2)	~0.2
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.

4.5 Spent fuel

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

Table 5 gives the masses of UK-owned spent fuel at 1 April 2019 and estimated in future arisings. The total mass of spent fuel at 1 April 2019 was about 6,000 tHM, with estimated future arisings of about 2,100 tHM. The figures for spent fuel at 1 April 2019 exclude about 0.7 tHM of overseas-owned spent fuel at Dounreay.

The remaining spent Magnox fuel and DFR breeder material will be reprocessed (apart from small quantities that are unsuitable). Reprocessing of spent AGR fuel came to an end in November 2018; existing stocks and future arisings produced over the planned lifetimes of the AGR stations (in total about 5,500 tHM) will remain in long-term storage.

The Sizewell B PWR station is expected to generate about 1,050 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 spent fuel
Mass in stocks and estimated for future arisings (tHM)

Location	Description	Stock at 1 April 2019 [1]		Estimated future arisings
		In reactor	In storage	
Sellafield	Magnox fuel	- [2]	625	- [3]
	AGR fuel	-	~2,050	- [4]
	SGHWR fuel	-	68	-
	WAGR fuel	-	21	-
	Other fuels [5]	-	~790	-
Dounreay	DFR breeder fuel	~21	~3	-
	PFR	-	10	-
	Other fuels	-	~1	-
Magnox power stations [6]	Magnox fuel	149	73	-
AGR power stations	AGR fuel [7]	~1,500	~150	~1,800
PWR power station	PWR fuel [7]	~90	~530	~430
Others	Various		~1 [8]	-
Total		**~1,800**	**~4,300**	**~2,200**

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

(2) Fuel at Calder Hall is included under 'Magnox power stations'.

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

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

(5) Includes various legacy uranium metal and oxide fuels, former overseas LWR fuel transferred to UK ownership and DFR breeder fuel transferred from Dounreay.

(6) Includes Calder Hall on the Sellafield site.

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

(8) Comprises low irradiated fuels at Harwell.

4.6 Miscellaneous materials

There are a number of uranic residues at Capenhurst from uranium enrichment operations. Table 6 includes 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 2019 Inventory.

Table 6: Miscellaneous materials
Mass at 1 April 2019 and estimated future arisings (tHM)

Site	Stream identifier	Stream description	Stock at 1 April 2019	Future arisings
Capenhurst	8A14	Uranic residues	13.5 (1)	0
	M8A1011	Chemical adsorber trap residues (CATR)	26	106
	M8A1012	Citric sludge	0.14	4.4
	M8A1013	Degreaser sludge	0.11	5.0
	M8A1014	Effluents	2.8	38
	M8A1015	Uranic residues	0.76	0.8

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

4.7 Contaminated land volumes

Table 7 gives volume estimates for potential radioactive land contamination and radioactively contaminated subsurface structures. Included are materials at Sellafield, Springfields, Aldermaston, the Low Level Waste Repository (LLWR) and various MOD sites.

The estimated volume of radioactive land contamination is about 6,100,000 m^3. Most of this is High Volume VLLW (HVVLLW) and LLW contaminated soil at Sellafield. Much of the radioactively contaminated soil on site can be managed in situ and will not require excavation and treatment as waste.

The estimate of radioactively contaminated subsurface structures is about 235,000 m^3. Most of this comprises building foundations at Sellafield.

The volumes given for Sellafield in Table 7 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 the methodology for estimating volumes of radiologically contaminated soil waste has recently been refined. Verification of the volumes can only be achieved once further characterisation is undertaken as facilities approach the final stages of decommissioning and demolition as the majority of the forecast volume is associated with below ground structures.

Table 7: Potential radioactive land contamination and radioactively contaminated subsurface structures

Site	Stream identifier	Stream description	Estimated volume (m^3) (1)
Sellafield	2D150	Contaminated Soil ILW	1,610
	2D151	Contaminated Soil LLW	2,560,000
	2D152	Contaminated Foundations ILW (2)	2,160
	2D153	Contaminated Foundations LLW (2)	32,900
	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	~3,130
Various (MOD)	7S5000	Contaminated soil, ash and rubble	350 (4)
LLWR	2N101	Vault Profiling Material from PCM Facilities VLLW	10,800
	2N102	Contaminated Land VLLW	3,700
All sites		**Total**	**6,340,000**

(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.

(4) Based on estimates from various MOD sites with known radiological contamination which may require disposal. There is a possibility that future land quality assessments may result in additional volumes.

The Defence Infrastructure Organisation (DIO) is responsible for managing the MOD Estate. This includes a major programme to assess and remediate contaminated ground at MOD sites in the UK.

At the LLWR the estimate of land contamination is based on non-targeted ground investigation and therefore has high uncertainty.

At all sites further site investigation work will give clearer information on potential volumes.

The 2019 Radioactive Waste Inventory itself includes 140,000 m^3 of contaminated soil and spoil from radioactive land contamination, principally at Sellafield, Dounreay, Harwell, Capenhurst and Magnox reactor sites. It also includes radioactively contaminated subsurface structures as a component of site decommissioning waste streams.

APPENDIX ASSUMPTIONS USED FOR REPORTING CIVIL NUCLEAR MATERIALS

All assumptions listed below are in line with those used in compiling data for the 2019 Inventory. These assumptions represent the planning positions at 1 April 2019 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.

A1. Generic assumptions

- Plutonium, uranium and spent 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 have already been designated as waste and are reported in the 2019 UK Radioactive Waste Inventory (i.e. excluded from this report).
- Some spent fuel from Magnox reactors remains to be reprocessed. To report this spent 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 2019, as well as future arisings of spent 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 2019 UK 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.

A2. Spent fuel

- In addition to the spent fuel already generated from the 11 shutdown Magnox power stations in the UK, spent 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

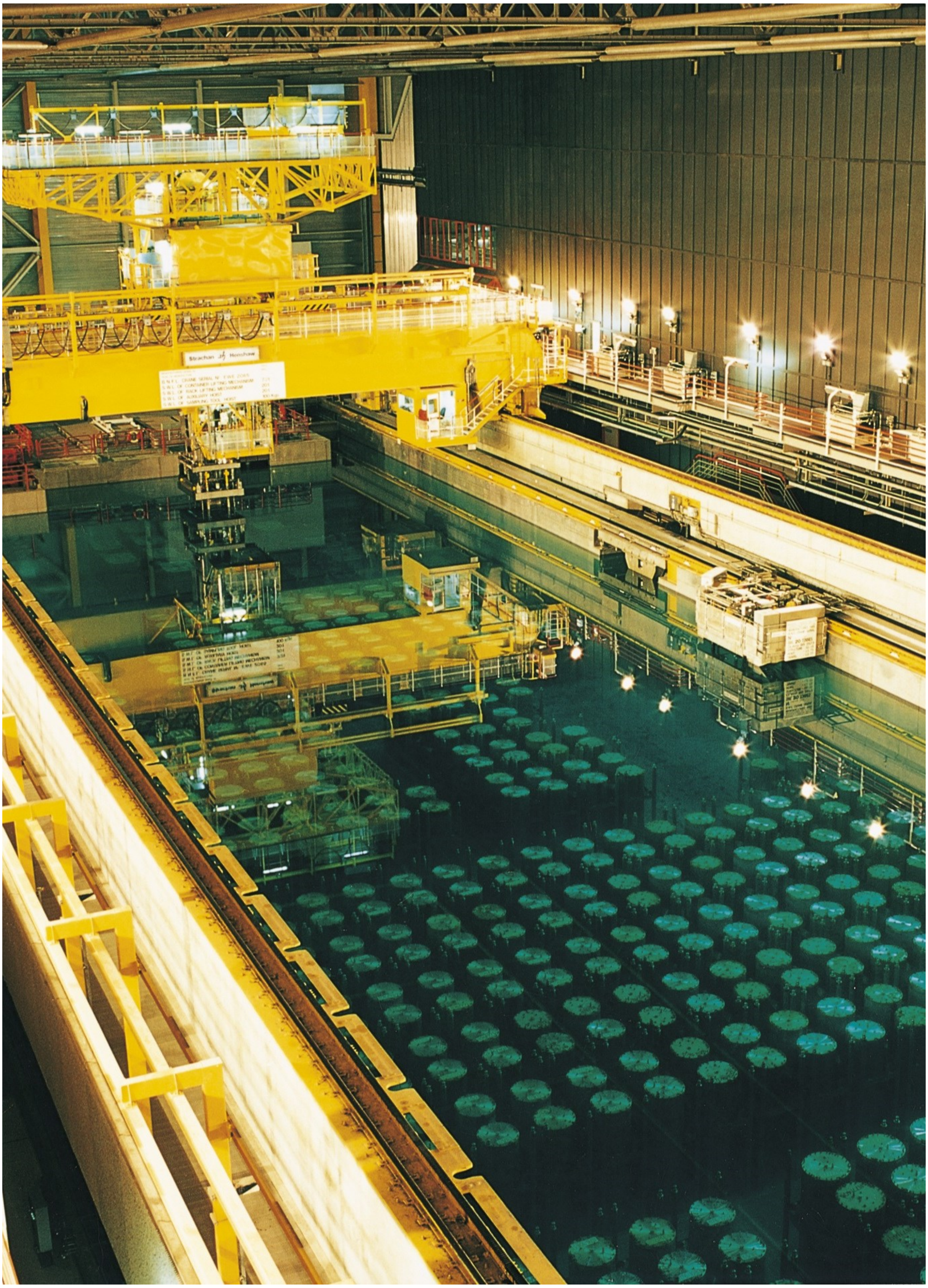
Note: Arisings from new nuclear power stations are not included in this report.

- New nuclear power stations built in the UK will produce spent fuel, but for the purposes of the inventory no new stations are assumed. An assumed new build programme is accounted for in LLWR's Environmental Safety Case and RWM's Inventory for Geological Disposal.
- Nuclear fuel manufacturing in the UK is assumed to continue until 2030.
- The Magnox spent fuel reprocessing plant at Sellafield is scheduled to shut down in 2020. The following spent fuel remains to be reprocessed:
  - ~850 tHM from Magnox reactors
  - ~10 tHM from DFR.
- Oxide fuel reprocessing in the Thermal Oxide Reprocessing Plant (Thorp) at Sellafield was completed in November 2018.
- The following quantities of spent fuel that have been produced or are forecast to arise from UK reactors will be held in long-term storage in the UK[18]:
  - ~5,500 tHM from AGRs
  - ~1,050 tHM from the Sizewell B PWR
  - Small quantities of other fuels, including some SGHWR and WAGR fuel.

[18] *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 – Working with Communities', an updated framework for long-term management of higher activity radioactive waste.*

A3. Separated uranium and plutonium

- Separated uranium and plutonium is assumed to arise in the UK from the reprocessing activities listed above
- All UK-owned separated uranium and plutonium is assumed to be held in long-term storage in the UK.



Spent AGR fuel storage at Sellafield

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 U235 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 (at Winfrith; shut down in 1976).
	DU	Depleted Uranium.
E	**Enriched uranium**	Uranium where the U235 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).
F	**Fission**	Spontaneous or induced fragmentation of heavy atoms into two (occasionally three) lighter atoms, accompanied by the release of neutrons and radiation.
	Fission products	Atoms, often radioactive, resulting from nuclear fission.
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, and the devolved administrations of Scotland, Wales and Northern Ireland.
H	**HEU**	Highly Enriched Uranium. Uranium where the U235 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).
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.
	Low Level Waste 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.
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	**Radioactive waste**	For legal and regulatory purposes, waste that contains, or is contaminated with, radionuclides at concentrations or activities greater than clearance levels as established by the regulatory body.
	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.
	RWM	Radioactive Waste Management Ltd. A wholly-owned subsidiary of the NDA with responsibility to deliver a Geological Disposal Facility for higher activity wastes.
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).
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	The main fissile isotope of uranium. Natural uranium typically contains 0.72% by weight of U235.
	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; 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**	Zero Energy Nitrogen heated Thermal reactor. A research reactor at Winfrith that has been decommissioned.