Introduction

The following report presents the UK National Profile for use in the International Atomic Energy Authority (IAEA) Status and Trends project.

The UK produces an inventory of radioactive waste and radioactive materials1 on a three yearly basis. The UK Inventory provides, in the public domain, the most comprehensive source of information on radioactive waste and radioactive material present in the UK or expected to arise in the future. As part of this process, the UK publishes a separate report which presents inventory information in a format suitable for meeting our international reporting obligations and agreements. This report is publicly available on the UK Radioactive Waste Inventory website: www.nda.gov.uk/ukinventory.

The timing of UK Inventory updates aligns with the triennial reporting requirements under the Joint Convention, the European Commission's Situation Reports on Radioactive Waste and Spent Fuel Management in the EU (the eighth and final Report is expected to be published in 2015) and, from August 2015 onwards, Council Directive 2011/70/Euratom on the responsible and safe management of radioactive waste and spent fuel. In addition to these triennial reporting requirements the UK regularly updates its reports to the IAEA and NEA:

- IAEA Country Nuclear Power Profile – includes information on radioactive waste management and the facilities involved in the back-end of the nuclear fuel cycle;
- NEA National Nuclear Energy Context – the profile includes information and data on the UK's inventory and radioactive waste management policies and programmes; and
- NEA Country Report – the UK's report covers our National Framework for the Management and Regulation of Radioactive Waste and Decommissioning.

The latest UK Inventory was published in 2014, based on a stock date of 1st April 2013. Assumptions used during the compilation of 2013 UK Inventory are set out in the *Scope and Conventions* report and *Scenario for Future Radioactive Waste & Material Arisings* report.

For the purposes of producing this stand-alone UK National Profile for the IAEA's Status and Trends project, the UK has used its 2013 UK Inventory data and information from other publicly available reports. However, it should be noted that for the majority of the questions asked, the UK does not have radioactive waste and materials inventory data in the format requested, and so it will not be possible to aggregate the UK data.

Should the IAEA adjust its reporting requirements, the UK would be willing to consider how these could be incorporated into its national inventory reporting exercise, as long as these requirements did not represent an unnecessary and unjustified additional international reporting burden. It should be noted that the next UK inventory contract will be let in summer 2015 (for the 2016 UK inventory). As a result, the earliest opportunity for considering any new IAEA inventory data reporting requirements developed as part of the Status and Trends Project would be the 2019 UK Inventory exercise.

[1] Safeguarded radioactive materials and not fully characterised radioactive substances that may become waste in the UK (referred to as radioactive materials for simplicity).

ANNEX A: United Kingdom - National Profile

a. National Framework for management of radioactive waste and spent fuel

UK policy on the management of radioactive waste and spent fuel is set out in the following key documents:

- DECC (2014), Implementing Geological Disposal, A Framework for the long-term management of higher activity radioactive waste;
- SCOTTISH GOVERNMENT (2011), Scotland's Higher Activity Radioactive Waste Policy 2011;
- DEFRA (2007), Policy for the Long Term Management of Solid Low Level Radioactive Waste in the United Kingdom;
- NDA (2010), UK Strategy for the Management of Solid Low-Level Radioactive Waste from the Nuclear Industry;
- DECC (2012), UK Strategy for the Management of Solid Low-Level Radioactive Waste from the Non-Nuclear Industry in the UK: Part 1 – Anthropogenic radionuclides;
- Policy on the civil nuclear decommissioning programme is set out in the Energy Act 2004;
- BERR (2008), Meeting the Energy Challenge, A White Paper on Nuclear Power
- SCOTTISH GOVERNMENT (2014), Strategy for the management of Naturally Occurring Radioactive Material (NORM) waste in the United Kingdom

b. National legal and regulatory framework

There are two principle strands to the UK's legislative and regulatory framework relevant to spent fuel and radioactive waste management:

1. nuclear safety and radiation protection (the Health and Safety at Work etc Act 1974; Energy Act 2013; the Nuclear Installations Act 1965, as Amended; and the Ionising Radiations Regulations 1999),
2. environmental protection (Environmental Permitting Regulations 2010 (in England and Wales) or the Radioactive Substances Act 1993 (in Scotland and Northern Ireland)).

Further details of these Acts, together with the UK's legislative and regulatory framework in regards to radioactive waste and spent fuel management, are available from the Department of Energy and Climate Change website (https://www.gov.uk/organisations/department-of-energy-climate-change).

The UK's Competent Regulator Authorities in regards to spent fuel and radioactive waste management are:

- Office for Nuclear Regulation (www.onr.org.uk);
- Environment Agency (England) (www.gov.uk/government/organisations/environment-agency);
- Scottish Environment Protection Agency (www.sepa.org.uk/);
- Natural Resources Wales (www.naturalresourceswales.gov.uk);
- Northern Ireland Environment Agency (www.doeni.gov.uk/niea).

The regulators take a coordinated and cooperative approach to regulating the UK's spent fuel and radioactive waste management activities and facilities.

c. Radioactive waste management, decommissioning and spent fuel strategy and current practices & technologies

The UK has a considerable civil nuclear legacy, some of which dates back to the 1940s. These sites are varied and include:

- Various research sites used during the development of the nuclear industry;
- Fuel reprocessing and fabrication facilities;
- UK's first generation nuclear power plants, the gas-cooled 'Magnox' fleet;
- UK's second generation nuclear power plants, the Advanced Gas-cooled Reactors;
- A Pressurised Water Reactor; and,
- UK's largest, most complex and challenging site, Sellafield.

Information on the UK's radioactive waste management, decommissioning and spent fuel policies and strategies and current practices and technologies is available from the documents listed above and/or from the Department of Energy and Climate Change and Nuclear Decommissioning Authority's websites (https://www.gov.uk/government/publications/); https://www.nda.gov/).

In addition, the UK's Fifth National Report to the Joint Convention (in particular Sections A and B) provides detailed information on the UK's waste and spent fuel management activities/facilities, overview of main waste and spent fuel issues, overview of research and development programs, and an overview of financing of waste and spent fuel management (available from the Department of Energy and Climate Change website).

d. Radioactive waste classification, waste and spent fuel quantities (inventory) (including disused sources that are declared radioactive waste)

UK Radioactive Waste Classification

In the UK radioactive wastes are classified in terms of the nature and quantity of radioactivity they contain and their heat-generating capacity, as High Level Wastes, Intermediate Level Wastes or Low Level Wastes:

- **High Level Wastes (HLW)** Wastes in which the temperature may rise significantly as a result of their radioactivity, so this factor has to be taken into account in the design of storage or disposal facilities.
- **Intermediate Level Wastes (ILW)** Wastes exceeding the upper boundaries for LLW, but which do not require heating to be taken into account in the design of storage or disposal facilities.
- **Low Level Wastes (LLW)** Wastes having a radioactive content not exceeding 4 GBq (gigabecquerels) per tonne of alpha, or 12 GBq per tonne of beta/gamma activity.

Very Low Level Waste (VLLW) is a sub-category of LLW that comprises:

- Low Volume VLLW ('dustbin loads') - wastes that can be safely disposed of to an unspecified destination with municipal, commercial or industrial waste, each 0.1 cubic metre of material containing less than 400kBq (kilobecquerels) of total activity, or single items containing less than 40kBq of total activity. There are additional limits for carbon-14 and tritium in wastes containing these radionuclides.
- High Volume VLLW (bulk disposals) – wastes with maximum concentrations of 4MBq (megabecquerels) per tonne of total activity that can be disposed of to appropriately permitted landfill sites. There is an additional limit for tritium in wastes containing this radionuclide.

The principal difference between the two VLLW categories is the need for controls on the total volumes of high volume VLLW being deposited at any one particular landfill site7. Low Volume VLLW is generated principally by so called "small users", while most High Volume VLLW (HVVLLW) is produced at nuclear licensed sites.

UK Radioactive Waste Quantities: In Stock and Forecast to Arise

The following data tables provide summary information from the 2013 UK Inventory based on the 2009 IAEA classification scheme. The criteria used to allocate individual waste streams within the classification are determined by known or planned disposal routes (see Table D.1).

Table D.1: Waste classification

Class (IAEA 2009)	Criteria (UK classification)
Very Low Level Waste (VLLW)	VLLW consigned for disposal at landfill sites
Low Level Waste (LLW)	LLW stream routinely disposed of to the LLWR LLW stream stored pending future disposal to the LLWR LLW stream that will be consigned to the Dounreay LLW facility LLW stream where the disposal route is not given LLW stream where the disposal route is not yet known ILW stream decay stored for disposal as LLW
Intermediate Level Waste (ILW)	ILW stream LLW stream unsuitable for disposal to the LLWR or Dounreay LLW facility
High Level Waste (HLW)	HLW stream

The following tables present an overview of radioactive wastes that were in stock in the UK at 1 April 2013 (Table D.2) and an estimate of total waste volumes from existing facilities to end of life volumes when packaged (Table D.3) using the IAEA 2009 waste classification system.

Table D.2: Radioactive wastes existing at 1 April 2013 from all sources

Packaged and unpackaged volumes

Waste type (IAEA classification)	**At 1.4.2013**	**Volume (m^3)(1)**
HLW	**Total**	**2,030**
	Packaged	1,100
	Unpackaged	931
ILW	**Total (2)**	**104,000**
	Packaged	37,300
	Unpackaged	66,900
LLW	**Total (3)**	**69,600**
	Packaged	50,000
	Unpackaged	19,700
VLLW	**Total**	**5,410**
	Packaged	0
	Unpackaged	5,410

(1) The packaged waste volume is the displacement volume of the containers in which the waste is conditioned. Volumes are given to three significant figures.

(2) Can be categorised as 755m^3 of LLW and 104,000m^3 of ILW.

(3) Can be categorised as 1,370m^3 of ILW, 64,700m^3 of LLW and 3,650m^3 of mixed LLW/VLLW.

Table D.3: Expected total waste volumes from existing facilities to end of life

Volumes when packaged (1)

Waste type (IAEA classification)	**At 1.4.2013**	**Future arisings (m^3)**	**Total (m^3)**
HLW (2)	1,550	-137	1,410
ILW (3)	151,000	311,000	462,000
LLW (4)	68,000	1,080,000	1,150,000
VLLW	4,570	3,100,000	3,110,000
Total	**225,000**	**4,490,000**	**4,720,000**

(1) The packaged waste volume is the displacement volume of the containers in which the waste is conditioned. Volumes are given to three significant figures.

(2) Volume is net of HLW exports to overseas customers (hence negative figure).

(3) Can be categorised as 449,000m^3 of ILW, 13,500m^3 LLW.

(4) Can be categorised as 9,230m^3 of ILW and 1,127,000m^3 of LLW and 14,700 of mixed LLW/VLLW.

The following tables present an overview of radioactive wastes in the UK by business activity, using the UK classification system for radioactive wastes (Tables D.4, D.5 and D.6).

Table D.4: Volume at 1 April 2013 and estimated future arisings (m^3) (1)

Business activity	UK Waste Classification:		HLW	ILW	LLW	VLLW	Total
Fuel fabrication & uranium enrichment		**Total**	**0**	**2.5**	**242,000**	**0**	**242,000**
		1.4.2013	0	0.66	1,150	0	**1,160**
		Future arisings	0	1.8	241,000	0	**241,000**
Nuclear power reactors	**Magnox**	**Total**	**0**	**54,200**	**453,000**	**2,750**	**510,000**
		1.4.2013	0	10,900	1,760	1,130	**13,800**
		Future arisings	0	43,200	452,000	1,630	**496,000**
	AGR	**Total**	**0**	**24,200**	**111,000**	**0**	**135,000**
		1.4.2013	0	3,230	618	0	**3,850**
		Future arisings	0	20,900	110,000	0	**131,000**
	PWR	**Total**	**0**	**4,370**	**18,500**	**0**	**22,900**
		1.4.2013	0	93.2	168	0	**261**
		Future arisings	0	4,280	18,300	0	**22,600**
Spent fuel reprocessing		**Total**	**1,080**	**173,000**	**249,000**	**2,820,000**	**3,240,000**
		1.4.2013	1,770	69,000	3,260	0	**74,000**
		Future arisings	-695 (2)	104,000	245,000	2,820,000	**3,170,000**
Nuclear energy R&D		**Total**	**0**	**14,800**	**157,000**	**6,720**	**179,000**
		1.4.2013	0	7,660	20,300	1	**28,000**
		Future arisings	0	7,100	137,000	6,720	**151,000**
Defence		**Total**	**0**	**9,440**	**27,400**	**8,530**	**45,400**
		1.4.2013	0	4,090	2,780	27	**6,890**
		Future arisings	0	5,360	24,600	8,500	**38,500**
Medical & Industrial		**Total**	**0**	**946**	**48,700**	**0**	**49,700**
		1.4.2013	0	380	33,500	0	**33,900**
		Future arisings	0	566	15,200	0	**15,800**
Total		**Total**	**1,080**	**286,000**	**1,370,000**	**2,840,000**	**4,490,000**
		1.4.2013	**1,770**	**95,600**	**66,700**	**1,170**	**165,000**
		Future arisings	**-695 (2)**	**190,000**	**1,300,000**	**2,840,000**	**4,330,000**

(1) Volumes are those reported by the waste producers. They are for untreated or partly treated wastes, apart from wastes that are conditioned (i.e. waste streams with a /C in the identifier) where the conditioned volume is reported.

(2) Future arisings of HLW have negative volumes. This is because Sellafield has reported future arisings of HLW to show that the volume of accumulated waste (liquid plus vitrified product) will fall as liquid waste existing at 1.4.2013 and forecast in the future is conditioned to a vitrified product. Thus, the volume of 1,770m^3 at 1.4.2013 is expected to fall by 695m^3, to 1,080m^3, by 2027 when all liquid waste (plus IFP residues) is expected to be conditioned.

Table D.5: Wastes at 1 April 2013

Number of packages, packaged volume and conditioned volume (m^3) [(1)]

Business activity	UK Waste Classification:		HLW	ILW	LLW	VLLW	Total
Fuel fabrication & uranium enrichment		Number of packages	0	0	0	0	**0**
		Packaged volume (m^3)	0	0	0	0	**0**
		Conditioned volume (m^3)	0	0	0	0	**0**
Nuclear power reactors	**Magnox**	Number of packages	0	1,865 [(2)]	0	0	**1,865**
		Packaged volume (m^3)	0	6,280	15.6	0	**6,290**
		Conditioned volume (m^3)	0	3,500	12.5	0	**3,510**
	AGR	Number of packages	0	0	0	0	**0**
		Packaged volume (m^3)	0	0	0	0	**0**
		Conditioned volume (m^3)	0	0	0	0	**0**
	PWR	Number of packages	0	0	0	0	**0**
		Packaged volume (m^3)	0	0	0	0	**0**
		Conditioned volume (m^3)	0	0	0	0	**0**
Spent fuel reprocessing		Number of packages	5,626	47,458	0	0	**53,084**
		Packaged volume (m^3)	1,100	27,100	0	0	**28,200**
		Conditioned volume (m^3)	844	23,500	0	0	**24,300**
Nuclear energy R&D		Number of packages	0	4,806	648	0	**5,454**
		Packaged volume (m^3)	0	4,000	14,200	0	**18,200**
		Conditioned volume (m^3)	0	2,990	11,400	0	**14,400**
Defence		Number of packages	0	0	0	0	**0**
		Packaged volume (m^3)	0	0	29.7	0	**29.7**
		Conditioned volume (m^3)	0	0	23.8	0	**23.8**
Medical & Industrial		Number of packages	0	0	1,901	0	**1,901**
		Packaged volume (m^3)	0	0	35,600	0	**35,600**
		Conditioned volume (m^3)	0	0	32,800	0	**32,800**
Total		**Number of packages**	**5,626**	**54,129**	**2,549**	**0**	**62,304**
		Packaged volume (m^3)	**1,100**	**37,400**	**49,900**	**0**	**88,400**
		Conditioned volume (m^3)	**844**	**30,000**	**44,200**	**0**	**75,100**

(1) Package numbers and volumes are for those wastes that had been conditioned (i.e. waste streams with a /C in the identifier) and wastes that have been packaged for later conditioning.

(2) ILW packages from Magnox nuclear power reactors include 1,788 1803-type drums. These drums are expected to be overpacked in 4m boxes (6 drums per box).

Table D.6: All wastes (at 1 April 2013 and future arisings) when packaged

Number of packages, packaged volume and conditioned volume (m^3)

Business activity	UK Waste Classification:		HLW	ILW	LLW	VLLW	Total
Fuel fabrication & uranium enrichment		Number of packages	0	5.3	694	0	**700**
		Packaged volume (m^3)	0	3.0	241,000	0	**241,000**
		Conditioned volume (m^3)	0	2.5	238,000	0	**238,000**
Nuclear power reactors	**Magnox**	Number of packages	0	10,100	27,500	0	**37,600**
		Packaged volume (m^3)	0	80,700	551,000	2,750	**635,000**
		Conditioned volume (m^3)	0	68,100	507,000	2,750	**577,000**
	AGR	Number of packages	0	3,210	3,560	0	**6,770**
		Packaged volume (m^3)	0	41,100	70,800	0	**112,000**
		Conditioned volume (m^3)	0	29,600	62,300	0	**92,000**
	PWR	Number of packages	0	1,730	699	0	**2,430**
		Packaged volume (m^3)	0	5,710	13,600	0	**19,400**
		Conditioned volume (m^3)	0	3,840	10,900	0	**14,800**
Spent fuel reprocessing		Number of packages	7,200	171,000	10,500	0	**189,000**
		Packaged volume (m^3)	1,410	281,000	205,000	2,820,000	**3,310,000**
		Conditioned volume (m^3)	1,080	221,000	168,000	2,820,000	**3,210,000**
Nuclear energy R&D		Number of packages	0	19,400	8,930	0	**28,300**
		Packaged volume (m^3)	0	35,700	218,000	6,720	**260,000**
		Conditioned volume (m^3)	0	24,400	183,000	6,720	**214,000**
Defence		Number of packages	0	8,730	301	0	**9,030**
		Packaged volume (m^3)	0	6,570	15,500	8,530	**30,600**
		Conditioned volume (m^3)	0	5,550	14,300	8,530	**28,400**
Medical & Industrial		Number of packages	0	866	2,810	0	**3,670**
		Packaged volume (m^3)	0	543	53,000	0	**53,500**
		Conditioned volume (m^3)	0	456	46,600	0	**47,000**
Total		**Number of packages**	**7,200**	**216,000**	**57,300**	**0**	**280,000**
		Packaged volume (m^3)	**1,410**	**458,000**	**1,420,000**	**2,840,000**	**4,720,000**
		Conditioned volume (m^3)	**1,080**	**359,000**	**1,280,000**	**2,840,000**	**4,480,000**

UK Radioactive Waste Quantities: Disposed Volumes

Please note that all commentary in this section relates to the UK waste classification system.

Between 1949 and 1982 about 33,000m^3 of packaged radioactive waste were disposed of in the North Atlantic and UK coastal waters[2].

Since 1959 most of the UK's solid LLW has been transported to the near-surface disposal facility, the LLWR, in Cumbria. Between 1959 and 1995 about 800,000m^3 of drummed, bagged and loose waste was disposed in a series of clay-lined trenches and covered with soil[3].

Since 1988 most waste has been placed in large metal containers, similar to shipping containers. These are then filled with cement and placed in engineered concrete vaults (Vaults 8 & 9). Suitable LLW is first supercompacted to minimise its volume. In this process drums or boxes of waste are compacted under high pressure of up to 2,000 tonnes per square metre.

At 1 April 2013 disposed waste containers in Vault 8 occupied approximately 182,000m^3. A small proportion of the waste containers in Vault 8 and all waste containers in Vault 9 are not yet classed as disposed[4]; these stored containers are included in the LLW quantities presented throughout this report.

Consignments to the LLWR over the past ten years have totalled about 91,000m^3 (see Table D.7). There is a trend to smaller annual consignment volumes driven by application of the waste hierarchy[5].

[2] This disposal route is closed.

[3] Disposal in the trenches at the LLWR is closed. As a result of compaction, the waste in the trenches occupies a volume of about 500,000m^3. The trenches have been covered by an interim soil cap; a final cap will be constructed over the trenches and vaults as part of site closure engineering.

[4] The current disposal permit issued by the Environment Agency applies to waste in the trenches and that originally planned for Vault 8, it does not apply to waste in Vault 9 and higher stacked waste in Vault 8.

[5] Central to the UK-wide strategy for managing LLW from the nuclear industry is an effective application of the waste hierarchy, with a preference for managing LLW at higher levels of the hierarchy and a move away from the past focus on disposal. The strategy makes best use of existing disposal capacity at the LLWR, and the extent to which other management and disposal options (e.g. recycling of metals, incineration of combustibles and recategorisation as VLLW with disposal to landfill) might be employed.

Table D.7: Annual consignments to the LLWR 2003 – 2012

Year	Total volume (m^3) (1)
2003	11,400
2004	12,900
2005	12,800
2006	12,900
2007	9,100
2008	8,600
2009	7,000
2010	4,830
2011	6,700
2012	4,820

(1) Volume is for waste and its primary containment.

Waste for consignment to the LLWR must comply with the site's Waste Acceptance Criteria, which stipulate that certain materials must not be present in the waste, and places limits on the maximum concentration of certain radionuclides for which the LLWR has authorised annual disposal limits.

To comply with the Waste Acceptance Criteria wastes must also have a valid Waste Characterisation form (WCH) at the time of disposal. The WCH describes the physical, chemical and radionuclide content, gives estimated arisings, conditioning and packaging information, and a justification of assessment methodology.

The capacity of the LLWR is subject to a permit from the Environment Agency (EA) for further waste disposals, and planning consent for additional engineered concrete vaults. For current operational planning purposes, it is currently assumed that the site will operate beyond 2080 and will generate small quantities of LLW from operational and maintenance activities.

There is a disposal facility at Dounreay consisting of six shallow pits, which in the past was used for LLW from the site and from the adjacent MoD Vulcan site. Total disposals are about 33,600m^3. As the facility does not meet current standards, the waste is to be retrieved, repackaged and consigned to a new solid LLW disposal facility adjacent to the Dounreay site[6].

Certain low activity solid wastes from the major waste producers, comprising HVVLLW and LLW with radioactivity at the lower end of the range, are disposed of to off-site landfill where authorised, and a few nuclear licensed sites have authorised on-site disposal.

[6] The new LLW disposal facility adjacent to Dounreay site began accepting waste for disposal in May 2015.

There is considerable uncertainty surrounding long-term waste routing projections. However, an indicative analysis of projected LLW disposal routes as declared by waste organisations in the 2013 inventory shows the following:

- About 124,000m^3 (9%) is expected to be recycled or incinerated;
- About 279,000m^3 (20%) is expected to go to landfill;
- About 473,000m^3 (35%) is expected to be disposed of to the LLWR or the Dounreay LLW disposal facility, with supercompaction of suitable waste;
- About 441,000m^3 (32%) is not expected to be disposed of to the LLWR. This is waste from final site clearance at nuclear power stations that will arise after the projected lifetime of the LLWR;
- About 10,500m^3 (1%) is unsuitable for disposal to the LLWR. This is predominantly Magnox and AGR core graphite;
- About 40,000m^3 (3%) does not yet have a confirmed management route.

Table D.8 gives a projection of waste consignments to the LLWR over the next few years. The values are packaged volumes for waste streams that are identified in the 2013 Inventory as routinely consigned to the LLWR or in interim storage pending future consignment to the LLWR. The former category accounts for about 98% of the waste. A further 11,500m^3 are identified as "expected to be disposed of to the LLWR" over the same period. Most of this waste is concrete, steel, rubble and soil from facilities decommissioning.

There are no disposal facilities in the UK for HLW and ILW; these wastes are being accumulated in stores. The policy of the UK Government and devolved administrations for Wales and Northern Ireland is geological disposal. The policy of the Scottish Government is that long-term management should be in near-surface facilities.

Table D.8: Projected future consignments to the LLWR 2013 – 2018

Year [(1)]	Total volume (m^3)[(2)]
2013	7,100
2014	6,820
2015	5,160
2016	5,190
2017	4,410
2018	3,820

(1) Financial years.

(2) Volume is the packaged volume and reflects the effect of both waste compaction and containerisation.

UK Nuclear Materials

The following provides information about irradiated fuel, unirradiated fuel, plutonium, uranium and thorium, as reported in the 2013 UK inventory. Quantities of nuclear materials (nuclear fuel, plutonium and uranium) are given as masses expressed as tonnes of heavy metal (tHM).

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 termed 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 UK nuclear fuels are used in Magnox reactor, Advanced Gas-cooled Reactor (AGR) and Pressurised Water Reactor (PWR) power stations. 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 station for a short cooling period before transfer to Sellafield in Cumbria. Magnox spent fuel and a proportion of AGR fuel is reprocessed at Sellafield. The remaining spent AGR fuel is held at Sellafield. 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[7].

Until 1996 there was also spent fuel reprocessing 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[8].

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 pending reprocessing.

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.

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[7] 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.

[8] 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.

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. The UK also holds stocks of foreign owned LWR fuel awaiting reprocessing[9].

Table D.9 gives the masses of UK owned irradiated fuel at 1 April 2013 and estimated in future arisings. The total mass of irradiated fuel at 1 April 2013 was about 9,600tHM, with estimated future arisings of about 2,200tHM. The figures for irradiated fuel at 1 April 2013 exclude about 290tHM of overseas owned LWR fuel at Sellafield, and about 0.7tHM of overseas owned spent fuel at Dounreay.

It is planned that the stocks of Magnox, SGHWR fuels and other spent fuels at Sellafield, as well as DFR breeder material currently stored at Dounreay[10], will be reprocessed (apart from a small quantity that is unsuitable). It is also planned that future arisings of spent Magnox fuel will be reprocessed. A proportion of the fuel produced over the lifetime of the AGR stations will be reprocessed. It is assumed that about 4,500tHM 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 1,000tHM spent fuel over its 40-year operating lifetime. It is currently assumed that this fuel will be held in long-term storage.

[9] 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.

[10] DFR breeder material is being transferred to Sellafield. Transfers started in December 2012 and are expected to continue over a period of five years.

Table D.9: UK owned irradiated fuel

Mass in stocks and estimated for future arisings (tHM)

Location	Description	Stock at 1 April 2013 [1]		Estimated future arisings
		In reactor	In storage	
Sellafield	Magnox fuel		820	- [2]
	AGR fuel		2,900	- [3]
	SGHWR fuel		120	0
	WAGR fuel		28	0
	Other fuels		740 [4]	0
Dounreay	DFR breeder fuel	32	10	
	PFR		10	
	Other fuels		<1	0
Magnox power stations [5]	Magnox fuel	~2,500	~180	11
AGR & PWR power stations	AGR & PWR fuel [6]	~1,700	~510	~2,200
Others	Various		~10 [7]	0

(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 1.6tHM 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 mainly low irradiated fuels including Zero Energy Breeder Reactor Assembly (ZEBRA) fuel as plutonium and natural uranium oxide plates on loan to Cadarache in France and other fuels at Harwell.

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.

Table D.10 gives the masses of UK owned unirradiated fuel in the UK. The total mass of unirradiated fuel at 1 April 2013 is estimated to be about 180tHM. 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 D.10: UK owned unirradiated fuel

Mass in stocks (tHM)

Location	Description	Stock at 1 April 2013
Sellafield	Various (1)	13.1
Dounreay	Various (2)	~16
All UK sites	Magnox fuel	11
All UK sites	AGR fuel	~100
All UK sites	PWR fuel	~40

(1) Includes unirradiated PWR and MOX fuels

(2) Includes unirradiated PFR, uranium, plutonium and thorium fuels.

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 in high integrity containers as plutonium oxide powder. These containers are held 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. 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. Fast breeder reactors make more efficient use of nuclear materials – effectively generating more fuel than they consume. 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.

However, plutonium can be used as a component of MOX fuel – a mixture of uranium and plutonium[11]. Some countries are using MOX fuel in their reactors, but MOX fuel (and hence UK owned plutonium) is not currently used in UK reactors[12].

Table D.11 gives the total masses of UK owned separated plutonium at 1 April 2013. Separated plutonium is held mainly as plutonium dioxide (PuO2) from the reprocessing of Magnox and oxide fuel at Sellafield, with a small amount in other forms and fuel residues.

[11] 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.

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

Table D.11: UK owned separated plutonium

Mass in stocks (tHM)

Location	Description	Stock at 1 April 2013
All UK sites	PuO_2	~93

There are currently about 93tHM of separated plutonium in stock. This excludes material from the reprocessing of overseas spent LWR fuel.

Forecast future arisings of UK owned plutonium from reprocessing spent fuel at Sellafield are about 21tHM.

In total about 27tHM of plutonium are forecast from reprocessing overseas spent LWR fuel.[13]

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 U-235 content of about 0.72% by mass. Natural uranium is used in its metallic form in Magnox reactor fuel[14].
Low-Enriched Uranium (LEU)	Uranium enriched in U-235 to less than 20% by mass. LEU as uranium dioxide (UO2) is used in the manufacture of AGR and PWR fuels. Power reactor fuels have a typical initial U-235 content of between 3 and 5% by mass. LEU uranium (with a reduced U-235 content) is also a product of reprocessing these fuels. This is stored as uranium trioxide (UO3).

[13] 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].

[14] Latterly some Magnox fuel has been slightly enriched (<1% U-235) to offset the effects of reactor ageing.

High-Enriched Uranium (HEU)	Uranium enriched in U-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 U-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 (UF6). DU is also a product of reprocessing spent Magnox reactor fuel. This is stored as UO3.

With regard to UK sites, fuel for civil nuclear reactors is manufactured at Springfields in Lancashire. Yellowcake is first converted through chemical processing into uranium tetrafluoride (UF4). The next process stage depends on the type of fuel to be manufactured. AGR fuel is fabricated from low enriched uranium (UO2). Here UF4 is first converted to UF6, which is enriched at Capenhurst in Cheshire. The enriched UF6 is then converted to UO2 at Springfields, which in turn is formed into ceramic pellets. For Magnox reactor fuel UF4 was converted to uranium metal: the manufacture of the 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 UF6 can be enriched to provide feed stock for new fuel. Depleted uranium can also be mixed with plutonium to make MOX fuel.

Radiation shielding applications and limited other industrial applications make use of specific properties of uranium.

Table D.12 gives the total masses of UK owned DNLEU (Depleted, Natural and Low Enriched Uranium) and HEU from all sources, at 1 April 2013.

Table D.12: UK owned uranium

Mass in stocks (tHM)

Location	Description	Stock at 1 April 2013
All UK sites	DNLEU	~104,000 (1)
All UK sites	HEU	<1

(1) The latest figure published by the Government is ~122,000tHM at 31 December 2013.

The major components of UK owned uranium stocks 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 other sites.

Future arisings of DNLEU are estimated at about 66,000tHM, based on the assumptions contained within the 2013 UK Inventory *Scenario for Future Waste and Material Arisings* report. The majority of anticipated future arisings are depleted uranium from enrichment operations. It

excludes approximately 70tHM of foreign owned DNLEU that is estimated to arise in the future from spent fuel reprocessing.

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.

At 1 April 2013, there was less than 1tHM of HEU in stock, comprising residues from reprocessing and fuel fabrication.

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 has already been designated as waste and is reported in the 2013 Inventory.

Non-nuclear industrial uses of thorium are in illuminants, electron emitters, ceramics and glass, catalysts and specialist alloys.

Table D.13 gives the total mass of UK owned thorium at 1 April 2013. There are no reported future arisings.

Table D.13: UK owned thorium

Mass in stocks (tHM)

Location	Description	Stock at 1 April 2013
All UK sites	Thorium metal	~11

The baseline strategy for the thorium metal is sale to a third party for reuse. If an appropriate buyer cannot be found the material may have to be managed as waste in the future. Thorium associated with spent Dragon reactor fuel is deemed to be waste and is reported in the radioactive waste inventory (stream 5C50).