The 2013 UK Radioactive Waste Inventory

Radioactive Wastes & Materials Not Reported in the 2013 UK Radioactive Waste Inventory

Report prepared for the Department of Energy & Climate Change (DECC) and the Nuclear Decommissioning Authority (NDA) by Pöyry Energy Limited and Amec plc.
PREFACE

The 2013 United Kingdom Radioactive Waste & Materials Inventory (hereafter referred to as the 2013 Inventory) will provide comprehensive and up-to-date information on radioactive waste and materials as at 1 April 2013. It is part of an ongoing programme of research jointly conducted by the Department of Energy and Climate Change (DECC) and the Nuclear Decommissioning Authority (NDA).

DECC and NDA have commissioned the 2013 Inventory to provide information on the status of radioactive waste stocks (at 1 April 2013) and forecasts of future arisings in the United Kingdom. Additional information on radioactive materials which may become wastes is collated. Its aim is to provide data in an open and transparent manner for those interested in radioactive waste and material issues.

Information collected for the 2013 Inventory is presented in a series of reports, as listed below:

- High Level Summary
- Summary of Data for International Reporting
- Scope and Conventions
- Scenario for Future Radioactive Waste & Material Arisings
- Waste Quantities from All Sources
- Radioactive Waste Composition
- Radioactivity Content of Wastes

All documents have been prepared on the basis of information supplied to the 2013 Inventory contractors, Pöyry Energy and Amec. This information was verified in accordance with arrangements established by Pöyry Energy and Amec.

This reporting output provides a summary of radioactive wastes and materials not reported in the 2013 Inventory. This includes nuclear materials not currently deemed to be waste (some spent fuels, uranium and plutonium). It also includes potential radioactively contaminated ground and other materials that are not yet sufficiently well characterised to be included in the radioactive waste inventory.

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Feedback

You are invited to provide feedback to the NDA on the content, clarity and presentation of this report and the UK Radioactive Waste Inventory (i.e. the Inventory). Please do not hesitate to contact the NDA if you have any queries on the Inventory and radioactive waste issues. Such feedback and queries should be addressed to:

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1 INTRODUCTION

Radioactive material is defined in UK legislation [1, 2] 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.

An inventory of radioactive waste in the UK is compiled periodically by the Department of Energy & Climate Change (DECC) and the Nuclear Decommissioning Authority (NDA) to meet the UK’s international reporting obligations, to provide up-to-date information for waste management policy development, and for the regulation and planning of waste treatment, storage and long-term management.

The 2013 UK Radioactive Waste & Materials Inventory (hereafter referred to as the 2013 Inventory) is the latest public record of information on the sources, quantities and properties of radioactive waste in the UK at 1 April 2013 and predicted to arise after that date based on assumptions as to the nature and scale of future operations and activities.

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 classified 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.

Government\(^1\) recognises that 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 which radioactive materials might come forward as waste. Consequently the UK Government’s “Managing Radioactive Waste Safely” (MRWS) programme for developing and implementing policy for managing the UK’s higher activity wastes in the long term is also considering radioactive materials not currently classified as wastes.

The policy of the UK Government and devolved administrations for Wales and Northern Ireland is geological disposal of higher activity wastes, preceded by safe and secure interim storage. The Scottish Government has a different policy for its higher activity wastes, which is that long-term management should be in near-surface facilities. Facilities should be located as near to the site where the waste is produced as possible and developers will need to demonstrate how the facilities will be monitored and how waste packages, or waste, could be retrieved.

With regard to plutonium, the Government’s preferred long-term management option is to reuse the UK’s civil plutonium stockpile, and the NDA will therefore progress reuse options as:

\(^1\) The use of “Government” in this report refers collectively to the UK Government and the devolved administrations for Scotland, Wales and Northern Ireland.
MOX fuel; as fuel in a CANDU reactor; and, as fuel in a PRISM fast reactor. In addition, NDA will also investigate options to immobilise and dispose of the plutonium as a waste [3].

Civil nuclear facilities are subject to the UK’s safeguards agreements with international bodies - the International Atomic Energy Authority (IAEA) and the European Atomic Energy Community (Euratom) - and to the safeguards provisions of the Euratom treaty. These are designed to detect diversion of material into clandestine weapons programmes, and involve accounting for material and submitting to international inspection. All civil plutonium and highly enriched uranium in the UK (whether separated or in spent fuel) is stored safely and securely under relevant national and international regulations including inspection by international safeguards authorities.

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 fourth national report for the Convention was provided in September 2011 [4]. 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 2012 [5].

The principal purposes of this reporting output are to bring together in the public domain information required for the UK to meet its international reporting obligations in respect of civil nuclear materials, and as part of the UK Radioactive Waste & Materials Inventory process to provide a comprehensive inventory of UK radioactive substances that might have to be managed as waste at some time in the future.

The scope of the UK Inventory excludes 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” [6]. Also excluded are small quantities of nuclear materials with very low concentrations of radioactivity typically from research establishments, universities and the non-nuclear industry (‘small users’).

The inclusion of a nuclear materials inventory allows development of management strategies and the planning of systems and facilities for managing radioactive wastes for the UK, as well as allowing it to be used as a basis for open and transparent discussions within the MRWS programme.

This reporting output also includes some potentially contaminated ground and some miscellaneous radioactive materials that are deemed to be waste or may be deemed to be waste at some point in the future. These have yet to be sufficiently well characterised, and so there is considerable uncertainty in their quantities. Waste producers have chosen not to include these in the inventory of radioactive wastes until there is more certainty on the waste quantities that might be produced.

The structure of the remainder of this reporting output is as follows. Section 2 describes the materials included. Section 3 presents material quantities in storage and projected to arise in the future. References are listed in Section 4. Annex 1 presents the assumptions used in reporting nuclear material quantities. Annex 2 presents some detailed information about

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

3 Nuclear licensed sites used solely for defence purposes are not subject to safeguards requirements. Nevertheless, it is 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.
potentially contaminated ground and miscellaneous wastes and materials. Annex 3 provides a glossary of terms and abbreviations.
2 TYPES OF RADIOACTIVE MATERIAL

2.1 Introduction

There are two categories of radioactive material included in this reporting output:

- Civil nuclear materials that are not currently deemed to be waste. This category comprises irradiated fuel, unirradiated fuel, uranium, plutonium and thorium;
- Land that is potentially contaminated and miscellaneous materials some of which are deemed to be waste. There is often considerable uncertainty in the quantities that might arise, and as a consequence some waste producers have chosen to report volume estimates here rather than in the radioactive waste inventory.

2.2 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.

Currently, 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 Sellafield⁴.

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 site⁵.

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.

⁴ 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.
⁵ 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.
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.

2.4 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 at reprocessing sites in purpose built facilities within high integrity containers at reprocessing sites as plutonium oxide powder.

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\(^6\). Some countries are using MOX fuel in their reactors, but MOX fuel (and hence UK owned plutonium) is not currently used in UK reactors\(^7\).

2.5 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\(_3\)O\(_8\)) – 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\(^8\).

**Low-Enriched Uranium (LEU)**

Uranium enriched in U-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 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 (UO\(_3\)).

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\(^6\) The Government’s preferred option for long-term management of the UK’s plutonium stockpile is reuse. Proposals on potential alternative approaches to long-term plutonium management have been made, and these are being reviewed by NDA.

\(^7\) MOX fuel delivered to overseas reactors only contained plutonium that the overseas customer owned.

\(^8\) 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.

2.6 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.

2.7 Contaminated ground

Ground and building foundations of some nuclear sites may become contaminated with low concentrations of radioactivity as a result of lifetime site operations. The removal of contaminated foundations and the remediation of contaminated ground will generate radioactive wastes. These wastes comprise principally soil and concrete/rubble, and most will arise during the final stage of site decommissioning and clean-up.

There is greater uncertainty in the future arisings of waste from the remediation of potentially contaminated ground than in facility dismantling and demolition wastes. This is particularly the case for radioactive wastes at the lower end of the activity range referred to as Very Low Level Waste (VLLW). As site clean-up plans are further developed, and full characterisation work is undertaken to quantify the extent and level of potential contamination, the volume estimates of these wastes can be expected to change.

At some non-nuclear defence sites low level radioactive contamination may be present as a result of the historic production, maintenance, storage and disposal of luminised instruments. The peak period for luminising was from the 1930s to the 1970s. The luminising paint used originally contained radium, though more recently promethium and tritium were used. The Ministry of Defence (MoD) has a continuing programme of land quality assessment.
Some contaminated ground is reported as radioactive waste in the 2013 Inventory (see ‘Waste Quantities from All Sources’ reporting output). However because of the uncertainties described above, some waste producers have chosen to report potentially contaminated ground in this reporting output until contamination surveys are extended and refined, and there is more certainty on volumes.

2.8 Miscellaneous wastes and materials

There is a limited number of radioactive wastes for which no final treatment, packaging or disposal route has yet been identified, and which are not sufficiently well characterised to be reported in the radioactive waste inventory. These wastes are included in this reporting output.
3 MATERIAL QUANTITIES

3.1 Introduction

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 (nuclear fuel, plutonium and uranium) are given as masses expressed as tonnes of heavy metal (tHM). Quantities of waste that may arise from the remediation of radioactively contaminated ground, and the miscellaneous wastes and materials, are given as volumes expressed as cubic metres.

Annex 1 sets out the assumptions used in reporting radioactive materials in the UK. Annex 2 provides more details on potentially contaminated ground, and miscellaneous wastes and materials.

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

Table 3.1 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 Dounreay10, 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.

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

<table>
<thead>
<tr>
<th>Location</th>
<th>Description</th>
<th>Stock at 1 April 2013 (tHM)</th>
<th>Estimated future arisings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>In reactor</td>
<td>In storage</td>
</tr>
<tr>
<td>Sellafield</td>
<td>Magnox fuel</td>
<td>820</td>
<td>2,900</td>
</tr>
<tr>
<td></td>
<td>AGR fuel</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SGHWR fuel</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WAGR fuel</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other fuels</td>
<td>740 (4)</td>
<td></td>
</tr>
<tr>
<td>Dounreay</td>
<td>DFR breeder fuel</td>
<td>32</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>PFR</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other fuels</td>
<td>&lt;1</td>
<td></td>
</tr>
<tr>
<td>Magnox power stations (5)</td>
<td>Magnox fuel</td>
<td>~2,500</td>
<td>~180</td>
</tr>
<tr>
<td>AGR &amp; PWR power stations</td>
<td>AGR &amp; PWR fuel (6)</td>
<td>~1,700</td>
<td>~510</td>
</tr>
<tr>
<td>Others</td>
<td>Various</td>
<td>~10 (7)</td>
<td></td>
</tr>
</tbody>
</table>

(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.

#### 3.3 Unirradiated fuel

Table 3.2 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 3.2: UK owned unirradiated fuel
Mass in stocks (tHM)

<table>
<thead>
<tr>
<th>Location</th>
<th>Description</th>
<th>Stock at 1 April 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sellafield</td>
<td>Various (1)</td>
<td>13.1</td>
</tr>
<tr>
<td>Dounreay</td>
<td>Various (2)</td>
<td>~16</td>
</tr>
<tr>
<td>All UK sites</td>
<td>Magnox fuel</td>
<td>11</td>
</tr>
<tr>
<td>All UK sites</td>
<td>AGR fuel</td>
<td>~100</td>
</tr>
<tr>
<td>All UK sites</td>
<td>PWR fuel</td>
<td>~40</td>
</tr>
</tbody>
</table>

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

3.4 Plutonium

Table 3.3 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.

Table 3.3: UK owned separated plutonium
Mass in stocks (tHM)

<table>
<thead>
<tr>
<th>Location</th>
<th>Description</th>
<th>Stock at 1 April 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>All UK sites</td>
<td>PuO₂</td>
<td>~93</td>
</tr>
</tbody>
</table>

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.¹¹

¹¹ 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 [3].
3.5 Uranium

Table 3.4 gives the total masses of UK owned DNLEU (Depleted, Natural and Low Enriched Uranium) and HEU from all sources.

Table 3.4: UK owned uranium
Mass in stocks (tHM)

<table>
<thead>
<tr>
<th>Location</th>
<th>Description</th>
<th>Stock at 1 April 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>All UK sites</td>
<td>DNLEU</td>
<td>~104,000 (1)</td>
</tr>
<tr>
<td>All UK sites</td>
<td>HEU</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

(1) The latest figure published by the Government [5] is ~118,000tHM at 31 December 2012. 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 2013 Inventory (see Table 3.1 and text below).

There are about 104,000tHM DNLEU in stock. This excludes about 8,500tHM of overseas owned material. The major components of UK owned uranium stocks are depleted uranium from enrichment in the form of UF₆, and from reprocessing of Magnox fuel in the form of UO₃. DNLEU stocks are held at Capenhurst, Springfields, Sellafield and other sites.

Future arisings of DNLEU are estimated at about 66,000tHM. This figure assumes expansion of enrichment capacity is completed in 2014 with operations continuing over the following ten years, and the reprocessing scenario reported in the 2013 Inventory. 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.

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

3.6 Thorium

Table 3.5 gives the total mass of UK owned thorium at 1 April 2013. There are no reported future arisings.

Table 3.5: UK owned thorium
Mass in stocks (tHM)

<table>
<thead>
<tr>
<th>Location</th>
<th>Description</th>
<th>Stock at 1 April 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>All UK sites</td>
<td>Thorium metal</td>
<td>~11</td>
</tr>
</tbody>
</table>

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).
3.7 Contaminated ground

The total reported volume of potentially contaminated ground is about 13,000,000\(\text{m}^3\). This is made up of soil (about 98\%) and building foundations (about 2\%). Much of the waste, about 90\%, is potentially contaminated VLLW soil from site clearance at Sellafield. Much of this soil may ultimately not require remediation (see Annex 2 for further information). Due to regulatory requirements contaminated soil at Sellafield is reported as an existing stock although remediation is not expected until the period 2090-2100.

A total of about 130,000\(\text{m}^3\) of contaminated ground is reported as waste in the 2013 Inventory.

3.8 Miscellaneous wastes and materials

Miscellaneous wastes that are not yet well characterised and materials that might be recategorised as waste at Sellafield and Capenhurst are reported (see Annex 2). Estimated waste stocks and future arisings are 570\(\text{m}^3\) and 47,000\(\text{m}^3\) respectively. The major streams in term of volume are hydrogen fluoride from uranium hexafluoride deconversion and contaminated uranic residues.
REFERENCES

ANNEX 1 ASSUMPTION USED FOR REPORTING CIVIL NUCLEAR MATERIALS

All assumptions listed below are in line with those used in compiling data for the 2013 Inventory. These assumptions represent the planning positions at 1 April 2013 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.

Since the 1 April 2013 there have been developments in the forward plans at a number of sites. This means that certain assumptions used in preparing data for the 2013 Inventory have already been revised or are being reviewed, and there will be or are likely to be some changes to waste and material estimates. Revisions can affect either, or both, the quantity and timing of future arisings.

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 radioactive waste inventory (i.e. excluded from this reporting output).
- Most irradiated fuel arising from UK reactors has been or will be reprocessed (see assumptions below). To report this irradiated fuel, as well as plutonium and uranium that has or will be produced by reprocessing the fuel, would result in double counting of nuclear materials. In addition some materials recovered from these (reprocessing) operations have been reused to manufacture fresh fuel. 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 2013; and future arisings of irradiated fuel. The estimated quantities of plutonium and uranium that will be produced 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 or ‘small users’ i.e. universities and research establishments.
- The 2013 Inventory includes radioactive waste that is expected to be produced when all the UK spent fuel that is planned to be reprocessed has been reprocessed - see assumptions below.
- Volumes of contaminated ground reported in the radioactive materials inventory are in-situ volumes of potentially radioactively contaminated ground and foundations that are not sufficiently well characterised for inclusion in the radioactive waste inventory. Radioactive wastes anticipated from radioactively contaminated ground and foundations where there is more certainty in the quantities that might be produced are reported in the radioactive waste inventory.
Irradiated fuel arisings

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

Table A1.1: Operational nuclear power stations in the UK

<table>
<thead>
<tr>
<th>Station</th>
<th>Planned shutdown date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnox:</td>
<td></td>
</tr>
<tr>
<td>Wylfa</td>
<td>2014</td>
</tr>
<tr>
<td>AGR:</td>
<td></td>
</tr>
<tr>
<td>Hinkley Point B</td>
<td>2023</td>
</tr>
<tr>
<td>Hunterston B</td>
<td>2023</td>
</tr>
<tr>
<td>Hartlepool</td>
<td>2019</td>
</tr>
<tr>
<td>Heysham 1</td>
<td>2019</td>
</tr>
<tr>
<td>Dungeness B</td>
<td>2018</td>
</tr>
<tr>
<td>Heysham 2</td>
<td>2023</td>
</tr>
<tr>
<td>Torness</td>
<td>2023</td>
</tr>
<tr>
<td>PWR:</td>
<td></td>
</tr>
<tr>
<td>Sizewell B</td>
<td>2035</td>
</tr>
</tbody>
</table>

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\(^1\)\(^2\).
- UK has contracts with other countries for reprocessing some of their spent nuclear fuel.

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:
  - 55,000tHM from Magnox reactors, of which about 52,000tHM had been reprocessed by 1 April 2013;
  - 5,000tHM from AGRs, of which about 3,000tHM had been reprocessed by 1 April 2013;
  - 28tHM from WAGR;
  - 120tHM from SGHWR;
  - About 44tHM from DFR;
  - Small amount of Post Irradiation Examination (PIE) type materials.

\(^1\) While the UK Government has stated that it supports new nuclear power stations and some operators are planning new stations, it is not yet clear how many reactors and of what design might be constructed.
- Approximately 4,400tHM of foreign owned LWR spent fuel is assumed to be reprocessed in the UK.

- 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)\(^\text{13}\):
  - 4,500tHM from AGRs;
  - 1,049tHM from PWR.

**Separated uranium and plutonium arisings & management**

- Separated uranium and plutonium is assumed to arise in the UK from the reprocessing activities listed above. Magnox fuel reprocessing is assumed to be complete by 2017; other spent fuel reprocessing by 2018.

- All UK owned separated uranium and plutonium is assumed to be held in long-term storage in the UK.

---

\(^{13}\) Although plutonium, uranium and spent fuel are not classified as waste, these materials are considered in the Government’s “Managing Radioactive Waste Safely” programme for developing and implementing a policy for managing the UK’s higher activity wastes in the long term.
ANNEX 2 CONTAMINATED GROUND WASTE AND MISCELLANEOUS WASTE AND MATERIAL STREAMS

This annex presents volumes of potentially contaminated ground wastes and miscellaneous material streams that are deemed or may be deemed to be waste. These are not in the radioactive waste inventory because the waste producers have chosen to include them with radioactive materials until there is more certainty in the quantities that might be produced.

Table A2.1 lists potentially contaminated ground waste (soil plus building foundations) streams at Sellafield, Springfields and Aldermaston. Other UK sites with anticipated contaminated ground waste have reported volumes in the radioactive waste inventory. Also contaminated ground at Aldermaston for which there is more certainty on volume is reported in the radioactive waste inventory.

The volumes given for Sellafield in Table A2.1 represent the best estimate of ground volumes affected by contamination in the various waste categories. They are, by necessity, estimates but are based on the most recent characterisation data and understanding of the site. They are subject to constant review as knowledge of the site improves. It is not envisaged that, on the basis of an overall balance between risk and benefit, all of this material will be excavated for management as waste. In particular, for the most lightly contaminated material within the HVVLLW category the optimum management plan may be some form of in-situ treatment. Excavation and remediation of appropriate Sellafield wastes is currently expected to take place in the period 2090-2100. However, the soil streams are considered to be an existing stock, rather than a future arising, as the Office for Nuclear Regulation (ONR) requires that these materials are adequately and safely managed throughout the lifetime of the site.

At Springfields the stock volume is based on land investigations and the results from test boreholes. Further investigation work will give clearer information on potential future arisings.

At Aldermaston about 110,000m$^3$ of land associated with process buildings have been identified as having the potential to be contaminated. Further investigations will be carried out after building decommissioning.
## Table A2.1: Potentially contaminated ground
Volume at 1 April 2013 and estimated for future arisings (m³)

<table>
<thead>
<tr>
<th>Site</th>
<th>Stream identifier</th>
<th>Stream description</th>
<th>Stock at 1 April 2013</th>
<th>Future arisings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sellafield</td>
<td>2D150</td>
<td>Contaminated Soil ILW</td>
<td>1,600</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>2D151</td>
<td>Contaminated Soil LLW</td>
<td>1,060,000</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>2D152</td>
<td>Contaminated Foundations ILW</td>
<td>0</td>
<td>2,200</td>
</tr>
<tr>
<td></td>
<td>2D153</td>
<td>Contaminated Foundations LLW</td>
<td>0</td>
<td>33,000</td>
</tr>
<tr>
<td></td>
<td>2D154</td>
<td>Contaminated Soil from Site Clearance - HVVLLW</td>
<td>11,800,000</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>2D155</td>
<td>Contaminated Foundations from Site Clearance - HVVLLW</td>
<td>0</td>
<td>200,000</td>
</tr>
<tr>
<td>Springfields</td>
<td>-</td>
<td>Radioactive Contaminated Land</td>
<td>~2,500</td>
<td>&lt;30,000 (1)</td>
</tr>
<tr>
<td>Aldermaston</td>
<td>7A33</td>
<td>Radioactive Contaminated Land</td>
<td>0</td>
<td>~110,000</td>
</tr>
<tr>
<td>All sites</td>
<td>Total</td>
<td></td>
<td>12,900,000</td>
<td>&lt;375,000</td>
</tr>
</tbody>
</table>

(1) Volumes are uncertain, but will be established during ongoing contaminated ground projects.
Table A2.2 lists miscellaneous waste and material streams at Sellafield and Capenhurst. These include wastes that are not yet sufficiently well characterised to be reported in the radioactive waste inventory and materials that are not yet classified as wastes but may be at some time in the future.

### Table A2.2: Miscellaneous wastes and materials

**Volume at 1 April 2013 and estimated for future arisings (m$^3$)**

<table>
<thead>
<tr>
<th>Site</th>
<th>Stream Identifier</th>
<th>Stream description</th>
<th>Stock at 1 April 2013</th>
<th>Future arisings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sellafield</td>
<td>2D64</td>
<td>Magnox interfacial crud - ILW</td>
<td>&lt;10</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>2D97</td>
<td>Miscellaneous Trench Silt ILW/LLW</td>
<td>43</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>2F28</td>
<td>Interfacial Crud ILW/LLW</td>
<td>0.12</td>
<td>~1</td>
</tr>
<tr>
<td></td>
<td>2Y60</td>
<td>Miscellaneous Minor Wastes - ILW</td>
<td>~40</td>
<td>~10</td>
</tr>
<tr>
<td></td>
<td>2Y61</td>
<td>Lead - ILW</td>
<td>~0</td>
<td>~50</td>
</tr>
<tr>
<td></td>
<td>2Y62</td>
<td>Oils and Solvents - ILW</td>
<td>~1</td>
<td>~90</td>
</tr>
<tr>
<td></td>
<td>2Y63</td>
<td>Metallic Wastes: Plant and Equipment - ILW</td>
<td>~180</td>
<td>~260</td>
</tr>
<tr>
<td></td>
<td>2Y64</td>
<td>Sludges, Resins and Flocs - ILW</td>
<td>~50</td>
<td>~80</td>
</tr>
<tr>
<td></td>
<td>2Y65</td>
<td>Miscellaneous Minor Wastes - LLW</td>
<td>~130</td>
<td>~100</td>
</tr>
<tr>
<td></td>
<td>2Y66</td>
<td>Lead - LLW</td>
<td>0</td>
<td>~100</td>
</tr>
<tr>
<td></td>
<td>2Y67</td>
<td>Oils and Solvents - LLW</td>
<td>~0.4</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>2Y68</td>
<td>Metallic Wastes: Plant and Equipment - LLW</td>
<td>~100</td>
<td>~310</td>
</tr>
<tr>
<td></td>
<td>2Y69</td>
<td>Sludges, Resins and Flocs - LLW</td>
<td>~1</td>
<td>~20</td>
</tr>
<tr>
<td>Capenhurst</td>
<td>2B13</td>
<td>Technetium Contaminated Uranic Residues</td>
<td>5.3</td>
<td>~16,100</td>
</tr>
<tr>
<td></td>
<td>2B14</td>
<td>Uranic Residues</td>
<td>8.2</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>2B18</td>
<td>HF from Hex Deconversion</td>
<td>0</td>
<td>~30,000</td>
</tr>
<tr>
<td>All sites</td>
<td>Total</td>
<td></td>
<td>~570</td>
<td>~47,000</td>
</tr>
</tbody>
</table>
ANNEX 3   GLOSSARY

The glossary contains a list of specialised terms and abbreviations used in this report.

~         Approximately.
~~        Very approximately.
AGR       Advanced Gas-cooled Reactor.
Contaminated ground  Contaminated ground is defined as ground, soil, water and, potentially, underground structural materials such as building foundations which have been impacted by radioactive and/or chemical substances from past or present operations (including authorised discharges and disposals), and for which the level of the radioactive or chemical substance is above natural background.
DECC     Department of Energy and Climate Change. The UK Government Department responsible for all aspects of UK energy policy and for tackling global climate change on behalf of the UK.
Depleted uranium  Uranium where the uranium-235 isotope content is below the naturally occurring 0.72% by mass.
DFR       Dounreay Fast Reactor.
DNLEU     Depleted, Natural and Low Enriched Uranium.
Dragon    Experimental high temperature reactor project sited at Winfrith and funded by the Organisation for Economic Cooperation and Development (shut down in 1976).
DU        Depleted Uranium.
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.
GLEEP     Graphite Low Energy Experimental Pile. Low energy, 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 includes the UK Government, the Scottish Government and the Devolved Administrations of Wales and Northern Ireland.
HEU       Highly Enriched Uranium. Uranium where the uranium-235 isotope content is 20% by mass or more.
HF        Hydrogen Fluoride.
HVVLLW    High Volume Very Low Level Waste
IAEA      International Atomic Energy Agency.
ILW       Intermediate Level Waste
Irradiated fuel  Fuel that is being or has been used to power nuclear reactors.
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEU</td>
<td>Low Enriched Uranium. Uranium enriched in U-235 to less than 20% by mass.</td>
</tr>
<tr>
<td>LLW</td>
<td>Low Level Waste</td>
</tr>
<tr>
<td>LWR</td>
<td>Light Water Reactor.</td>
</tr>
<tr>
<td>Magnox</td>
<td>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.</td>
</tr>
<tr>
<td>MoD</td>
<td>Ministry of Defence.</td>
</tr>
<tr>
<td>MOX</td>
<td>Mixed Oxide. Refers to nuclear fuel consisting of uranium oxide and plutonium oxide for use in reactors.</td>
</tr>
<tr>
<td>MRWS</td>
<td>Managing Radioactive Wastes Safely.</td>
</tr>
<tr>
<td>NDA</td>
<td>Nuclear Decommissioning Authority. A public body set up by the Government in April 2005 with responsibility for the UK’s public sector civil nuclear liabilities, and their subsequent management. In October 2006, the Government also gave the NDA the responsibility for developing and ensuring delivery and implementation of the programmes for interim storage and geological disposal of the UK’s higher activity wastes. From March 2007, the NDA was also given responsibility for developing a UK wide strategy for managing the UK nuclear industry’s Low Level Waste (LLW) and for securing disposal capacity for LLW generated by non-nuclear industry users.</td>
</tr>
<tr>
<td>NU</td>
<td>Natural Uranium.</td>
</tr>
<tr>
<td>Nuclear fuel</td>
<td>Fuel used in a nuclear reactor. Most fuel is made of uranium, and produces heat when the uranium atoms split into smaller fragments.</td>
</tr>
<tr>
<td>ONR</td>
<td>Office for Nuclear Regulation (an agency of the Health and Safety Executive).</td>
</tr>
<tr>
<td>PIE</td>
<td>Post-Irradiation Examination.</td>
</tr>
<tr>
<td>PFR</td>
<td>Prototype Fast Reactor (at Dounreay site).</td>
</tr>
<tr>
<td>Plutonium</td>
<td>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.</td>
</tr>
<tr>
<td>Pu</td>
<td>Plutonium.</td>
</tr>
<tr>
<td>PuO₂</td>
<td>Plutonium dioxide.</td>
</tr>
<tr>
<td>PWR</td>
<td>Pressurised Water Reactor.</td>
</tr>
<tr>
<td>Radionuclide</td>
<td>A general term for an unstable nuclide that emits ionising radiation (e.g. cobalt-60).</td>
</tr>
<tr>
<td>Reprocessing</td>
<td>The chemical extraction of reusable uranium and plutonium from waste materials in spent nuclear fuel.</td>
</tr>
<tr>
<td>Safeguards</td>
<td>Nuclear safeguards are measures to verify that countries abide by their commitments to use nuclear material for declared peaceful purposes.</td>
</tr>
<tr>
<td>Spent fuel</td>
<td>Fuel that has been used in nuclear reactors that is no longer</td>
</tr>
</tbody>
</table>
capable of efficient fission due to the loss of fissile material.

**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.

**U-235**
Uranium-235 is the main fissile isotope of uranium. Natural Uranium typically contains 0.72% by weight of U-235.

**UF₄**
Uranium tetrafluoride

**UF₆**
Uranium hexafluoride.

**U₃O₈**
Triuranium octoxide.

**UO₂**
Uranium dioxide.

**UO₃**
Uranium trioxide.

**Uranium**
A radioactive element that occurs in nature. Uranium is used for nuclear fuel and in nuclear weapons.

**Unirradiated fuel**
Fuel that has not yet been used to power nuclear reactors.

**VLLW**
Very Low Level Waste.

**WAGR**

**Yellowcake**
Yellowcake is concentrated uranium oxide, obtained through the milling of uranium ore. Yellow cake typically consists of 70-90% U₃O₈ with the remainder consisting of UO₂ and UO₃.

**ZEBRA**
Zero Energy Breeder Reactor Assembly. ZEBRA was a fast reactor that operated from 1962 to 1982 at Winfrith.

**Zenith reactor**
A research reactor at Winfrith that has been decommissioned.
Electronic copies of this and other 2013 Inventory documents can be obtained from the NDA (see contact details below) or via the UK Radioactive Waste Inventory website

www.nda.gov.uk/ukinventory

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ISBN: 978-1-905985-37-1

Front cover images: left - waste packages at Dounreay, top - LLW vaults, bottom left - deplanting and demolition at Sizewell A, bottom right - demolition, making room for new facilities

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