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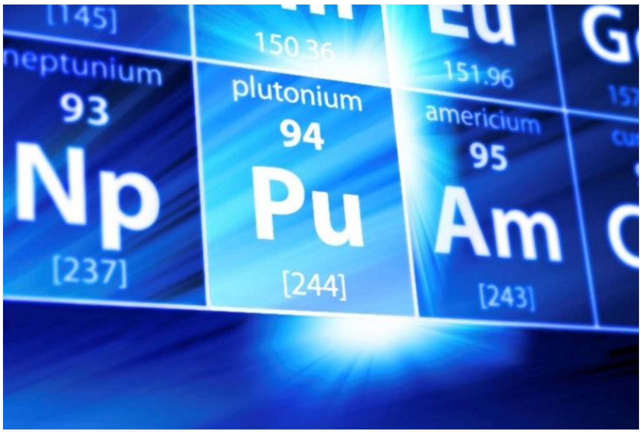
Managing the UK Plutonium Stockpile



The UK has been amassing its plutonium stockpile since the 1950s[1] and is yet to make a decision on its long term management. This POSTnote describes the state of the stockpile, current plutonium policy and the options for managing the plutonium: indefinite storage, reuse in UK power plants, conversion to fuel to send overseas and disposal as waste. It then outlines the safety, security, economic and energy policy implications of these options.

Overview

- The UK is storing the largest 'separated' civil plutonium stockpile in the world. This poses safety, security and cost challenges.
- The Nuclear Decommissioning Authority is assessing long term options for managing the stockpile with industry pushing for a timetable for the selection and delivery of an option.
- Options include disposal of the plutonium in a treated form, reusing it as fuel in UK power plants or sending plutonium overseas in fuel form.
- These options all reduce some of the safety and security concerns associated with storage, but they introduce their own risks.
- Energy policy goals would be helped by one option: reusing the plutonium as fuel in UK power plants.
- It is not currently clear which of the options offers the best economic value for money.

The UK Plutonium Stockpile

Plutonium (Box 1) is produced as a by-product from the use of uranium fuel in nuclear reactors. In the UK, the plutonium has been separated out from the used fuel since the 1950s. This 'separated' plutonium is stored in powder form in steel and aluminium cans kept in reinforced concrete buildings above ground at Sellafield.[2] By 2014, the UK had accumulated a total civil separated plutonium stockpile of 126 tonnes, the largest civil separated stockpile in the world. Of this, 23 tonnes is overseas-owned.[4] UK-owned civil separated plutonium makes up 38% of global separated civil plutonium.[3,4] The UK stockpile is expected to reach 140 tonnes by 2020, after which UK plutonium extraction is due to cease.[8] In addition to the civil plutonium, the UK has 3.2 tonnes of military plutonium, either in the form of nuclear weapons or reserve stocks.[7] The military stockpile is not discussed further in this briefing.

Box 1. Properties of Plutonium

- Some plutonium isotopes[5] are 'fissile': under specific conditions they can cause a self-sustaining nuclear chain reaction. This process is known as **criticality** and can result in an explosive release of energy, which is the principle behind nuclear weapons.[6]
- Plutonium is radioactive and toxic if inhaled. Outside of the body, it is much less harmful because plutonium's radiation can only very weakly penetrate skin and other tissue.[7]
- Plutonium is heat generating and canisters of plutonium need to be stored in air conditioned facilities to prevent them from over-pressurising and deteriorating.

Cost of Storing the Stockpile

Storing the plutonium stockpile requires expenditure on safety and security measures. If the UK continues to store the stockpile, the Government expects that the average (undiscounted) cost over the next 110 years would be £73 million per year.[9]

Safety and Security Risks

The Government is confident that the storage of plutonium in the UK is safe and secure and there have not been many international plutonium incidents (see Box 2), but plutonium poses safety and security risks that have to be managed and some stakeholders still have concerns about the risks.

- **Safety**: Inhalation of plutonium powder increases the risk of developing cancer.[10] It can also self-sustain a nuclear chain reaction under certain conditions. These risks are managed by handling the plutonium either remotely or in glove boxes (sealed containers with inserted gloves) and by storing it in small amounts.

Box 2. Plutonium Safety and Security Incidents
Safety and security incidents involving nuclear material are monitored globally by the International Atomic Energy Agency and within the UK by the Office for Nuclear Regulation.

- **Criticality:** There have been 22 criticality (see Box 1) incidents globally. One was in the UK at Sellafield in 1970 and involved plutonium reaching criticality for less than 10 seconds. Two workers were exposed to low levels of radiation.[11]
- **Security:** There have been 11 global incidents of unauthorised possession of plutonium and plutonium-containing nuclear material between 1993 and 2015.[12] Incidents can range from theft and loss to criminal activities but further details are not publically available.
- **Health**: Although exposure to radiation can be linked to an increase in cancer rates, a study of plutonium workers at Sellafield did not show an overall increase in cancers compared to workers not handling plutonium nor the wider population of Cumbria.[13]

Box 3. Organisations Responsible for Safety and Security
The plutonium in the UK that is UK owned, is owned by the Government. Responsibility for the civil plutonium stockpile lies with a range of organisations.

- The Nuclear Decommissioning Authority (NDA), a non-departmental public body funded by the UK Government, manages the UK plutonium stockpile. It has an annual budget of £3.2 billion in 2016/17.[24]
- Sellafield Ltd, a wholly-owned subsidiary of the NDA, is the operator for the site on which most of the UK plutonium is stored and is responsible for its safety and security.
- The Office for Nuclear Regulation and the Environment Agency are responsible for enforcing compliance with laws on the environmental impact, safety and security of nuclear sites.
- The Civil Nuclear Constabulary, an armed response unit, provides on-site security at Sellafield.

- **Security**: Sabotage of nuclear facilities could lead to the dispersal of plutonium.[14] Alternatively, if plutonium was stolen, it could be dispersed in a 'dirty bomb', which is a conventional explosive device containing radioactive material, or be used to make a nuclear weapon. However, using it for a nuclear weapon would require sophisticated knowledge and technology and the plutonium is not of sufficient quality to generate predictable explosions.[7,14,15] To manage all these risks, the UK's civil plutonium is secured behind multiple barriers, protected by armed guard and a number of organisations are responsible for its security and regulation (Box 3).

Policy

Long-held concerns about cost and risk have meant that the Nuclear Decommissioning Authority (NDA) has been reviewing the long-term options for the stockpile since 2004 and is advising the Government on its choice.[16,17] The NDA outlined its preferred option in January 2014 and is expected to publish an update of its work in late 2016. Industry is pushing the Government for a clear timetable for the selection and delivery of options.[18] Industry claim that this would help to place the UK as a global leader in nuclear development.[18] It may also help the UK to retain its plutonium skills and knowledge; there is currently a skills shortage in the nuclear industry.[9,19] However, the Government has stated that a decision will not be taken quickly because they need time to build confidence in the ability to implement any chosen option.[20,21]

Plutonium Management Options

Four options for plutonium management are outlined in this briefing: indefinite storage at Sellafield; reuse as fuel in UK nuclear power plants; combining the plutonium with natural or depleted uranium to form Mixed Oxide (MOX) fuel to send overseas;[22] and disposal of the plutonium in a solid form. All options ultimately end in disposal, with reused fuel being disposed of after use. Around 5% of the stockpile is not suitable for reuse (because it would need considerable treatment) and is recommended for disposal by the NDA.[23]

Indefinite Storage

This involves continued storage of plutonium at Sellafield.[2] It is the current default option, but most stakeholders do not consider it a long term solution.[2,8]

Reuse in UK Nuclear Power Plants

The Government's preferred option for plutonium management has always been to reuse it in commercial-scale UK power plants, although this has never been achieved.[9,25] This option requires the plutonium to be processed into fuel (of which there are various forms) that can then be used in nuclear power plants. The NDA consider three types of power plant to be credible: light water reactors, the CANDU EC6 reactor and the GE Hitachi PRISM reactor.[8] Other options including small modular reactors are not discussed in this briefing.

Light Water Reactors (LWR)

This is the Government's current preferred option.[9] It would use plutonium to part-fuel or fully-fuel the UK's part-planned fleet of around eleven new LWRs (Box 4) or the existing Sizewell B power plant or both.[26] Plutonium fuel for the LWRs would be formed by mixing the plutonium (oxide) with uranium (oxide) to form MOX, which would be used to replace some conventional uranium fuel.[22,27] MOX has been used in this way in around 40 LWRs in Europe and all the new UK LWRs should be able to operate with 50% MOX fuel if they meet European Utility Requirement guidelines.[22,28,29] However, these guidelines are not mandatory and MOX use in LWRs would be a change to the current UK LWR plans (and current practice at Sizewell B), which are based on using only conventional uranium fuel. This change would need to go through regulatory decision processes, which could take a number of years (see POSTnote 457).[30] Higher MOX proportions would also be possible but may require some reactor design modifications.

To produce the required MOX, the UK would need to build a new MOX plant, since the UK's previous MOX plant at Sellafield closed in 2011.[31,32,33] The company AREVA has proposed building and operating the MOX plant based on their MELOX plant in France.[34] It would take 40 years to use all of the reusable plutonium if there were five LWRs using 30% MOX fuel; the timeframe would change with a different number of reactors or different MOX proportion.[35] Sizewell B would only have time and capacity to use a small proportion of the plutonium stockpile.

CANDU EC6 Reactor

The company CANDU Energy is proposing to build four EC6

Box 4. UK Planned New Nuclear Reactors
In 2013, the Government set out a strategy to help the UK build a set of new light water reactors in England and Wales to replace the UK's closing nuclear power stations.[36] Plans for these power stations are at different stages of development (see POSTnote 457), but none of them have received a final decision from the Government that would allow building to commence yet. The most advanced plan is for two reactors at Hinkley Point in Somerset. The Government has offered the proposed plant a contract that would guarantee the power station £92.50 for each Megawatt-hour of electricity it generated.[37] However, a final decision has been delayed for a number of years, amid financing, legal, security and cost concerns.

(Enhanced CANDU) reactors, specifically for the purpose of reusing plutonium.[38] Plutonium would be converted to 'CANMOX' (MOX specifically made for use in CANDU reactors) using a specially built CANMOX fuel plant. The reactors could use the UK's reusable plutonium in 30 years.[38] CANDU estimates that it would take 15 years to have a plant operating. There are currently 10 operational CANDU 6 reactors globally, from which the CANDU EC6 reactor is adapted.[39] No EC6 reactors have been built and the NDA has stated that further tests are still required of the reactor's fuel's performance and how the fuel is produced; this work is in progress.[38]

GE Hitachi PRISM Reactor
GE Hitachi's PRISM unit would consist of two reactors and be capable of processing all of the reusable UK plutonium over its 60 year life.[40] Fuel would be formed by converting the plutonium powder to its metal form and combining it with uranium and zirconium to form a solid, metal fuel rod.[41] PRISM reactors have a modular design, allowing for serial production with a potential for quick construction times.[42,43] PRISM is based on the EBRII reactor that operated for over 30 years in the US but was shut in 1994. The NDA has voiced concerns over the technological readiness of both PRISM's reactor and fuel manufacturing plant.[8] However, GE Hitachi estimate that PRISM can be operational within a comparable timeframe to that of other reuse options.

Conversion to MOX to Send Overseas
The UK could convert plutonium into MOX to send overseas for re-use in overseas reactors. The previous MOX plant at Sellafield was used for this purpose and a new MOX plant would need building for this option. However, countries that use MOX have their own MOX plants or are in the process of building them, so there is no demand for UK produced MOX. Without a known demand for UK produced MOX, it is considered high risk to build a MOX plant for this option and the NDA does not consider this to be a credible option.[31]

Disposal
Plutonium could be classified as waste and then disposed. The NDA's proposed process of disposal involves treatment (immobilisation) of the plutonium and then disposal in a geological disposal facility (GDF).

Immobilisation
To dispose of plutonium it needs to be chemically fixed (immobilised) in to a material that will minimise the waste volume and environmental exposure to radioactivity.[44] Plutonium immobilisation is not commercially-available, but two materials are being researched: glass and ceramic. Glass is currently used for other nuclear wastes but there have been concerns over its durability.[44] Ceramics have not yet been used with plutonium in industry, but the NDA is funding a pilot plant that is being built by the National Nuclear Laboratory in Sellafield.[45,46] Since 5% of the stockpile is unsuitable for reuse and is likely to need immobilisation, some stakeholders are encouraging more investment in research to prove the technology.[45]

Geological Disposal
Immobilised plutonium would be disposed of in a GDF – an underground repository designed to isolate radioactive waste deep underground inside rock.[47,48] An attempt to secure a location for the GDF in Cumbria fell through in 2013 after Cumbria County Council withdrew its support. A new process to identify a location for the GDF is expected to start in 2017.[49] If successful, the facility will take decades to build.[48] Plans for the GDF take into account that it will eventually be used to dispose of some, and potentially all, of the plutonium.[47] The GDF will be located in England, Wales or Northern Ireland; Scotland has opted against hosting a GDF.[48,50] Sweden, Finland and France are ahead of the UK in developing their GDFs and the USA has a GDF for defence waste, but not used fuel or separated plutonium.[51]

Implications of the Options
Safety and Security
The new management options – reuse in UK power plants, sending MOX overseas and disposal – will decrease some current safety and security risks, while introducing some new risks, described below. Most changes are option specific, although all will ultimately remove the risk of inhalation because they all convert the plutonium from a powder into a solid. There is not a consensus about which option offers the best change in safety and security risks.

Power Plants and Sending MOX Overseas
These options would have a mix of benefits and drawbacks for safety and security. The risk of theft could initially increase because there would be more opportunities to access the fuel during transit to and from fuel conversion plants and power plants and to overseas.[52] However, once the separated plutonium is converted into fuel there would be a reduction in the theft risk as it would be more difficult to extract the plutonium from the fuel. The plutonium would continue to be difficult to extract once used in a reactor and the used fuel would also be harder for thieves to handle as it would generate more radiation than the fuel or separated plutonium.[53] Furthermore, the weapons potential of the material would be even further reduced as the fissile proportion of plutonium is reduced when used in a reactor.

Disposal
Disposal may reduce the risk of theft. Once the plutonium is immobilised, a thief would require a crane to lift each plutonium canister. Even if a canister were stolen, the plutonium would be extremely difficult to access as it would

be chemically fixed in glass or ceramic. A further barrier to theft would be introduced by placing the immobilised plutonium in an underground GDF, with cement blocking access to the site after closure.[47,54,55] However, as with the power plant options, the risk of theft of plutonium (in powder or immobilised form) during transit would increase.

There is debate about the possibility of radiological leakage from a GDF, with Greenpeace raising concerns.[56,57] Radioactive Waste Management (RWM), a wholly-owned subsidiary of the NDA, has indicated that the probability of leakage would be very low as the waste would be secured by a series of barriers: the glass or ceramic used in immobilisation, a canister, a clay buffer surrounding the canister and the rock surrounding the GDF.[47] Greenpeace argues that even this low risk is unacceptable and suggests that the possibility of undetected faults and fractures in the rock surrounding the GDF make the risk difficult to define.[56,57] RWM have stated that any future facility will meet the required high standards for safety, security and environmental protection required by the Environment Agency and the Office for Nuclear Regulation.

Economics

The NDA is assessing the overall cost (and income) of the options to Government. It is not clear which option offers best value for money as economic estimates are not publically available, although CANDU and AREVA have released some estimates (see Box 5). The broad costs involved are outlined below.

Indefinite Storage

This incurs indefinite annual expenses for security management. Costs are likely to rise over time because:

- the number of steel cans (that store the plutonium) that need to be replaced is set to increase[9]
- over time the plutonium radioactively decays to produce by-products that emit harmful radiation and may necessitate further spending on treatment if the plutonium is to be reused at a future date.[7]

Power Plants and Sending MOX Overseas

These options require nuclear infrastructure to be built and would have high upfront costs to companies and possibly government. They would also offer revenue to companies and government from the sale of electricity, fuel or both. Companies have suggested that the Government would need to provide financial support to encourage these options.[58] For the reuse as MOX fuel in UK LWR option, the NDA estimates that the total amount that companies would pay for the MOX fuel would be less than the cost of building and running a plant, making the plutonium a liability to government if it pursues this option.[59] The NDA has not commented on the economics for CANDU and PRISM, but CANDU has published some estimates (see Box 5).

There have been some concerns about the ability of projects to deliver on budget and on time. For MOX plants, environmental groups and academics have highlighted that a number of international projects have been late and over budget (see Box 6).[30,61] For the CANDU option, the last reactor build was completed in 2007 and this would be its first MOX plant build. However, CANDU delivered its previous seven reactors on schedule and on budget.[60]

Box 5. CANDU and AREVA economic case studies

CANDU estimate the following costs, which do not account for a contingency budget for the project going over budget or time:

- £11.2 billion for construction of four EC6 CANDU reactors
- £0.9 billion for construction of the CANMOX plant
- £81 per MWh – the average electricity charge from plant.

CANDU have proposed that the Government provide financial support to cover the extra cost of using MOX (from plutonium) rather than pure uranium. This would be subject to negotiation with the Government.[60]

AREVA estimates that the income from MOX fuel would be £1.8 billion.[34]

Disposal

This option may present lower upfront costs than reuse in power plants or sending MOX overseas.[62,63] A large part of this cost is already being incurred because the GDF would be used for other radioactive waste. However, unlike the reuse options the bulk of costs from this option may fall to the Government as private investment may be difficult to secure because of a lack of revenue stream.[62]

Energy Policy

The nuclear power plant options would provide a low carbon source of electricity, which could help the UK to achieve its policies of maintaining a secure energy supply and reducing greenhouse gas emissions by 80% by 2050.[64,65] The Government plans to build 16,000 MW of new LWRs by 2030. (For comparison, in 2014, the UK had 8,250 MW of nuclear power plants, which generated 19% of the UK's electricity.[66]) However, there is growing scepticism about this target being met. Implementation of the PRISM and CANDU options would generate an additional 622 MW and 2,920 MW of electricity respectively.[39,40]

Box 6. International MOX Production

A number of MOX plants have been developed internationally.

- In the UK, the Sellafield MOX Plant converted overseas plutonium into MOX from 2002 before being shut in 2011, suffering severe criticism for its high cost and low performance.[31] Although designed to produce 120 tonnes of fuel per year, it only produced a total of 13.8 tonnes during its lifetime.[33] It had a total net cost of £1.4 billion.[59]
- In Japan, delays to its MOX plant development have exceeded two decades with completion now due in 2018.[67]
- In the USA, the construction of the Savannah River MOX plant[68] has slowed down as budget cuts and escalating costs have caused alternative options for plutonium management to be assessed.[69,70]
- In France, AREVA's MELOX MOX plant produces MOX for a number of French commercial nuclear reactors.[71,72]

Endnotes

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