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# Plutonium management policy in the United Kingdom: The need for a dual track strategy



Neil C. Hyatt

Immobilisation Science Laboratory, Department of Materials Science and Engineering, The University of Sheffield, Sir Robert Hadfield Building, Mappin Street, Sheffield S1 3JD, UK

## HIGHLIGHTS

- Policy and technology developments in US plutonium disposition programme are analysed.
- The vulnerabilities of the UK policy for plutonium reuse as MOX fuel are assessed.
- Adoption of dual-track approach to management of UK plutonium is recommended.

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## ABSTRACT

The United Kingdom holds the largest stockpile of separated civil plutonium in the world, projected to reach 140 t, at the end of this decade, when reprocessing operations are complete. UK Government policy is that this material should be reused as MOX fuel in Light Water Reactors. This policy is re-examined in the light of recent experience of the US plutonium disposition programme, in which the MOX Fuel Fabrication Facility is now considered to be potentially unaffordable. Problematic aspects of US programme, relevant to the UK scenario, are reviewed, to understand the possible impact on UK policy. Based on the US experience and inherent uncertainty regarding the capital and operational costs of MOX fuel fabrication and plutonium immobilisation facilities, and the associated technical risks, it is concluded that the UK policy should explicitly adopt a dual track strategy to plutonium management, with commitment that: *any remaining plutonium which is not converted into MOX fuel, or otherwise reused, will be immobilised and treated as waste for disposal*. This will also ensure that the UK is positioned and prepared to take forward an immobilisation and disposal programme for the plutonium stockpile, should reuse as MOX fuel not prove an economic or viable option.

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## 1. Introduction

The UK holds stockpile of separated plutonium which is projected to exceed 140 t at the end of planned nuclear fuel reprocessing operations in 2020 (Nuclear Decommissioning Authority, 2014), this is the largest stockpile of plutonium under civil safeguards worldwide. Current stocks of UK plutonium are summarised in Table 1 (Office of Nuclear Regulation, 2014).

In the 1960's, the projected growth of civil nuclear energy, and depletion of finite fossil fuel reserves, focused attention on the development of fast reactor systems capable of improving the efficiency of uranium resource utilisation, by breeding Pu-239 from fertile U-238 (99.3% natural abundance). Such fast reactor systems

require an initial core of plutonium driver fuel, which, in the UK, was to be produced by reprocessing of nuclear fuel from Magnox, and, later, Advanced Gas Cooled Reactors (AGRs). Ultimately, fossil fuel prices remained largely stable, accessible reserves of uranium ores increased, and the anticipated growth of civil nuclear energy was not realised. In this context, the commercial viability of fast reactor systems could not be demonstrated and development was largely abandoned. Commercial scale reprocessing and MOX fuel fabrication also proved challenging, with throughput below target in the Magnox reprocessing plant, Thermal Oxide Reprocessing Plant (THORP), and Sellafield MOX Plant (Global Fissile Material Report, 2015). The UK cancelled its fast reactor programme in 1994, but plutonium separation continued due to technical constraints and reprocessing contract obligations. This, combined with below target reprocessing and MOX fuel fabrication, led to the accumulation of the current stockpile, in the absence of a

E-mail address: [n.c.hyatt@sheffield.ac.uk](mailto:n.c.hyatt@sheffield.ac.uk)

**Table 1**  
UK civil plutonium inventory as of 31 December 2014, as published by the Office of Nuclear Regulation; of the total reported 23.0 teHM is owned by foreign bodies (Office of Nuclear Regulation, 2014).

Item	Amount (teHM)
Unirradiated separated plutonium in product stores at re-processing plants	122.1
Unirradiated separated plutonium in the course of manufacture or fabrication and plutonium contained in unirradiated semi-fabricated or unfinished products at fuel or other fabricating plants or elsewhere	0.8
Plutonium contained in unirradiated MOX fuel or other fabricated products at reactor sites or elsewhere	1.9
Unirradiated separated plutonium held elsewhere.	1.5
<b>Total</b>	<b>126.2</b>

suitable route for reuse in either light water or fast reactor systems.<sup>1</sup>

In the UK, plutonium management policy is defined by Government, supported by the Nuclear Decommissioning Authority (NDA) who provide the necessary strategic analysis and options for the implementation of policy. The risk and hazard associated with the UK plutonium stockpile has been the focus of considerable debate. An influential report of the Royal Society in 2007, concluded that “The status quo of continuing to stockpile a very dangerous material is not an acceptable long-term option” and urged Government “to develop and implement a strategy for the management of separated plutonium as an integral part of its energy and radioactive waste policies” (The Royal Society, 2007).

The Nuclear Decommissioning Authority (NDA) commissioned a Credible Options Analysis for long term plutonium management, which identified three primary options for plutonium management, that could conceivably be implemented within 25 years (Nuclear Decommissioning Authority, 2010):

- The current strategy of long-term storage (followed by immobilisation disposal);
- Prompt immobilisation and direct disposal;
- Reuse as fuel, with conversion to Mixed Oxide (MOX) fuel for burning in current Light Water Reactor (LWR) designs as the reference scenario<sup>2</sup>.

NDA later concluded that plutonium reuse as MOX in the CANDU EC6 heavy water reactor and reuse in the GE Hitachi PRISM fast reactor, were also credible options, but acknowledged significant technical and commercial risks in implementation of all reuse and immobilisation options (Nuclear Decommissioning Authority, 2014). The science and strategy of plutonium

<sup>1</sup> At the time, reprocessing was considered the only feasible approach to the management of Magnox and AGR fuels, due to their susceptibility to corrosion in prolonged wet storage.

<sup>2</sup> MOX fuel comprises a mixture of uranium and plutonium oxides, as a solid solution (U,Pu)O<sub>2</sub> and/or a blend of discrete UO<sub>2</sub> and PuO<sub>2</sub> phases. MOX fuels are fabricated in a similar fashion to ordinary UO<sub>2</sub> (UOX) fuels, with a typical reactor grade PuO<sub>2</sub> content of ca. 7% for use in LWRs, which generally operate with a core loading of 30% MOX fuel (Status and Advances in MOX Fuel Technology, 2003). The fissile content of such fuels is equivalent to a <sup>235</sup>U enrichment of ca. 4% in UOX fuel (Status and Advances in MOX Fuel Technology, 2003). The World Nuclear Association estimates 40 European LWRs are licensed to use MOX fuel, with more than 30 doing so (World Nuclear Association, 2016). The key strategic driver for adoption of MOX fuel is sustainability of fissile material resources, by production of energy from plutonium created from irradiation of UOX fuels in LWRs. However, the hazard, security and safeguards of plutonium separation, through reprocessing of nuclear fuels, and the attendant proliferation risks, are of international concern. These strategic drivers and the international status of MOX fuel technology are summarised in a recent IAEA Technical Report (Status and Advances in MOX Fuel Technology, 2003).

### Box 1—Plutonium disposition by immobilisation.

The aim of plutonium disposition by immobilisation is to incorporate plutonium, at the atomic scale, within a suitable host material, yielding a passively safe and proliferation resistant waste package for final disposal. In this approach, the host material, which may be an amorphous glass or crystalline ceramic, may incorporate plutonium by substitution of another chemical element within the framework of its constituent atoms. For example, in the case of the candidate ceramic material zirconolite, CaZrTi<sub>2</sub>O<sub>7</sub>, the mechanism of substitution could involve Pu<sup>4+</sup> replacing Zr<sup>4+</sup>, e.g. CaZr<sub>1-x</sub>Pu<sub>x</sub>Ti<sub>2</sub>O<sub>7</sub>. Glass-ceramic materials are also considered for plutonium immobilisation, in which plutonium is partitioned within a highly durable ceramic phase encapsulated within a glass matrix that incorporates entrained impurities.

Selection of the host phase and plutonium incorporation mechanism is made against material performance criteria, which typically include: durability – stability toward corrosion by ground water in the disposal environment; waste loading – the quantity of plutonium incorporated per unit volume; radiation tolerance – the resistance to loss of mechanical integrity through self radiation damage; process compatibility – the efficacy of manufacture within the constraints of a nuclear facility; and availability of natural analogues – the existence of corresponding natural mineral phases which demonstrate material longevity for the required service lifetime of > 10<sup>5</sup> years. A considerable body of evidence has established a tool box of glass and ceramic phases which admirably fulfil these criteria, including the example of zirconolite given above; for authoritative reviews see (Ewing, 2005, 2007; Weber et al., 1998, 1997).

The selection of one or more candidate materials for application in plutonium (or other actinide) immobilisation, is the focus of national programmes which, in addition to providing the fundamental scientific evidence to support selection of a host phase, must also demonstrate compatibility with the nature of the waste feedstock (e.g. metal or oxide form, particle size and habit, entrained contaminants) and deployment within an industrially mature manufacturing process.

Immobilisation and disposal of plutonium in a passively safe tailored wastefrom offers two considerable advantages over disposition by irradiation and disposal as MOX fuel (or vitrified waste from MOX reprocessing). First, the thermal output of MOX fuels (or vitrified waste) at the envisaged time of emplacement, demands a much larger repository footprint to separate waste packages than is the case for a tailored wastefrom (in order to preserve the integrity of clay buffer material used to surround the waste containers). Second, disposal of MOX fuel demands an environment in which geochemically reducing conditions are maintained for the required timescale (such that uranium is maintained as more insoluble uranium (IV) and oxidation to soluble uranium (VI) is precluded); this is not necessarily a constraint for a tailored wastefrom. In the context of geological disposal of radioactive wastes, these factors are important considerations in safety assessment and overall cost of a geological disposal facility, and hence the choice of a MOX or immobilisation strategy for plutonium disposition.

immobilisation and disposal are briefly summarised in Box 1.

Building on NDA's Credible Options Analysis, the UK Government commissioned a consultation exercise in 2011, to support identification of a preferred plutonium management option (Department of Energy and Climate Change, 2011). The policy position was defined by the Department of Energy and Climate Change in the consultation response published in 2013 (Department of Energy and Climate Change, 2013):

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