

Management options for the UK's separated plutonium: Royal Society submission to the Nuclear Decommissioning Authority's consultation

Summary of key points

- The Government must develop and implement a strategy for the management of the UK's stockpile of separated plutonium as an integral part of its energy and radioactive waste policies. This strategy cannot be discussed in isolation from decisions about new nuclear power stations in the UK, which would open up a new set of management options. However, the Nuclear Decommissioning Authority's (NDA) remit does not extend to consideration of new nuclear power stations (NDA 2006). When formulating a management strategy for the UK's plutonium stockpile, the Government must adopt a broader view that is not restricted by such administrative limitations.
- Decisions about the management of the stockpile should also be incorporated in the NDA's current deliberations about developing and delivering a UK nuclear waste strategy in general, and the design and operation of a geological repository in particular.
- If new nuclear power stations are built in the UK, then the stockpile could be burned as Mixed Oxide (MOX) fuel in a new generation of thermal reactors. The NDA should recognise that this would be an effective and technically proven reuse and waste management strategy for the UK's separated plutonium prior to final disposal. If reuse as a fuel is a serious possibility, then the NDA assessment will fall short if it does not include this option and its economic consequences.
- Not all of the stockpile can be converted into MOX fuel and reused in a thermal reactor. However, there are currently no technically proven and commercially deployable immobilisation technologies that the UK could use to dispose of its plutonium stockpile other than MOX fuel fabrication and re-use. The NDA should therefore maintain its research programme on alternative wasteforms and process routes for the immobilisation of these wastes.
- A proposal to sell the UK's plutonium stockpile would be deeply controversial and would face significant economic and political challenges. Selling the stockpile could set a precedent for nuclear proliferation.
- The NDA presents a traffic light table to summarise its evaluation of the management options. This is not an effective way to communicate the advantages and disadvantages of the options to the Government.

Background

The Royal Society first expressed concern about the lack of a strategy for managing the UK's growing stockpile of separated plutonium in a report in 1998. The Society urged the Government to commission a review. In the absence of such a review, the Society published a further report in 2007, *Strategy Options for the UK's Separated Plutonium*. The Society stressed that much had changed that made it all the more urgent to review UK options, including the emergence of climate change as a constraint on energy production and the possibility of new nuclear power stations in the UK. The Nuclear Decommissioning Authority (NDA) had also been created. The NDA acquired all the nuclear sites and facilities owned by the British Nuclear Group and the UK Atomic Energy Authority. It is responsible for decommissioning them and managing their nuclear waste.

Since the publication of the Society's report, the Government published its White Paper on nuclear power in January 2008. This sets out principles for the development of a new generation of nuclear power stations in the UK. It also committed the Government to consult on the future of the UK's stockpile of separated plutonium, which led to the publication by the NDA of a consultation in August 2008 to seek advice about options for the management of the stockpile (NDA 2008).

The Royal Society welcomes the opportunity to submit evidence to this consultation. This submission has been prepared in consultation with nuclear science, engineering, regulation and security experts, including Fellows of the Royal Society and the Royal Academy of Engineering. We address each of the questions in the NDA consultation below.

1 NDA's Role and Responsibilities

Q1 The factors we are planning to include in our consideration are described above and can broadly be categorised to be economic, socio-economic and safety (including security) or environmental. Are there any other significant drivers you think we should be considering in the final analysis?

1.1 Integrating plutonium management into national energy and radioactive waste policies

We reiterate the main recommendation of the Society's 2007 report, that the Government must develop and implement a strategy for the management of the UK's stockpile of separated plutonium as an integral part of its energy and radioactive waste policies. As these policies now include a positive desire to develop new nuclear power stations, the strategy for plutonium should also include options that may arise from such developments, including the use of plutonium as a fuel. If new nuclear power stations are built in the UK, then the stockpile could be burned as MOX fuel to the spent fuel standard in a new generation of thermal reactors. This would be an effective and technically proven management strategy prior to final disposal.

However, the NDA's remit does not include consideration of new nuclear power stations (NDA 2006). When formulating a management strategy for the UK's plutonium stockpile, the Government must adopt a broader view that is not limited by such administrative boundaries. This poses difficult problems for the NDA's evaluation of management strategies for plutonium. It is possible that the pathway to ultimate geological disposal will be complex, involving elements of both immobilisation and reuse options. If reuse as a fuel is a serious possibility, then the NDA assessment will fall short if it does not include this option and its economic consequences

Plutonium is currently regarded as a zero-value asset. Irrespective of whether the stockpile is classified as a waste or as a fuel for reuse, long term management pathways for both classification scenarios must be analysed in a way that identifies what key decisions need to be made, when they need to be made and how they could affect future decisions. This is essential to avoid pre-empting future strategic options.

It is essential to recognise which decisions will close off and which will maintain future options, and what their cost implications will be. Failure to do so could prove costly. For example, options for plutonium management must be incorporated into NDA's current deliberations about developing and delivering a UK nuclear waste strategy in general, and the design and operation of a geological repository in particular. This should be done as a matter of urgency.

1.2 Distinguishing between safety, security and proliferation

The NDA consultation confuses the categories of security, safety and proliferation, which leads to an overstatement of the risks of plutonium management. Safety relates to the effects of accidental release of plutonium on the health of plutonium workers and members of the public. Although the consultation properly highlights the issue of worker safety, it tends to overstate the risks as it does not distinguish between hazard potential and risk. The hazard potential of the stored stockpile is significant but the risk to workers, the public and the environment is small because of the way in which the plutonium is currently managed and regulated in the UK.

Security relates to the prevention of theft or the deliberate release of plutonium arising from an attack on plutonium facilities. There are extensive security measures in place relating to the design, operation and protection of plutonium storage facilities. Continued upgrading of plutonium storage facilities at Sellafield and rigorous inspections need to be given the highest priority since they will minimise the risks of terrorist attacks and security breaches (Royal Society 2007).

The consultation also confuses the categories of security and proliferation. These are different categories that pose different problems for the UK. Proliferation refers to the diversion of plutonium for weapons purposes. Arrangements for the storage of civil separated plutonium in the UK adhere to international nuclear safeguards standards designed to provide timely warning of diversion. The NDA fails to provide any details about how it defines proliferation resistance. Although some work was done on this as part of the IAEA International Nuclear Fuel Cycle Evaluation exercise from 1977-1980, a new study, including reviews of recent US analyses, is needed before considerations of proliferation resistance are used to influence decisions about plutonium management.

2 Immobilisation and Disposal

Q2 We are considering the factors above, addressing the behaviour of packages in the repository and the process to treat the waste to produce a form suitable for disposal. Are there any other significant factors that you think should be taken into consideration?

2.1 Repository design and volume

The NDA is correct to note that all the management options will require some plutonium to be disposed of in a geological repository. Current discussions about the design and size of a repository for the UK's radioactive wastes must include considerations about the eventual type and volume of the plutonium wastefrom, both of which will depend on the particular management option chosen.

Discussions of repository design now taking place should accommodate scenarios for the disposal of plutonium. A late decision to incorporate plutonium wasteforms in the repository after the design had been agreed or implemented could be very costly and difficult to accommodate. Rather than trying to redesign or retrofit a repository or build new repositories at a later date, the repository should be designed to accommodate the UK's legacy wastes, spent fuel, the plutonium stockpile and future spent fuel and radioactive wastes arising from any new nuclear power stations. Even if this extra capability were ultimately not to be used, the cost of excess repository capacity would be much less than re-engineering an existing repository or creating an additional one for unanticipated wastes.

2.2 *Repository safety case*

The repository safety case will be one of the most important considerations for repository design. Because plutonium is fissile, the safety case must address the probability and impact of criticality issues on the overall safety and performance of the repository. The stockpile would need to be stored in small amounts, which would require a large number of canisters. For reasons of proliferation resistance, plutonium wasteforms would also need to be dispersed amongst other wasteforms, which would have a major impact on the volume and design of the repository.

2.3 *Proliferation safeguards*

Any nuclear waste containing plutonium would need to be safeguarded against leakage and removal. The NDA needs to consider the impact of international safeguard requirements on the design and operation of a geological repository. The IAEA has provided safety standards for the geological disposal of radioactive waste but these do not explicitly consider the disposal of plutonium (IAEA 2006). There are currently no international standards for the disposal of plutonium in spent fuel. Guidelines exist for the management of separated plutonium but they do not apply to plutonium contained in spent fuel (IAEA 1998).

2.4 *Specific immobilisation technologies*

If plutonium is to be classified as waste, the safest way of storing plutonium prior to geological disposal is to immobilise it by embedding it in a matrix of other material (Royal Society 2007). Some parts of the stockpile have already been identified as waste. They consist of materials that cannot be converted into MOX fuel or be burned in a thermal reactor, and so will have to be immobilised into a non-MOX wasteform. The NDA should proceed with its research programme to determine alternative wasteforms and engineering studies for the process routes required to immobilise these wastes, as well as appropriate repository designs.

The NDA considers several immobilisation options based on incorporating plutonium into cement, ceramic or glass wasteforms. Cement is not considered to be a durable wasteform under likely UK repository conditions so the current repository safety case means that only very low amounts of plutonium could be embedded into standard quantities of cement matrices. Compared to other options, this would lead to an extremely large number of waste packages and significant increase in the volume of material to be disposed of and the repository space required for it.

Glass vitrification is not a proven technology for immobilising plutonium. Its use as a matrix for active plutonium would present serious engineering and safety challenges.

Hot isostatic pressing (HIP) is currently being developed for the immobilisation of relatively small quantities of intractable plutonium residues into a ceramic wasteform. To develop HIP as an immobilisation option for the rest of the stockpile would require a major engineering programme.

3 Immobilisation with High Level Waste

Q3 Technically this option may be deliverable; however, it is likely to be very expensive and would involve slowing down the hazard reduction at Sellafield. We believe that the advantages in terms of increased proliferation resistance are outweighed by the disadvantages in slower hazard reduction at Sellafield. Do you think that this is a valid assumption?

It has been suggested that the stockpile could be immobilised with high level liquid wastes (HLW) to improve its proliferation resistance, thereby making it difficult to handle without heavy shielding. Reprocessing spent fuel separates plutonium and uranium from highly radioactive fission products. Provided that precautions are taken to limit exposure and to contain the material to avoid ingestion and inhalation, separated plutonium could be relatively safely handled by those wishing to divert it for illicit purposes. Immobilising the plutonium with HLW would provide a gamma radiation barrier by either incorporating the plutonium directly into vitrified HLW or pouring vitrified HLW around the outside of plutonium wasteforms. However, the increased proliferation resistance provided by this option is debatable. The majority of the fission products in the HLW have half lives less than 30 years, which would therefore offer only short term proliferation resistance. The NDA is correct to conclude that after 200-300 years this option would offer no higher proliferation resistance than any of the other waste options.

Immobilising the stockpile with HLW would require hazardous liquid HLW to be retained at Sellafield until the plutonium disposal facility was designed and constructed. The NDA is correct to make the vitrification of HLW stocks its highest priority since, as a liquid, HLW is the most hazardous material stored at Sellafield. This option could become more attractive if reprocessing were part of a long term UK energy strategy. Additional liquid HLW generated by reprocessing could then be transferred directly to a vitrification plant for immobilising the plutonium stockpile. However, significant technical and engineering challenges would have to be overcome before this option could be implemented.

4 Fuel Manufacture

Q4 Inert Matrix Fuel (IMF) is an unproven technology, requiring significant further development and as such carries a higher risk than other fuel options. We believe that this means that IMF is not a credible option at this time. Do you agree that it is sensible to exclude the IMF option from the credible options that we present to Government?

MOX fuel is currently the most widely used and proven plutonium bearing fuel. An alternative fuel could be created by mixing plutonium dioxide with a non-uranium, ceramic carrier to produce an Inert Matrix Fuel (IMF). However, IMF is currently an unproven technology and there is currently no viable fuel design or nuclear reactor design that could safely or viably use such fuel.

IMF could become a more attractive option in the future, especially if a global expansion of nuclear power places pressure on the supply of uranium. Not only does IMF offer the possibility of being used as a fuel to generate electricity, but it also destroys plutonium and produces a spent fuel material that may be better tailored for long term disposal. By replacing uranium with a non-fertile fuel material it is

possible to manufacture a plutonium-bearing fuel that produces no additional fissile material through burning. This results in an increase in the plutonium consumption rate. The remaining plutonium is of poor quality and undesirable for future use in either nuclear weapons or fuel. Matrix materials can also be chosen that are optimised for different behaviour, such as stability during long term disposal. Spent IMF could be an attractive future plutonium wastefrom.

The Society does not agree that the IMF option should be excluded, as it is unnecessary for the NDA to take any position on the issue. If the plutonium stockpile is reused as fuel, then it will be for reactor operators and vendors, and not the NDA, to specify fuel designs, subject to regulatory requirements.

If IMF is to be developed, a major new research programme would be needed to demonstrate its viability. The NDA should maintain a research interest in ceramic matrices for waste purposes since this has similarities with the development of IMF. This would also permit the UK to participate in major international IMF research programmes, such as those currently being funded by the European Union.

5 Sell

Q3 Do you believe that selling plutonium to allow fuel manufacture, in compliance with all the requisite security and international treaty requirements, should be considered as a credible option?

A proposal to sell the UK's plutonium stockpile would be deeply controversial and would face significant economic and political challenges. It would require an international plutonium or MOX fuel market, which would have many associated difficulties. Even if there were such a market, it is unclear that this option would be likely to be the cheapest, as claimed by the NDA. It is unlikely that any buyer would take all the UK's plutonium and therefore the UK would be left with a quantity of its most complex plutonium-containing residues that would still require an effective management strategy. It is also unlikely that the UK could sell at a price that truly reflected the energy content of the plutonium and that would cover the costs of dealing with the plutonium residues. At the same time, potential income from the use of MOX fuel to generate electricity would be lost.

This option does not take into account that the UK's civil stockpile of separated plutonium is the largest in the world, which has political significance in a world that sees proliferation as a major issue. Selling the stockpile could set a precedent for nuclear proliferation, and the eventual disposition of the re-used plutonium would be a particularly sensitive issue. Selling plutonium to an overseas customer would also require extensive transportation by sea. Due to criticality concerns, the stockpile would have to be shipped in small amounts, entailing hundreds of material movements. The security risks associated with so many movements coupled with the above issues do not make this option credible.

6 Summary

Q6 Is there anything else you would like to tell us or comment on in relation to the options in this paper, for example are there any of the initial traffic lights that you think seem to be categorised wrongly?

6.1 Communicating plutonium management options to the Government

The NDA presents a traffic light table to summarise its evaluation of the management options but the meanings of red, amber or green traffic lights, and the criteria used to apply them, are not defined. This

is not an effective way to communicate the advantages and disadvantages of the options to the Government.

Whilst a traffic light table might indicate that one option or technology is relatively more credible or better understood than another, green and red traffic lights suggest to the lay reader a level of certainty of which the Society is sceptical. For example, it is questionable whether a green light should be allocated for the costs of spent fuel disposal when there is no fully proven technology and as yet no estimation of repository costs for spent fuel or other HLW. Other than continued storage, there is no option or technology in the traffic light table that can be implemented without major development and investment. The traffic light table also fails to reflect the plutonium stockpile's potential contribution to the UK's long-term energy security, the economic value to UK from electricity sales generated from UK Mixed Oxide (MOX) fuel and transport costs.

When formulating a management strategy for the UK's plutonium stockpile, the Government will need to consider a set of crucial issues that are missing in the NDA's analysis, including:

- the amount of plutonium that can be managed by each option;
- the physical form of the plutonium required by each option;
- the nuclear science and engineering skills and facilities required for each option;
- the cost of each option;
- when each option will be technically viable;
- the management lifetime for each option;
- how each option may affect any future decisions.

6.2 *Economic analysis*

The NDA consultation document lacks rigorous economic analyses. This may be because of the large uncertainties associated with many of the options under consideration since many of them are not yet technologically well developed. These analyses should identify any uncertainties about costs, where these uncertainties are important in influencing the choice of option and where uncertainty needs to be reduced by further research.

6.3 *Indefinite storage*

Storing the stockpile indefinitely is not a sustainable long-term option (Royal Society 2007). As the NDA notes, this would involve considerable expense in operating the depository for centuries, and leave to future generations in the UK the social and financial burden of sustaining its viability and credibility.

The Government has accepted CoRWM's proposal by that deep geological disposal should be the ultimate fate of medium and high level legacy wastes (HLW), but that in the interim, prior to the creation of an appropriate repository, surface storage will continue to be important. Different parts of the plutonium stockpile require different management strategies, involving a combination of immobilisation and reuse. Any interim storage must be coupled with a decision to reuse or immobilise and eventually dispose of the plutonium. Indefinite storage is simply not an acceptable long-term option.

6.4 *Immobilisation via MOX*

The stagnation of UK activity and research in nuclear power technology and waste management, as a consequence of the uncertain future of nuclear technology in the UK, has inhibited progress on plutonium immobilisation technologies. There are currently no technically proven and commercially deployable immobilisation technologies that the UK could use to dispose of its plutonium stockpile other

than MOX fuel fabrication and re-use, which is established both technically and commercially. It provides an immediately available immobilisation option.

The NDA asserts that reuse and immobilisation are expensive and technically very challenging. Cost and technical difficulty are different categories and should be treated separately. The cost uncertainty and technological complexity of disposal via immobilisation should not be confused with the comparatively well established route of reuse of MOX fuel.

Both the reuse and immobilisation options need to be subject to full engineering analyses of the necessary plants and processes required by the proposed management pathways. This is particularly necessary for the immobilisation option. Unlike the reuse option, this is less technically mature, highly uncertain and with much less available experience internationally.

For the parts of the stockpile that can be converted into MOX fuel, using it in a thermal reactor would be an effective and technically proven management strategy prior to final disposal (Royal Society 2007). If a new nuclear power stations are built in the UK, then the stockpile could be burned as MOX fuel in a new generation of thermal reactors. Whether this becomes an available option will depend upon the willingness of the generating companies to use MOX fuel, which will be affected by its cost and availability.

If new nuclear power stations are built in the UK and if the stockpile is to be used to fuel them, then research may be necessary on the best use of plutonium-containing fuels in the reactor designs to be used.

6.5 *Reuse as a waste strategy*

Reuse should also be considered as a waste management strategy. If MOX use in new reactors were part of a least cost route for the long term management of plutonium but represented a higher cost to reactor operators than using uranium-only fuel, the NDA could offer a financial incentive to operators to use MOX fuel. Strictly this would represent a subsidy for nuclear operators, but would not breach the spirit of the Government's principle that operators of new reactors should not be subsidised provided that the incentive did not reduce the overall cost of fuel below that of uranium-only fuel.

6.6 *The 300 year re-definition as waste*

The NDA consultation states that CoRWM recommended that if any material had not been used within 300 years, then it should be regarded as waste. This is misleading. CoRWM did not consider the issue and made no pronouncement on it. CoRWM's work emphasised the need to avoid unnecessary delay either in the classification of material or its effective management. The Society agrees with this view, and urges that work on a plutonium management strategy is carried out expeditiously. This would ensure that the future of the plutonium stockpile is incorporated into decisions on the overall management and disposal concepts for nuclear waste.

6.7 *Fuelling new reactors*

Intrinsic to the realisation of this option is the capacity to produce MOX fuel. Since the publication of its 2007 report, the Society has become aware of the extent of the Sellafield MOX Plant's (SMP) technical difficulties and underperformance. The Society's current understanding is that SMP as currently configured could not perform any significant role in converting the UK derived plutonium into MOX fuel. The NDA indicates that the alternative to SMP is either to export the plutonium to a MOX fuel fabrication

plant abroad or build a new plant in the UK. The export option is not credible due to the associated security risks and transport costs. If a new MOX plant were to be developed, its design should learn from successful commercial MOX plants operating internationally.

It is unclear why the NDA claims that the Magnox-derived plutonium requires its own individual management strategy. The SMP is currently justified in processing foreign-owned material and would have to be re-justified if it were to process UK-derived plutonium. However, this is essentially a legal requirement. If a new UK MOX plant is built, there is no major engineering reason why it could not process both UK-derived and overseas-owned plutonium.

6.8 *The accumulation of americium*

The NDA overstates the technical problems for MOX production associated with the accumulation of americium in the stockpile. Even though it has been stored for several decades, the accumulation of americium in the plutonium derived from the UK's Magnox reactors is low enough to allow it to be manufactured and burned as MOX fuel. Plutonium derived from the UK's Advanced Gas-cooled Reactors (AGR) could be managed by blending it with Magnox-derived plutonium. The NDA claims that the new facilities required for blending would increase the cost of the process. It would be useful if the NDA could provide an estimate of this extra cost.

Early manufacture of MOX fuel followed by reuse in a reactor is the best americium management option. In a sustainable programme, plutonium derived from spent fuel would need to be converted into MOX fuel immediately after reprocessing to avoid any significant decay to americium. It should then be followed by reuse to avoid creating a new plutonium stockpile of MOX fuel. If MOX fuel is to be used in new thermal reactors in the UK, then it would be better to begin by using the AGR derived plutonium. Magnox derived plutonium, with its longer 'shelf life', could probably be stored as MOX fuel for many more years before re-use without the need for reprocessing.

6.9 *The potential of fast reactors*

The NDA implies that if the stockpile is to be reused, it will be as MOX fuel in a Generation III thermal reactor. However, it is important to recognise that if new nuclear power stations are built in the UK, then the associated rejuvenation of the relevant technical and skills base would increase the probability that a future UK programme of Generation IV fast reactors could be developed. This option would significantly increase the energy output from a given mass of MOX fuel. Fast reactors could also convert the stockpile to the spent fuel standard if it did not prove possible to do so prior to their introduction.

6.10 *The potential of closed fuel cycles*

The NDA only considers an open, once through fuel cycle. However, it should also consider the potential of a closed fuel cycle. This would help keep the option open to extract the valuable energy resources contained within spent fuel, which would add to the UK's long term energy security.

A closed fuel cycle could also help to reduce the total volume of spent fuel generated by new nuclear power stations. If the stockpile was converted into MOX fuel and reused, one way to minimise the volume required in the repository would be to reprocess the spent MOX fuel. This would recover uranium and plutonium so that only a small volume of HLW would then need to be disposed of. The NDA could consider the potential benefits of recycling spent MOX fuel compared to the uncertainties surrounding direct disposal.

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