MIXED OXIDE NUCLEAR FUEL (MOX)

POST 137

Post Note April 2000

MOX is a mixture of uranium and plutonium oxides used in some overseas nuclear power stations. British Nuclear Fuels plc (BNFL) produced MOX for export on a small scale at Sellafield. A full-scale plant has been built but is awaiting government approval for operation. Recent events surrounding the falsification of data about MOX fuel pellets by BNFL workers raised international concerns and may have implications for the approval of the new plant.

This POST Note gives an overview of how MOX is made and used, and looks at some of the issues raised.

BACKGROUND

Data falsification incident

In September 1999, BNFL reported to the Nuclear Installations Inspectorate (NII) that quality control data concerning secondary checks on the diameter of MOX fuel pellets manufactured in the Sellafield MOX Demonstration Facility (MDF) appeared to have been falsified. The NII investigated the incident and published a report on 18 February 2000, alongside two other reports on Sellafield[1]. BNFL also published a report on the falsification on the same day. The MDF is currently shut awaiting the NII's approval to reopen (see page 4 for further details).

As a result of the falsification, four process workers at the MDF have been dismissed and BNFL's Chief Executive left the company. On the publication of the NII reports, the Energy Minister Helen Liddell called for *"a root and branch review of the company"*.

Nuclear power and reprocessing

A nuclear power plant converts the energy generated by the fission of uranium 235 (U-235) and plutonium 239 (Pu-239) into electricity. Details of the process are given in **Box 1**. After about 3-6 years in the reactor, fuel is past its useful life and is removed. At this point it contains about 0.8% U-235 and 1% plutonium, depending on the fuel used. 'Spent' fuel generates heat and radioactivity, and is generally stored underwater to provide radiation shielding and to cool the fuel rods.

Although spent fuel can be stored safely for years, storage underwater is not a permanent solution. Options for dealing with the fuel include dry storage, deep underground disposal, conversion into a less harmful substance (transmutation) and reprocessing (see 1997 POST Report *Radioactive Waste - Where Next?*). Reprocessing is the separation of plutonium and uranium from the residue of the fission reactions (the 'fission products', which are about 3% of the spent fuel and account for most of the radioactivity). Separated uranium and plutonium can potentially be 'recycled' into useable nuclear fuel - this is known as 'closing the fuel cycle'.

BOX 1: NUCLEAR FISSION

Naturally occurring uranium comes in several forms (isotopes), the principal ones being: U-235, which has 235 particles in its nucleus (92 protons and 143 neutrons), and U-238, with 238 particles (92 protons and 146 neutrons). Naturally occurring uranium consists of 99.3% U-238 and 0.7% U-235. Uranium for use as fuel in a nuclear reactor is normally either natural uranium in metallic form, or enriched oxide, with about 4% U-235 present.

The U-235 isotope is the 'active' ingredient in the fuel. In a nuclear reactor, a U-235 nucleus can absorb a further neutron, which makes it unstable. It splits ('fissions') into fission fragments, converting mass into energy as it does so.

The U-238 nucleus can also absorb a neutron, turning into plutonium (Pu-239). If Pu-239 absorbs a neutron, it may fission, giving off energy. In a Light Water Reactor, 40% of the energy produced is from Pu. If a Pu-239 atom escapes fission and absorbs a further neutron, it forms Pu-240. The plutonium in spent fuel normally consists of 60% Pu-239. It is not well suited for use in nuclear weapons, since military grade plutonium typically has at least 93% Pu-239.

MOX fuel releases energy from the fission of Pu-239, as well as the U-235 found in uranium fuel. Using MOX also creates Pu-239 from U-238 in the fuel. The balance between consumption and creation of Pu-239 depends on reactor and fuel types.

WHAT IS MOX?

MOX fuel is made from uranium *and* plutonium oxides, rather than just the uranium oxide which is used in conventional nuclear fuel. MOX fuel used in Light Water Reactors (LWRs) typically contains between 3 and 10% plutonium, depending on the specific design of the reactor for which it is destined.

Uranium and plutonium oxide powders are mixed together by milling. The mixed powders, together with a small quantity of dry lubricant, are pressed into cylindrical pellets about 1cm in diameter. They are sintered (or 'fired') in a high temperature furnace, to make hard, dense pellets which are then ground to size. These are loaded into zirconium alloy tubes, which are sealed and welded to make fuel rods. The fuel rods are loaded together into fuel-assembly frameworks and placed in approved metal containers for transport to the nuclear power station.

Since the mid-1980s, MOX development has been mainly aimed at overseas LWRs which are designed to use uranium oxide fuel. To use MOX they need

[1] *'An Investigation into the Falsification of Pellet Diameter Data in the MOX Demonstration Facility at the BNFL Sellafield Site and the Effect of this on the Safety of MOX Fuel in Use', 'HSE Team Inspection of the Control and Supervision of Operations at BNFL's Sellafield Site', 'The Storage of Liquid High Level Waste at BNFL Sellafield'*, February 2000.

BOX 2: MOX USE

The first MOX element was loaded into a Belgian LWR in 1963. Large scale use started in Germany in 1981 and France in 1985. By 1999, 34 operating LWRs, 6 fast breeder reactors and one advanced thermal reactor had used MOX.[2] The fuel has been used in reactors in Belgium, France, Germany, Switzerland, Japan, USA, UK and Russia and over 750 tonnes of MOX have been used in LWRs. No reactors in the UK currently use MOX.

Spent MOX fuel can theoretically be reprocessed and used again, although plans for this are currently at a trial stage. The build-up of contaminants means that MOX can be reprocessed only up to four times.

Because it contains plutonium, which is toxic and radioactive, people cannot directly handle MOX outside sealed containment and contamination is a risk. Therefore it is more difficult and expensive to make and use than conventional uranium fuel, although BNFL assert that this is offset by savings on uranium enrichment and mining. Due to the plutonium content of MOX, there are additional security issues which do not arise with conventional uranium fuel.

to be adapted and relicensed. At present, up to a third of the fuel in a LWR core can be MOX without substantial redesign of the reactor, although work is underway to increase this proportion. **Box 2** gives further details of how MOX is used.

WORLD TRADE IN MOX

Four plants in Europe can manufacture MOX fuel: one in Belgium run by Belgonucleaire; two in France run by COGEMA; and the MOX Demonstration Facility at Sellafield in the UK. The Japan Nuclear Cycle Development Institute has also operated MOX manufacturing pilot plants for research purposes at Tokai, and Japan has a plan to build a commercial MOX fabrication facility as part of its policy to close its own nuclear fuel cycle. German utilities had planned to produce MOX commercially, but a small MOX plant at Hanau was closed and the start-up of a larger plant stopped in the mid-90s, at least in part due to political opposition. In 1996 worldwide MOX production capacity was 188 tonnes per year.

MOX is used regularly in France, Germany, Switzerland and Belgium, and Japanese utilities also intend to do so (see page 8). Only the Sizewell B reactor in the UK is able to use the fuel, although British Energy has stated it believes this would not be economic at present.

WHY MOX IS USED

MOX contains plutonium separated by reprocessing. Thus the fuel is inextricably linked to reprocessing, which began fifty years ago as a means of obtaining plutonium for nuclear weapons and research. As nuclear power transferred to the civilian sphere, reprocessing became a tool for waste management and for using spent fuel from conventional reactors in fast breeder reactors (FBRs). The use of MOX fuel now has two potential justifications: to extract energy from plutonium; and for plutonium management. The relative importance of each of these varies from country to country. As the UK currently does not use the fuel, BNFL's reason for the manufacture of MOX is economic.

Assumptions and realities

When current civil reprocessing programmes were being proposed, several assumptions were made about the future of nuclear power:

- uranium was seen as a limited resource, likely to become very expensive.
- the nuclear power industry was expanding and it appeared that there would always be a market for nuclear fuel.
- FBRs were planned, which would use plutonium and be able to extract up to sixty times more energy from uranium than conventional reactors.

Therefore, it was decided to reprocess spent fuel to recover the unused uranium and plutonium. However, the current situation is not as envisaged:

- the growth of the nuclear industry did not proceed as expected.
- large amounts of uranium are still available to mine at economic prices, supplemented by ex-military uranium released into civil markets.
- technical difficulties have contributed to the slowing of work on FBRs in most of the world. The UK Government announced in 1990 that no further public funds would go towards FBR development, while the French Superphénix reactor last operated in 1996, and was closed permanently in 1997 for 'economic reasons'.

Since the FBR programmes ended, utilities have examined other means of dealing with the products of reprocessing. MOX allows plutonium from reprocessed spent fuel to be used in LWRs. For some countries with limited natural fuel resources, such as France, this closing of the fuel cycle is seen as important in maintaining independent energy production capabilities. However, the economics are not clear-cut (see page 5).

Proliferation risks and radiotoxicity mean that separated plutonium needs to be carefully managed. Managing increasing plutonium stockpiles produced by reprocessing is a key reason for MOX use (**Box 3**).

When plutonium is made into MOX fuel, its use in a reactor consumes about a quarter of the original

[2] Source: International Atomic Energy Agency

BOX 3: PLUTONIUM MANAGEMENT

Plutonium is a “fissile” material, which under certain circumstances can undergo a chain reaction. Plutonium management is internationally regulated by the International Atomic Energy Agency and in Europe by the European Atomic Energy Community.

Plutonium is one of the most radiologically toxic materials known. In particular, it can cause damage if inhaled. It is radioactive, but the main type of radiation it emits (alpha particles) does not penetrate thin layers of material.

In 1997 it was estimated that there were about 1,240 tonnes of plutonium in the world, the majority in the form of spent fuel.[3] Russia and the US have declared almost half their weapons plutonium as excess: about 100 tonnes in total. There were around 140 tonnes of separated civil plutonium, mostly held at three reprocessing plants: Sellafield in the UK, La Hague in France and Chelyabinsk in Russia. Civil reprocessing programmes in France and Britain are separating about 20 tonnes of plutonium each year. The civil separated plutonium stockpile stored in the UK was about 67 tonnes in December 1998, mainly stored at Sellafield (**Table 1**). This is estimated to be more than one-third of the world total.

These stockpiles of plutonium raise proliferation concerns and are thus stored to international security standards. 'Weapons grade' plutonium contains more Pu-239 than reactor grade plutonium, but it would still be possible (although difficult) to make nuclear weapons from the latter.

Plutonium in spent fuel is extremely difficult to extract. One approach, therefore, would be to store already separated plutonium in a form that is as secure as spent fuel. This 'spent fuel standard' was suggested in 1994 by the US National Academy of Sciences. Unused MOX does not meet the spent fuel standard.

Plutonium from overseas spent fuel sent to Sellafield for reprocessing must be returned to its country of origin. This is governed by reprocessing contracts, international agreements and exchange of letters. In 1997 there were 5 tonnes of overseas separated civil plutonium at Sellafield, with a further 35 tonnes due to be separated from spent fuel awaiting reprocessing. At present, this is seen as an energy source, and it is planned that some will be returned to its countries of origin in the form of MOX.

The US and Russia have recently classed 100 tonnes of military plutonium as waste. Were reprocessed plutonium to be classed as waste, there are a number of possibilities for disposition, including:

- immobilisation in a waste matrix, either by mixing the plutonium with waste or by placing a small amount of plutonium oxide in the centre of a canister containing waste ('can-in-canister'), which can be disposed of or stored.
- less immediately feasible concepts, such as firing the plutonium into space; disposing of it directly in a deep borehole; or transmutation[4] of the plutonium.

Although some of the immobilisation options are technically possible, none is yet available commercially. Immobilisation would require purpose-built facilities and one option would be for BNFL to provide plutonium management services to its customers. Plutonium could also be stored, as it is now at Sellafield, but further storage capacity would have to be built. The plutonium would remain a security risk and costs could be high.

TABLE 1: CIVIL PLUTONIUM STORED IN UK - DECEMBER 98

	In spent fuel	Separated or in MOX	
	UK and Overseas owned	UK owned	Overseas owned
Amount (tonnes)	46	59	10

Source: Department of Trade and Industry, June 1999

plutonium (Box 1). The remainder is embedded in spent fuel, and therefore more securely stored or transported than separated plutonium. However, in current LWRs, MOX can only fuel 30% of the core – the rest requires conventional uranium fuel, some of which converts to plutonium as it is used. The U-238 in the MOX fuel itself also makes plutonium.

Thus a LWR fuelled by MOX can produce more plutonium than it uses, or can consume plutonium, depending on the specifics of the fuel and the reactor. So current MOX use does not necessarily reduce stockpiles of separated plutonium nor decrease proliferation risks. A LWR with 30% MOX in the core consumes as much plutonium as it makes, so using MOX in this way can result in no net increase in plutonium stocks (unlike using conventional uranium fuel). Designs for reactors and MOX fuel assemblies are being examined which could use up more of the plutonium.

Countries that have sent spent fuel to Sellafield for reprocessing are required to receive their plutonium back. However, the transport of plutonium is politically sensitive and MOX transport has proved controversial. The Environment Agency has stated that *"the risks of transport and proliferation"* would be similar for plutonium oxide or for MOX.

UK PRODUCTION OF MOX

MOX Demonstration Facility

MOX has been produced at Sellafield for more than 30 years, by the UK Atomic Energy Authority and BNFL. Initial development was in support of the UK FBR programme and more than 20 tonnes of MOX was produced. After the FBR programme was abandoned, BNFL developed a two-stage strategy to manufacture MOX for LWRs. This involved construction of a small MOX Demonstration Facility (MDF), and then a larger plant for bulk supply of commercial fuel (the Sellafield MOX Plant).

Building of the Sellafield MDF began in 1991, and uranium and plutonium commissioning took place in 1993. It is a small pilot plant for commercial fuel with an annual capacity of 8 tonnes. By the time data falsification became apparent (September 1999), it had produced MOX for Swiss, German and Japanese fuel utilities. MOX for the Japanese Kansai Electric Power Company was en route to Japan, but had not yet been loaded into reactors.

Data falsification

Box 4 details the timing of events surrounding the falsification of MOX fuel pellet data in the MDF.

3 *Management of Separated Plutonium*, The Royal Society, February 1998
4 The conversion of one element into another

The MDF mixed plutonium and uranium oxides to make MOX fuel pellets. These were then loaded into fuel assemblies for use in reactors. Each pellet's diameter was recorded at three points along its length using an automated laser micrometer. Pellets that were the wrong size[5] were rejected, while those which passed the checks had a visual inspection. About 5% of the pellets which had passed both stages were then checked manually by workers who typed their measurements into a computer spreadsheet. The falsification of data occurred at this last stage, which was an extra quality assurance check at the customer's specification.

The NII gave a low priority to quality assurance for the MOX fuel: it is seen as an issue between BNFL and their customer. However, the NII does have responsibility to ensure that BNFL operates its sites safely. It investigated the data falsification problems because they were a breach of Nuclear Site Licence requirements. There were also wider concerns over Sellafield's safety culture. The NII has powers to inspect the plant, recommend changes and close down operations on site if necessary.

Following BNFL's internal investigations, the NII report confirmed that some of the data from secondary pellet diameter checks had been copied from previous spreadsheets. It was determined that four of the five shifts working in the MDF were involved to varying extents with the data concerned. Because of the automated primary checks on the pellet size, the NII concluded that this **did not affect the safety of the fuel**. However, they did conclude that, *"The events at MDF ... could not have occurred had there been a proper safety culture within this plant"*. The NII report on control and supervision of operations at Sellafield contains 28 recommendations, and that on MOX, 15. BNFL was given two months to respond to these: the company's action plan is expected in mid-April 2000.

The incident has had significant implications for BNFL's relationship with its main MOX customers:

- **Japan** - a delegation from the UK Government had meetings in Japan between 7-10 February 2000, to discuss the data falsification issue, to apologise to the Japanese Government on behalf of BNFL and to explain to the Japanese nuclear safety regulator the findings of the NII's investigations and reasons for believing the fuel would be safe in use. Kansai Electric and the Japanese Ministry of International Trade and Industry have asked that the BNFL MOX be returned to the UK. Environmental groups have called for the fuel to remain in Japan and be treated as waste because of transport risks. In December 1999 Mr Fukaya, the Japanese Minister for International Trade and Industry, said *"Unless sufficient investigation has been made by Kansai Electric, countermeasures have been established and confidence in BNFL has been recovered, it is impossible to import from BNFL"*. The Japanese Government is awaiting proposals from the UK Government on the destination of the fuel already in Japan and the Japanese electricity companies await BNFL's response to the NII.[6]
- **Germany** - data relating to the secondary pellet diameter checks for German fuel were lost due to a computer error. Workers on the following shift copied previous data to try to recover the situation. Although it was not suggested that safety had been compromised, PressenElektra, who run the Unterweser reactor where the fuel

BOX 4: MOX PELLET DATA FALSIFICATION - TIMING

21 July 1999 - two armed ships left Europe, carrying the first shipment of MOX fuel for Japanese customers

20 August 1999 - a member of the MDF's quality control team identified similarities between quality control data for successive lots

25 August - BNFL plant management informed of the similarities

3 September - process worker at the MDF admitted falsification and a second worker said he was aware falsification was taking place

10 September - the *Independent* newspaper indicated to BNFL that it planned to publish an article on the falsification. BNFL informed NII and Mitsubishi Heavy Industries (the fuel vendor to the Japanese customer) of falsification

12 September - BNFL suspended operations in MDF. NII obtained BNFL's agreement not to re-open the MOX plant without notifying NII

14 September - NII began on-site investigation

21 September - NII wrote to the Japanese embassy stating pellet diameter checks for fuel on route to Japan showed *"unusual"* results

8 November - BNFL informed that it would have to produce a safety case and seek NII's agreement before restarting the MDF. NII wrote to the Japanese embassy confirming that *"two of the assemblies containing pellets with suspect data are in Japan"*.

13/14 December - NII met with officials from Japan's Ministry of International Trade and Industry (MITI), confirming that two of the fuel assemblies in Japan contained pellets with suspect data

16 December - further NII meeting with MITI, informing them that four of the eight assemblies in Japan were now implicated

18 February 2000 - NII published report into MOX data falsification and two other reports on BNFL, concerning the safety management at Sellafield and the vitrification of liquid high level waste. NII required an action plan from BNFL within 2 months.

28 February - John Taylor, Chief Executive of BNFL, left the company.

Sources: NII report on falsification of pellet diameter data in the MDF, 18 February 2000; BNFL press releases

[5] Oversize pellets would not fit into the fuel cladding tube, while, if too small, they could move around and possibly cause the cladding to collapse.

[6] Japanese companies also have MOX contracts with COGEMA, which recently reported a software fault in the secondary tests on samples of MOX fuel pellets. COGEMA state that this had no impact on the safety of the pellets.

was used, decided to shut down the plant and replace the fuel rods. Further shipments of MOX from BNFL were suspended. The reactor at Unterweser was re-opened in March, and BNFL has been told it can apply for transport licences once the MDF has reopened and the company meets all the German licensing conditions.

- **Switzerland** - confidence in BNFL appears to have been damaged. Swiss safety regulators have advised transport regulators to delay consideration of applications to ship spent fuel to Sellafield.

Sellafield MOX Plant

Conceived in the late 1980s, planning permission for the full-scale Sellafield MOX Plant (SMP) was granted in March 1994, and construction began in April of that year. The plant was completed in 1998, at a cost of £300m. It is intended to fabricate MOX for foreign customers from plutonium and depleted, natural or recycled uranium, with a production capacity of up to 120 tonnes per year (containing 7.2 tonnes of plutonium).

However, before the SMP can start production, it will need a consent to operate from the NII and a variation in its authorisation from the Environment Agency (EA) for discharges from the Sellafield plant. Details of the consultations and analysis undertaken so far by the EA are given in **Box 5:** these include an assessment of the wider justification for the plant. A decision has not yet been given. However, it is likely that, given the implications of recent events at Sellafield for relations with BNFL's main customers, the economic case for MOX may have altered and hence further consultation may be sought.

BOX 5: MOX PLANT GOVERNMENT DECISIONS

BNFL applied to the EA in January 1997 to make MOX fuel from plutonium owned by their foreign customers. If BNFL wish to make MOX fuel from UK plutonium they would need to apply to the EA separately. Actual discharges from the plant would be small. However, due to the 'Potts Judgement' in 1994[8], the EA is required to consider **justification** for all practices giving rise to radioactive waste: the benefits must outweigh the detriments to society. Therefore, the EA has to consider all the factors involved, including safety, health, proliferation risk and economic factors, as well as the environmental impact.

The EA undertook an eight week consultation in early 1997, during which concern was expressed about the economic case for the SMP. It therefore engaged PA Consulting Group, to assess the economic justification for the plant. PA's report concluded that the plant would make an operating profit. Based on a public domain version of this report, the EA conducted a further consultation exercise.

In October 1998, the EA released proposed decisions on the uranium commissioning, the full commissioning and operation of the MOX plant, and the discharge variation applications. These proposed decisions concluded that operation of the plant was justified. However, the Secretaries of State at the Department of the Environment, Transport and the Regions and Ministry of Agriculture, Fisheries and Food can both direct the EA on its decision.

Ministers agreed with the EA that uranium commissioning was justified, but decided that a further consultation on the full operation and plutonium commissioning of the SMP would be beneficial. In particular, this consultation looked at the economic case for the plant. Ministers expressed concern that too much information had been withheld from the public domain version of the report, and that if BNFL failed to win enough business, the costs of comissioning, operating and decommissioning the SMP would fall to the taxpayer. BNFL produced an updated assessment of the market, which was endorsed by DTI, and the consultation closed in July 1999.

ISSUES

MOX economics

An initial justification for reprocessing was that uranium costs would be high, so utilising the energy in plutonium and uranium from spent fuel would be economic. However, at present the price of natural uranium is low. Research at the Science Policy Research Unit[7] has suggested that it is likely to remain so for some time. This is partly due to surplus military uranium from the former USSR and the USA being allowed onto the world market.

The cost of uranium enrichment is also low, so the economic incentive for the use of MOX over uranium fuel is currently questionable. Research at Harvard University has suggested that MOX costs around $1500 per kilogram of heavy metal: about $450 more than uranium fuel.[9] A utility will also have further additional costs, such as security. Taking reprocessing and MOX production together, the research concluded that costs are considerably higher than 'once-through' use of uranium fuel followed by direct disposal of spent fuel. MOX could have other benefits in terms of plutonium disposition and waste management (see below), but these need to be compared with alternative immobilisation options.

Sellafield MOX Plant (SMP) economics

Economic feasibility is a key influence on whether ministers accept the justification for the SMP. The PA report (Box 5) considered a range of options relating to their 'reference case' assumptions, and concluded that the SMP would be economically viable. They estimated the net present value as unlikely to be less than £100m, and £230m averaged over all the options. Considering a wider (but *"plausible"*) range of opportunities led to greater predicted value.

[7] Evidence to House of Commons Trade and Industry Select Committee, 21 March 2000.

[8] Made at the judicial review into whether the Thermal Oxide Reprocessing Plant (THORP) at Sellafield should be allowed to open.

[9] *The Economics of MOX fabrication*, and *Economics of Reprocessing Compared to Direct Disposal of Spent Nuclear Fuel*, Matthew Bunn, in "*Nuclear Reprocessing, has it a future?*", Oxford Research Group, October 1999.

TABLE 2: PREDICTED MOX FUEL REQUIREMENTS IN 2005

Country	Requirement (tonnes/year)
Belgium	14 (year 2000 requirement)
France	118
Germany	100
Japan	95
Switzerland	18 (year 2000 requirement)
UK	7
Total	**352**

Source: PA report for the EA on the MOX economic case

The PA reference case, which formed the basis of their report, considered the revenue to be generated from processing overseas plutonium separated under some of BNFL's existing baseload reprocessing contracts[10]. Key customers for BNFL MOX are Japan, Germany and Switzerland. **Table 2** shows estimated demand (from the PA report) for the countries assumed to be in the commercial market for MOX in 2005. This can be compared with the 1996 estimated MOX production capacity of 188 tonnes and SMP capacity of 120 tonnes. COGEMA has plans to increase the output of one of its plants to 180 tonnes (from its present 120 tonnes). However, the market for MOX is not totally free; it is tied to nuclear policy in the customer countries, and may therefore not be stable (page 8).

BNFL has stated that to cover the costs of the SMP (excluding 'sunk' capital costs - see page 7), it would need to secure 30-40% of Japanese, German and Swiss sales within the reference case market. In June 1999 it had 6.7% of the reference case contracted, with 11% covered by a letter of intent and 25.7% *"under offer"*.

Analysis commissioned by Friends of the Earth in response to the third consultation on the SMP[11] suggested that BNFL would need to charge £2052/kg for MOX to break-even if it won 40% of the reference case. This compares with a reported price of around £1850/kg which COGEMA has charged German utilities, and around £750/kg which COGEMA charged the French utility EdF.

PA Consulting Group reviewed this analysis in the context its original economic case. It noted that the two assessments were critically dependent on assumptions regarding the future market for MOX and the operating costs for the SMP. PA was confident that its original assumptions did not need to be revised; full details of PA's reference case and assumptions are not in the public domain. Much of the analysis of the economic case for SMP took place prior to the data falsification incident. Given subsequent effects on relations with BNFL's customer countries, previous analysis may need to be revisited (see page 8).

Reprocessing and waste management

As mentioned on page 2, because the plutonium used in MOX comes from reprocessed spent fuel, MOX is closely linked to reprocessing. The decision to reprocess spent fuel has implications for the amount and type of waste produced. The exact implications depend on a number of factors, including what is done with the separated uranium and plutonium i.e. whether they are made into MOX fuel, reused in some other form, disposed of, or stored. No country has re-used reprocessed uranium from uranium oxide fuel on a major scale, although uranium from Magnox fuel[12] has been reused.

In the UK, reprocessing of spent fuel has taken place at three sites:

- the Sellafield Thermal Oxide Reprocessing Plant (THORP) , which deals with fuel from Advanced Gas-cooled Reactors and water-cooled reactors.
- the B-205 building at Sellafield, for reprocessing Magnox fuel.
- a small facility at Dounreay for research reactor fuel from the UK and overseas, although this is currently shut.[13]

As MOX production is seen (by BNFL) to be an inherent part of reprocessing, the question arises whether reprocessing at THORP would still be warranted, were Ministers to refuse to accept the SMP justification. However, THORP has contracts for 100% of its capacity up to 2004, and about 50% of its capacity for the following 10 years. Nevertheless, commentators have suggested[14] that the utilities and BNFL would be financially better off renegotiating the THORP reprocessing contracts into storage contracts. The long-term storage of overseas waste would require a change in UK Government policy.

Were the route of reprocessing at THORP not available, policy issues about the long-term management of nuclear waste may be seen as more pressing, both in the UK and overseas. A UK Green Paper on options for nuclear waste management is expected within the next few months. Marine discharges from reprocessing at Sellafield have been

[10] Full details of the 'reference case' have not been made public on the grounds of commercial confidentiality.

[11] *Analysis of the Economic Case for the Sellafield MOX Plant*, Fred Barker, Mike Sadnicki and Gordon McKerron, July 1999.

[12] From the earliest type of nuclear reactors.

[13] A consultation on the future management of fuels from this site was launched by the Department of Trade and Industry in April 2000.

[14] *The Economics of Reprocessing in THORP*, Fred Barker, Mike Sadnicki, Gordon McKerron, in "*Nuclear Reprocessing, has it a future?*", Oxford Research Group, October 1999.

the subject of some international concern, particularly from Ireland and Nordic countries. Ireland and Denmark have tabled proposals which would end reprocessing at Sellafield, under the Ospar convention - the international protocol on marine pollution to which the UK is a signatory. The proposals will be debated in June.

Plutonium disposition

The SMP is to make MOX for overseas customers, so will not reduce the UK's plutonium stockpile. Questions about the disposition of the UK's plutonium (see Box 2) will also have to be answered. The UK currently has a separated civil plutonium stockpile of around 60 tonnes stored at Sellafield (see Table 1). This mainly belongs to BNFL, and comes from reprocessing Magnox fuel. British Energy[15] has contracts with BNFL for reprocessing 4,700 tonnes of spent fuel at THORP. Only 1,200 tonnes have so far been reprocessed, and British Energy has said that it is *"a matter of indifference"* whether the fuel is reprocessed or stored, although it would prefer more flexibility to move towards storage.[16]

The UK separated plutonium stockpile is predicted to reach 100 tonnes, around two thirds of the world's total, by 2010. Of the UK reactors, only Sizewell B could be modified to take MOX fuel, and would take 35 to 50 years to use up 25 tonnes of separated plutonium. British Energy has stated that it considers MOX use uneconomic at present, while the Government is in the early stages of reviewing its policy for the management of UK plutonium. **Box 6** details the conclusions of two key recent reports which have considered these issues.

One option for dealing with plutonium is not to reprocess, leaving the plutonium in spent fuel form. This avoids the circular difficulty of reprocessing and then trying to find a method of disposition which meets the 'spent fuel standard'. However, the plutonium which has already been separated would still need to be managed.

Transport

The transport of nuclear materials is regulated by the International Atomic Energy Agency, principally concerning the package design for the radioactive materials. Transport by sea is also governed by regulations, conventions and codes from the International Maritime Organisation. In continental western Europe, transport of MOX from the factory to the power reactor is usually by lorry. Intercontinental transports are by sea.

BOX 6: RECENT REPORTS

The 1998 Royal Society Report *"Management of Separated Plutonium"* highlighted four options for disposition of UK plutonium:

- Immobilisation and deep disposal in geological structures
- Using MOX in existing or specially built UK thermal reactors
- Sending MOX to other countries for use as fuel in their reactors
- Possible future alternative fuel cycles and reactor designs to use plutonium.

They also proposed that steps be taken to reduce the amount being added to the plutonium stockpile, primarily by reducing the amount of reprocessing. They suggested the Government *"commission a comprehensive review by independent experts of the options"* for plutonium management.

The 1999 House of Lords Science and Technology Committee Report on *"Management of Nuclear Waste"* concluded that:

- There is a large and growing stock of plutonium. The excess over foreseeable need should be declared as waste
- Phased disposal of nuclear waste in a deep repository is feasible and desirable
- There is a need for widespread public consultation
- A Radioactive Waste Management Commission should be established to develop a comprehensive strategy.

Some plutonium from the reprocessed Japanese spent fuel originates from uranium enriched in the USA. The USA therefore has rights of prior consent over the transport of Japanese nuclear materials, under the 1988 US-Japan Agreement for Peaceful Nuclear Co-operation. US consent was received for the transfer of reprocessed plutonium back to Japan, in the form of plutonium powder or MOX. However, this transfer had to take place by ship (not by air) and stringent security requirements were put in place. For example:

- a dedicated transport ship
- no scheduled port of call during the journey
- an armed escort vessel to accompany the transport ship.

The two ships taking MOX fuel to Japan were both armed, and were acting as each other's escort. Armed officers of the UK Atomic Energy Authority Constabulary were on board each ship. The transport proved internationally controversial, although the cargo was delivered without major incident. The fate of the fuel in Japan is still to be settled, but similar arrangements would be necessary if the BNFL MOX shipment is to be returned to the UK.

Regulation and timing

Under the Radioactive Substances Act 1993, there are no powers for the EA to require an application for discharge authorisation to be submitted before a

[15] Which owns Advanced Gas Cooled Reactors and the Sizewell Pressurised Water Reactor

[16] Evidence to House of Commons Trade and Industry Select Committee, 21 March 2000.

nuclear plant is built.[17] In the case of the SMP, BNFL submitted their application when £300m had already been spent on constructing the plant. These costs are therefore regarded as 'sunk' and are not included in the EA analysis of the economic case.

Stakeholders have expressed concern over this approach. The EA has also stated its dissatisfaction with being unable to consider the full economic case for the plant. However, revised Euratom Basic Safety Standards have been adopted, and must be incorporated into UK law by 13 May 2000. This will involve new regulations and directions to the EA. The revised Directive requires the justification for a new class or type of practice to be considered before it is first adopted or approved. The Health and Safety Commission is developing draft regulations to require generic justification for new classes or types of practice. It has proposed that Government decide a single case for justification. One option would be to provide guidance on seeking justification earlier in the process.

International issues

The existence of the international market for MOX is determined by the nuclear policies of the customer countries, so is not a 'normal' commercial market. It is therefore worth examining briefly the current situations in the three main customer countries for BNFL MOX – Japan, Germany and Switzerland. Details of the use of nuclear power and reprocessing in Japan and Germany are given in **Box 7**.

Japan

In 1997 the Federation of Electric Power Companies gave details of plans to load MOX into 16-18 LWRs by 2010. Japan has also been working towards the use of plutonium in FBRs, although this was delayed by a leakage incident at a prototype reactor in 1995. Confidence in the nuclear industry in Japan was damaged by the 1999 accident at the Tokaimura nuclear fuel plant.

Japan has a policy not to store any surplus plutonium which it is not planned to use. This may have implications for the final destination of the recent pellet shipment.

Germany

The German Government plans to phase out the use of nuclear power. BNFL stated in June 1999 that the German Government and utilities planned to fulfil their THORP baseload contracts. However, it is not yet clear what effect the recent NII reports and data falsification incident has had on this view.

BOX 7: NUCLEAR POWER IN JAPAN AND GERMANY

Japan
Nuclear power makes up about one third of Japan's power supply. Its nuclear policy includes the use of reprocessing and the manufacture of MOX, aiming to close the nuclear fuel cycle. A reprocessing plant is being built in Japan, but at present Japanese utilities send fuel to the UK and France for reprocessing; all the Japanese spent fuel contracted up to 2004 has been delivered to Sellafield. Negotiations on reprocessing contracts beyond this period are likely to have been affected by the falsification and safety issues.

Germany
Nuclear power produces about a third of Germany's energy. Until recently, Germany had reprocessed around 30% of its spent fuel, split between BNFL and COGEMA. Its plutonium is made into MOX in France, Belgium or the UK, since the closure of the sole German plant. At present, 12 reactors are licensed to use MOX; to date approximately 250 tonnes have been used in German reactors.

It is also now uncertain whether any new German contracts for MOX will be signed, which may have implications for the profitability of SMP. However, PA Consulting Group re-analysed the case for the SMP, assuming the removal of the demand for German fuel, and concluded that this would not affect the viability of the plant.

Switzerland

Switzerland is a much smaller market for MOX fuel than Japan or Germany, and so less central to the case for SMP. Three reactors in Switzerland are using MOX fuel and until the recent intervention by the Swiss regulator (page 5) the relationship with BNFL had been good. There will be two referenda this year about use of nuclear power in Switzerland, adding to the uncertainty over the longer term market for MOX.

Public Private Partnership

The Government (in the form of the Secretary of State for Trade and Industry) is currently the sole shareholder in BNFL. There are plans for a 49% stake in BNFL to be sold under public private partnership (PPP) and it has been suggested that operating with shareholders may make BNFL more commercially focussed. The Government announced on 29 March 2000 that PPP would be delayed until at least late 2002, due to recent *"setbacks"*. The House of Commons Trade and Industry Select Committee are conducting an inquiry into PPP plans, and will report in due course.

[17] However, though a Memorandum of Understanding with the Health and Safety Executive EA does have the opportunity to comment on the adequacy of the design of all new plant at Sellafield.