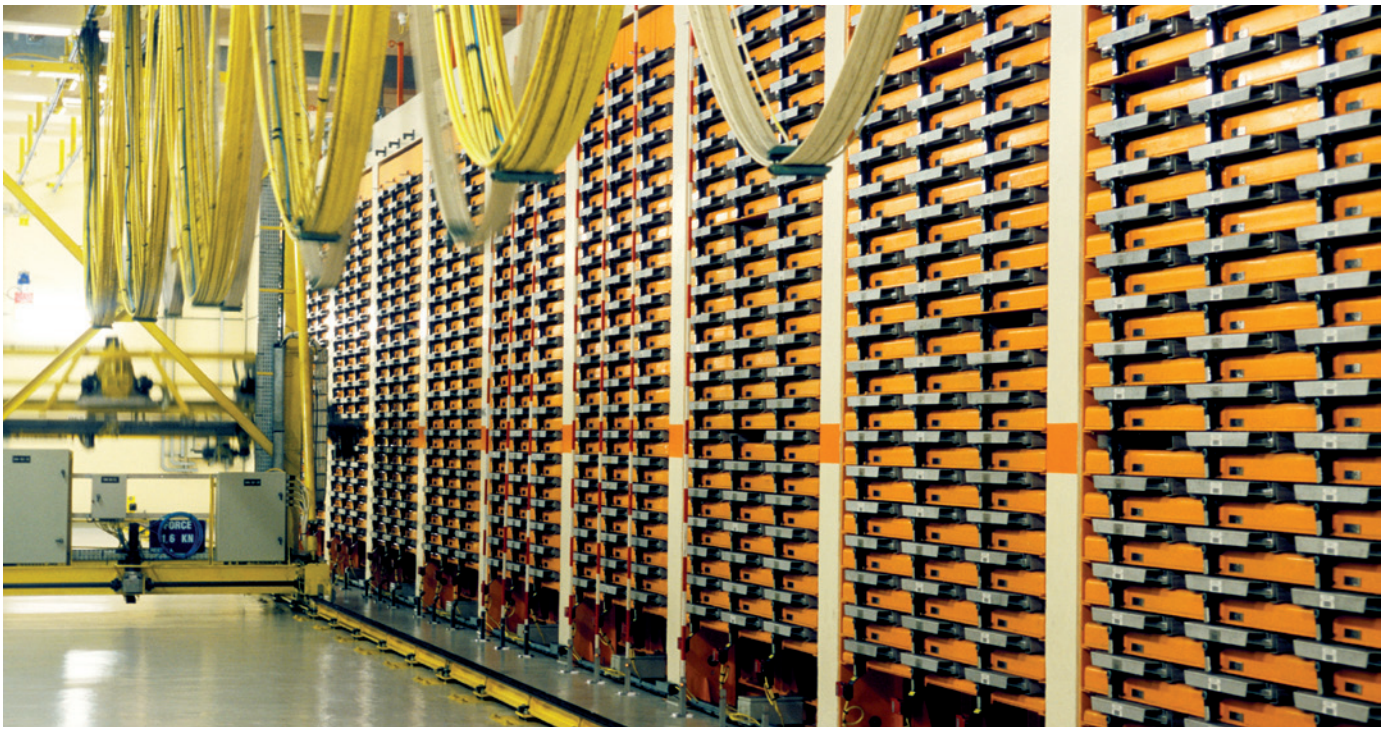
# COMMENT





P. LANDMANN/SPL



**The production of plutonium nuclear fuel in France (storage facility shown) adds millions of dollars each year to the cost of electricity generation.**

# Time to bury plutonium

Recycling plutonium is dangerous and costly. Britain should take the lead on direct disposal, say **Frank von Hippel**, **Rodney Ewing**, **Richard Garwin** and **Allison Macfarlane**.

The world today has a stock of about 500 tonnes of separated plutonium — enough to make 100,000 nuclear weapons[1]. As observed in a report[2] by the US National Academy of Sciences in 1994, this material is "a clear and present danger to national and international security". Yet, almost two decades later, programmes to dispose of it are in disarray.

This plutonium is a legacy of the cold war, and of a 1960s enthusiasm for a nuclear-powered future using revolutionary plutonium 'breeder' reactors. Some countries separated plutonium from the spent fuel of uranium-fuelled nuclear plants, expecting to use it to power this new generation of reactors. But the revolution never materialized. Only Russia (which has the world's largest plutonium stockpile, when counting both civilian and weapons stocks) and India still have active programmes to commercialize breeder reactors in the near term.

The United Kingdom, which owns the largest civilian stocks of separated plutonium (about 90 tonnes), announced plans last December to manufacture it into fuel for proposed water-cooled nuclear power reactors. This proposal matches that of the United States — to use already-separated plutonium as an alternative fuel for existing nuclear power reactors. France and Japan, the other nations with significant stockpiles, combine this approach with the dangerous and costly policy of continued separation of plutonium from spent fuel, which prolongs the associated international security risks.

On the basis of past experience in Britain, the United States and Japan, the UK strategy is likely to run into technical and political difficulties, as well as escalating costs. Before major investments are made, Britain should seriously evaluate the less costly and less risky method of direct plutonium disposal, and take the opportunity to lead the world towards a better solution for reducing stockpiles.

## THE ALTERNATIVES

The 1994 report[2] by the National Academy of Sciences focused on two alternatives for plutonium disposal. The first involves mixing plutonium with depleted uranium ▶

to make 'mixed oxide' (MOX) fuel that can be used by current-generation nuclear power reactors. Once used, the MOX fuel needs to be disposed of with other spent reactor fuel. The second option is direct disposal: immobilizing the plutonium in ceramic and burying it in a geological repository with spent fuel or radioactive waste. Both options require about the same repository space[3].

In 1994, France was already pursuing the MOX fuel option as part of a larger, controversial strategy of separating and recycling plutonium from its spent uranium-based nuclear fuel. It initially separated plutonium for weapons, and then for demonstration breeder reactors. After becoming the global expert in this technology, France's government-owned nuclear services company, now called Areva, built a reprocessing plant to separate plutonium from the spent fuel of other countries. However, Areva's main foreign customers have not renewed their contracts, and the national electricity utility is becoming increasingly restive about having to support a domestic MOX programme that is making France's own power more expensive. According to a 2000 estimate, recycling plutonium from spent fuel adds about US$750 million each year to the cost of electric power generation in France, in comparison with the cost of using fresh uranium fuel and disposing the waste in a geological repository[4].

Japan has pursued a similar strategy of reprocessing spent fuel and using it in MOX, largely to put off a politically difficult decision about where to site a nuclear waste repository. It built its own costly reprocessing plant for domestic fuel — designed mostly by Areva — but escalating costs and delays prevented completion by more than a decade. The plant separated about 4 tonnes of plutonium in 2006–08, but was forced to shut down because of a malfunction. An attempted restart in January this year resulted in the same malfunction. Construction is scheduled to start this spring on a MOX fuel fabrication plant but, following the Fukushima accident in March 2011, Japan's entire nuclear programme is being reviewed.

***"By 2018, Britain's stock of separated plutonium will have increased to more than 100 tonnes."***

Britain's Nuclear Decommissioning Authority is now completing contracts to separate plutonium from UK spent reactor fuel. By 2018, when the two UK reprocessing plants are expected to have fulfilled their contracts, they will have increased the country's stock of separated plutonium to more than 100 tonnes. In December 2011, the UK Department of Energy and Climate Change tentatively concluded that the best option for disposing of this plutonium would be to buy a new MOX fuel fabrication plant.

O. ANDERSEN/AFP/GETTY

**Plutonium fuel pellets must be precisely made.**

## LEARNING FROM HISTORY

Previous attempts to produce MOX in Britain have seen poor results. A fabrication plant at the Sellafield reprocessing site in Cumbria opened in 2001, initially to deal with plutonium separated for Japan. But because of design flaws and difficulties in achieving the exact manufacturing standards of MOX fuel, the plant operated at only 1% of its design capacity in its first ten years. In August 2011, after expenditures of £1.4 billion (US$2.3 billion), it was shut down.

In evaluating methods for plutonium disposal, Britain should also consider the experience of the United States. It decided to pursue both MOX and immobilization routes, estimating in 1999 that it would cost about $4 billion to dispose of 34 tonnes of its 85-tonne stockpile of weapons-grade plutonium. But Russia, which had also committed to disposing 34 tonnes of its own weapons plutonium, objected to immobilization because the plutonium could be made into weapons if it were recovered. This, along with the cost of paying for two different programmes, led the United States to abandon the immobilization track. Instead, it commissioned an Areva-designed MOX plant. The cost of disposing of its 34 tonnes of plutonium has since soared to more than $13 billion[5], with the value of fuel produced likely to offset costs by only $1 billion to $2 billion.

Britain should therefore give plutonium immobilization another look. Although the technique has not been demonstrated at full scale, there is substantial literature on how to do it[6,7]. Immobilization should be easier and cheaper than MOX production. Converting 100 tonnes of plutonium into MOX fuel requires fabricating 100 million pellets of fuel, machined to exact dimensions to fit into long zirconium tubes. For disposal, however, the plutonium could be immobilized in fewer, less-precisely-sized 'pucks'.

This immobilized plutonium could be packaged with spent fuel or solidified reprocessing waste, which emits γ-radiation that would ward off any thieves or terrorists for a century before its disposal in a 500-metre-deep geological repository. Another option would be irreversible disposal in a few 5,000-metre-deep boreholes. The National Academy of Sciences discussed this method in 1994, and there has been more design work since[8,9]. Britain's decommissioning authority found in a 2009 study that most immobilization options would be less costly than MOX but are technologically less mature (see go.nature.com/rbxmsl). The failure of the UK MOX plant and other problems, however, suggest that immobilization is lower risk.

The United Kingdom is ideally placed to spearhead this effort. It has the world's largest stockpile of separated civilian plutonium and has seen the failure of a MOX plant. It should take the lead in developing plutonium immobilization through laboratory-scale tests, a pilot project and then a full-scale plant. It is time to follow a different path, in which plutonium is treated unambiguously as the dangerous weapons material that it is. ■

**Frank von Hippel** *is professor of public and international affairs at Princeton University, New Jersey, USA, and co-chair of the International Panel on Fissile Materials.* **Rodney Ewing** *is professor of earth and environmental sciences at the University of Michigan, Ann Arbor, USA.* **Richard Garwin** *is a physicist and IBM Fellow emeritus at the Thomas J. Watson Research Center, New York, USA.* **Allison Macfarlane** *is associate professor of environmental science and policy at George Mason University, Fairfax, Virginia, USA.*
*e-mail: fvhippel@princeton.edu*

1. International Panel on Fissile Materials. *Global Fissile Material Report 2011* (IPFM, 2011); available at http://go.nature.com/fi58zk
2. Committee on International Security and Arms Control. *Management and Disposition of Excess Weapons Plutonium* (National Academies Press, 1994).
3. Wigeland, R. A. *et al.* Paper 496 in *Proc. GLOBAL '05*, Tsukuba, Japan, October 2005.
4. Charpin, J. M., Dessus, B. & Pellat, R. *Economic Forecast Study of the Nuclear Power Option* (Commissariat Général du Plan, France, 2000).
5. US Department of Energy *FY 2013 Congressional Budget Request* Vol. 1, 460–461 (2012); available at http://go.nature.com/4posor
6. Yudintsev, S. V. *et al.* in *Structural Chemistry of Inorganic Actinide Compounds* (eds Krivovichev, S. V. *et al.*) 457–490 (Elsevier, 2007).
7. Ewing, R. C. & Weber, W. J. in *The Chemistry of the Actinides and Transactinide Elements* Vol. 6 (eds Morss, L. R. *et al.*) 3813–3887 (Springer, 2011).
8. Halsey, W. G., Jardine, L. J. & Walter, C. E. *Disposition of Plutonium in Deep Boreholes* (Lawrence Livermore National Laboratory, 1995).
9. Gibb, F. G. F., Taylor, K. J. & Burakov, B. E. *J. Nucl. Mat.* **374,** 364–369 (2008).