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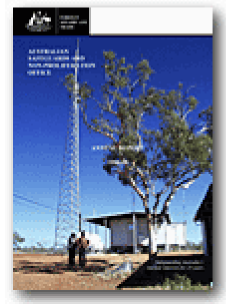


PLUTONIUM

RECYCLING: THE USE OF 'MOX' FUEL

With the transport and use of MOX (mixed oxide) fuels attracting increasing public attention, readers may find the following background information useful.

Plutonium is formed in uranium fuel during the operation of a reactor. Plutonium has substantial potential as a source of energy, and in fact is a significant contributor to the energy produced in a uranium-fuelled reactor.

The use of MOX fuel reduces inventories of separated plutonium, and is likely to assume increasing importance for 'degrading' weapons-grade plutonium released by disarmament.

The element plutonium is practically non-existent in nature, and principally arises through the irradiation of uranium in a reactor. Irradiation of the 'fertile' uranium isotope U-238 by neutrons results in formation of the plutonium isotope Pu-239. Continued irradiation leads to neutron captures by the isotope Pu-239, producing Pu-240 and subsequently the isotopes Pu?241 and Pu-242.

The isotopes Pu-239 and Pu-241 are fissile, meaning they can be made to fission by 'thermal' (slow) neutrons in a light water or other 'moderated' reactor to produce energy. The isotopes Pu-240 and Pu-242 are fissionable, meaning they can be made to fission only by 'fast' neutrons, requiring a fast neutron reactor to produce energy.

Why recycle?

The concept of plutonium recycling involves reprocessing of spent fuel from a reactor, in order to separate the plutonium produced in the fuel, fabricate it into fresh fuel, and use it for further energy production. When uranium is used to fuel a reactor, energy is produced primarily from the fissile isotope U-235, which constitutes only around 0.7% of natural uranium. Plutonium recycling offers substantially greater efficiency, because energy is produced from the most abundant uranium isotope, U-238 (which constitutes around 99.3% of natural uranium), through conversion of U-238 to plutonium. In theory therefore plutonium recycling offers some 150 times as much energy from a given quantity of uranium as the 'once-through' cycle (i.e. use of uranium without reprocessing). Practical factors prevent this theoretical maximum from being reached, but a very substantial increase appears to be practicably attainable. Plutonium recycling would therefore be extremely attractive if uranium were in short supply and high-priced.

Programs for the recycling of plutonium were developed in the 1970s when it appeared that uranium would be in scarce supply and would become increasingly expensive. It was proposed that plutonium would be recycled through 'fast breeder reactors', that is, fast neutron reactors with a uranium 'blanket', which would produce slightly more plutonium than they consume. Thus it was envisaged that the world's 'low cost' uranium resources, then estimated to be sufficient for about 50 years' consumption, could be extended for hundreds of years.

For a variety of reasons, high uranium prices have not eventuated, and future prices are uncertain. Some of the influences on this situation include:

- the discovery of considerable further deposits of uranium recoverable at low cost;
- the run-down of very extensive uranium stocks which had been accumulated in various countries;
- the high capital cost of nuclear plants, which combined with lengthy licensing processes, and exacerbated by difficulties in public acceptance in many countries, have led to a much lower than anticipated growth in nuclear energy; and
- more recently, arrangements for the gradual release on to world markets of large quantities of uranium from the dismantling of nuclear weapons.

At the moment the consumption of uranium in the world's nuclear energy programs substantially exceeds uranium production (by about 50%), and low cost uranium resources are still equivalent to only about 40 to 50 years' consumption at present levels. These factors might be expected to result in higher uranium prices, but prices remain depressed. In these circumstances there is no impetus to develop fast breeder reactors, particularly since these reactors present major engineering challenges which will be expensive to resolve. Meanwhile, however, around 30% of spent fuel arisings are covered by long-term reprocessing contracts, and the approach of plutonium recycling using light water reactors has been developed as a way of avoiding the accumulation of separated plutonium, and deriving an immediate economic return on this plutonium.

MOX fuel

The term 'MOX' is derived from 'mixed oxides', and refers to reactor fuel made from a mixture of plutonium and uranium oxide. For use in a light water reactor, the proportion of plutonium is about 5%. This is a similar fissile content as low enriched uranium fuel. As is the case with uranium fuel, the MOX is formed into ceramic fuel pellets, which are extremely stable and durable, and which are sealed in metal (usually zirconium) tubes, which in turn are assembled into fuel elements. In most cases about a third of the reactor core can be loaded with MOX fuel elements without engineering or operational modifications to the reactor.

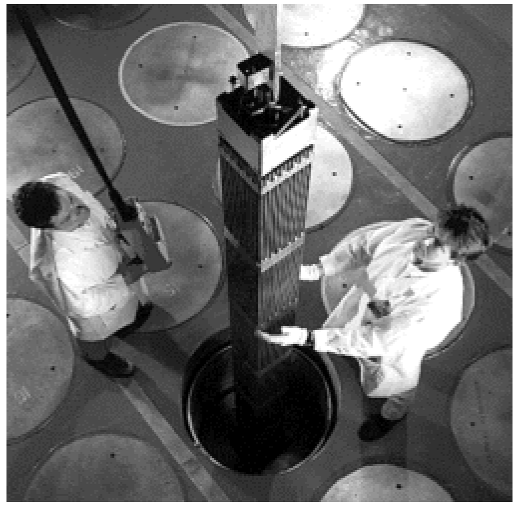
Contrary to suggestions from some commentators, there is nothing unusual in the presence of plutonium in light water reactors. Plutonium is produced during the operation of a reactor. The plutonium content of spent fuel from the normal operation of a light water reactor will be a little less than 1%, usually around 0.8%, when the fuel is unloaded. During the operation of the reactor, plutonium formed in the fuel will contribute an increasing proportion of the overall energy production of the reactor—towards the end of an operating cycle, a substantial proportion of the initial U-235 content of the fuel will have been consumed, and the energy produced by fission of plutonium will be very close to that produced by the remaining uranium.

Use of MOX fuel is expected to significantly reduce plutonium inventories. As an example, the Euratom Supply Agency estimates that the use of a single MOX fuel element consumes 9 kg of plutonium, and avoids the production of a further 5 kg (compared with the use of low enriched uranium fuel). Thus in this example each MOX fuel element used results in a net reduction of 14 kg of plutonium.

Currently plutonium is being recycled with 32 light water reactors in Europe, and this is shortly to commence in Japan. Use of MOX fuels in light water reactors will increase over the next decade. While this will involve mainly reprocessed civil plutonium, the use of MOX fuel to 'degrade' weapons-grade plutonium (1), transferred from military programs as part of the disarmament process, will assume increasing importance. By 2010 it is expected that MOX fuels will be used with 45 reactors in Europe, together with 16–18 in Japan, and possibly five in Russia and six in the US, that is, some 15–20% of the world's power reactors.

(1) There are two ways in which use of weapons-grade plutonium in MOX fuel degrades that plutonium: through the plutonium being associated with highly radioactive fission products in spent fuel (the 'spent fuel standard'); and through changes in isotopic composition during the irradiation process-in normal power reactor useage the plutonium would become reactor-grade.

As noted earlier, plutonium recycling programs were first developed with the breeder cycle in mind. There have been active fast breeder reactor research and demonstration programs in France, Japan and Russia. Future plans for fast breeder reactors are now uncertain, a major factor being economics, especially the price of uranium. At the moment the greatest interest appears to be in operating such reactors, not as *breeders*, but as net *consumers* or 'burners' of plutonium and of minor actinides. Clearly of crucial importance here is the future direction of nuclear energy, which will be determined by a complex range of political and economic considerations (see Nuclear Industry - some current issues). If nuclear energy continues to make a significant contribution to world electricity production, and particularly if this contribution increases, plutonium could become an energy source as significant as uranium is today.



A MOX fuel assembly for a PWR
Photograph courtesy of BNFL

Is the plutonium in MOX fuel 'weapons-useable'?

> *Opponents of the use of MOX fuels commonly state that such fuels represent a proliferation risk because the plutonium in the fuel is said to be 'weapons-useable.' This is a complex subject, where there is no consensus amongst experts, but the short answer is that there would be serious technical difficulties in attempting to make nuclear weapons from plutonium of the quality currently used for MOX (reactor-grade), and none of the countries possessing nuclear weapons has ever made weapons using plutonium of this quality.*

'Weapons-useable' is not a technical term, and it is not clear what those using it mean, but if it is supposed to imply that reactor-grade plutonium is a material that could readily find its way into weapons, this overlooks two important facts: that there has been no practical demonstration of the use of such plutonium in nuclear weapons, and that rigorous IAEA safeguards apply to this material in non-nuclear-weapon States party to the NPT. It is misleading to conclude, because this material is subject to safeguards, that it is therefore 'weapons-useable'.

To better understand this issue, it is necessary to appreciate that plutonium exists as several isotopes. As noted earlier, longer reactor irradiation times result in the formation of higher plutonium isotopes, Pu-240, Pu-241 and Pu-242 (and also the isotope Pu-238). The mix of isotopes (isotopic composition) of a particular quantity of plutonium will depend on how the plutonium was produced, that is, its irradiation history. The isotopic composition of plutonium affects its suitability for particular purposes, such as use in a reactor or use in nuclear weapons.

The plutonium isotope most suitable for weapons use is Pu-239. Plutonium used in nuclear weapons, **‘weapons-grade’**plutonium, comprises at least 92%, usually more, Pu-239. This plutonium is produced in dedicated plutonium production reactors, specially designed and operated to produce plutonium of this quality by removal and reprocessing of fuel after short irradiation times.

The plutonium produced in the normal operation of light water reactors, from which MOX fuel is being made, is what is known as **‘reactor-grade’** plutonium. Because of the very long time fuel is irradiated in a power reactor (typically 3–4 years), reactor-grade plutonium has a substantial proportion of higher plutonium isotopes. Reactor-grade plutonium typically comprises less than 60% of the isotope Pu-239.

Reactor-grade plutonium contains a large proportion of isotopes which create serious technical difficulties for weapons use, namely Pu-238, Pu-240 and Pu-242. These difficulties include ‘pre-initiation’ (a high spontaneous fission rate leading to the nuclear chain reaction starting too early), and radiation and heat levels which will adversely affect vital weapons components such as high explosives and electronics. While these difficulties could possibly be overcome, to some extent at least, by experienced weapons designers (e.g. from the nuclear-weapon States, with experience from hundreds of tests to draw upon), ASNO is not aware of any successful test explosion using reactor-grade plutonium, typical of light water reactor fuel. (2)

> (2) There is some confusion over a 1962 test by the US using what was then described as 'reactor-grade' plutonium, but at that time 'reactor-grade' was much closer to weapons-grade than is currently the case. While the US has never revealed the quality of the plutonium used in that test, there are indications that it was of 'fuel-grade', an intermediate category between weapons-grade and reactor-grade, which has been recognised as a separate category since the 1970s.

IAEA definition of ‘direct-use’ material

The confusion in the public mind regarding the suitability of reactor-grade plutonium for nuclear weapons appears to arise from the fact that, **for the purpose of applying IAEA safeguards measures**, <u>all</u> plutonium (other than plutonium comprising 80% or more of the isotope Pu-238) is defined by the IAEA as a ‘direct-use’ material, that is, ‘nuclear material that can be used for the manufacture of nuclear explosives components without transmutation or further enrichment’. In order to understand what this actually means, it is important to appreciate the following:

- The IAEA is <u>not</u> saying that all plutonium is suitable for nuclear weapons. The IAEA has chosen its terminology very carefully, and refers to ‘nuclear explosives’, rather than nuclear weapons. While this distinction might seem a fine one, in fact it is very important. It can be shown by theoretical studies that reactor-grade plutonium could be made to explode under certain (technically demanding) conditions. For this reason it is clearly prudent to adopt a conservative approach, and the IAEA applies safeguards measures to all grades of plutonium.

- Theoretical calculations relating to reactor-grade plutonium however do not indicate what happens in real life. There are several characteristics required for a practical nuclear weapon, including reliability, useful yield, a deliverable size and storage life. These requirements would be adversely affected by the difficulties associated with reactor-grade plutonium, mentioned above. It is for good reason that those countries that have made nuclear weapons have done so with plutonium specially produced for the purpose.

- The IAEA definition of 'direct-use' material also applies to plutonium in spent fuel, and to MOX - yet clearly the IAEA is not saying that nuclear explosives can be made from spent fuel or from MOX (i.e. without processing to separate the plutonium). 'Direct-use' and 'weapons-useable' are not synonymous.

How does this relate to MOX?

With respect to the use of MOX fuel, arguments about the 'weapons-useability' of reactor-grade plutonium miss the point: as we have seen, MOX is a mixture of uranium and plutonium oxides, with the plutonium being very much in the minority. For light water reactor fuel, the plutonium content is typically around 5%. MOX cannot be used in nuclear weapons or nuclear explosives. To separate the plutonium content from MOX fuel elements would be a major undertaking, similar to reprocessing. IAEA safeguards measures would readily indicate if any attempt were made to process the fuel to separate plutonium.

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