Plutonium as an Energy Source (Issue #1)

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In French (coming soon) – Le plutonium comme source d’énergie

- Le plutonium comme source d’énergie (Arjun Makhijani)
- Les recommandations de l’IEER pour la gestion du plutonium
- Le nucléaire et sa place dans la production d’électricité et d’énergie mondiale (Compilation d’Anita Seth)
- Comparaisons entre combustibles fossiles et puissance nucléaire (Arjun Makhijani)
- Le programme de IEER : “Les dangers des matières nucléaires” (Anita Seth)
- Glossaire
- Unités de mesure
- Bibliographie annotée
- Une sélection des publications de l’IEER

In English

- Plutonium as an Energy Source (by Arjun Makhijani) (*also reprinted below*)
- This article reviews the basic facts regarding plutonium use and provides some cost and technical analysis of the issue.
- Editorial: IEER Recommendations on Plutonium Management
- Disposition of world-wide plutonium stockpiles is an urgent problem. While many speak of reprocessing and using plutonium to fuel nuclear reactors as “recycling,” IEER believes that vitrification, not use as fuel, is the best method of plutonium disposition.
- Nuclear Power and its Role in Global Electricity and Energy (by Anita Seth)
- Statistics on global energy consumption, nuclear power production, new reactor construction, and more.
- Comparison of Fossil Fuels and Nuclear Power (by Arjun Makhijani)
- A qualitative comparison of the environmental effects of projected uses of fossil fuels and nuclear reactors to provide power.
- Annotated Bibliography
- Glossary of terms used in this newsletter

In Russian (coming soon) – ?????????? ???????? ??? ???????? ???????

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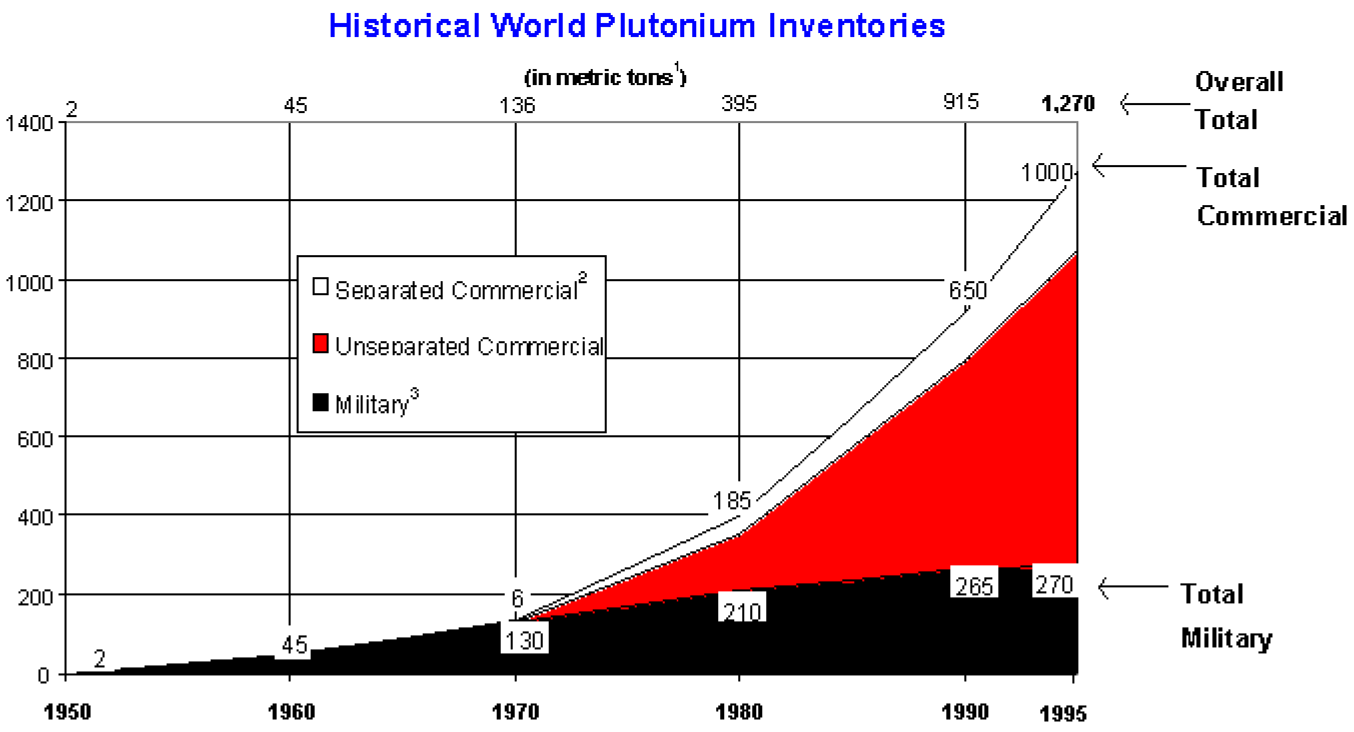
Article: Plutonium as an Energy Source

Over the past few years, the dismantlement of excess nuclear warheads has left the United States and Russia with large stocks of plutonium and highly enriched uranium (HEU). These surpluses have re-ignited the debates around the world about the use of plutonium as an energy source and provided new arguments for continued assistance to on-going plutonium projects. This article reviews the basic facts regarding plutonium use and provides some cost and technical analysis of the issue.



1. All figures are rounded either to one significant figure or to the nearest 5 metric tons. The total is not rounded further.

2. Separated commercial plutonium is owned by the only countries that are currently reprocessing: France, Britain, Japan, Russian, India. In addition, countries that have no current reprocessing have contracts for reprocessing with France and Britain, and also own substantial commercial plutonium

stocks. They are: Germany, Belgium, Holland, Italy, and Switzerland. The United States also has a relatively small stock of commercial plutonium from its West Valley reprocessing plant in New York, which was shut down in 1972.

3. No country besides the U.S. has released historical military plutonium production data. All other military data are rough estimates. We have assumed a figure of 150 metric tons of military plutonium for Russia in the 1990 and 1995 totals. Recent data form Russia indicate that the figure may be lower, at about 130 metric tons (rounded).

Source: Arjun Makhijani and Scott Saleska, The Nuclear Power Deception (Takoma Park, Maryland: Institute for Energy and Environmental Research, 1996.)

Uranium and plutonium resource basics

For all practical purposes, uranium-235 is the only naturally-occurring fissile material (one that can sustain a chain reaction and can fuel nuclear reactors). However, uranium-235 makes up only about 0.7 percent of natural uranium ore. Almost all the rest is another isotope, uranium-238, which cannot sustain a chain reaction.

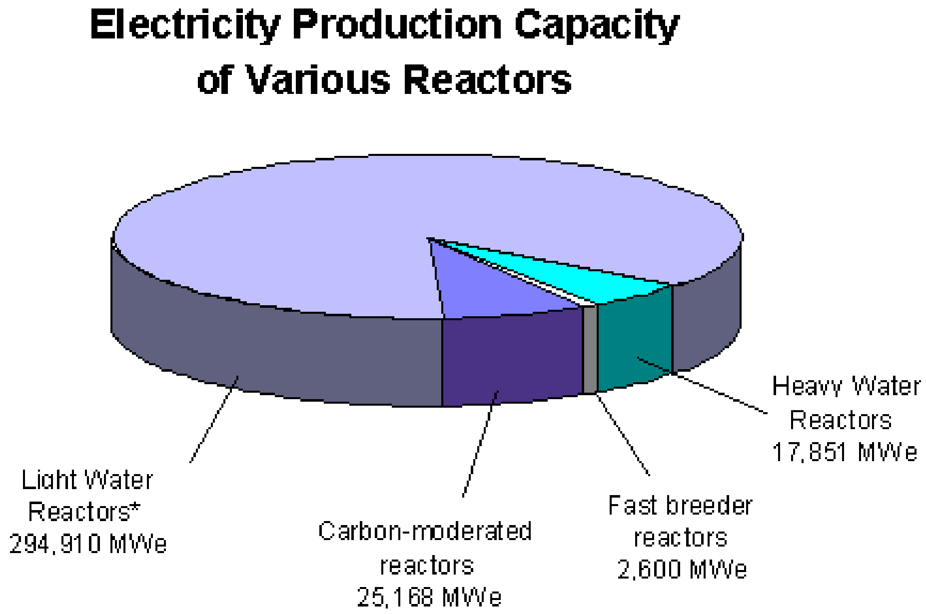
But although uranium-238 is not a fissile material, it can be converted into fissile plutonium-239 in a nuclear reactor. This property has led nuclear proponents to see uranium-238 as the key to the long-term future of nuclear energy. In fact, reactors can be designed so that they produce more fissile material from uranium-238 in the form of plutonium than they consume in the course of power production. Such reactors have come to be called “breeder reactors” and uranium-238 a “fertile” material. Promoters of nuclear power have used the expression “magical energy source” to describe a breeder reactor electricity production system because the amount of fuel at the end of production would be greater than at the beginning.1

In the 1950s and 1960s, uranium was thought to be a very scarce resource. Scientists realized that uranium resource requirements for a power system based on breeder reactors would be far lower than for one based on once-through use of uranium. For instance, the amount of natural uranium needed over the life of a 1,000 megawatt 2 power plant with a light water reactor (LWR-the most common nuclear reactor), is roughly 4,000 metric tons. By contrast, only about 40 metric tons are required for a breeder reactor of the same size. This hundred-fold theoretical reduction in resource requirements convinced proponents of nuclear power that breeder reactors, along with the recovery of plutonium from irradiated reactor fuel (reprocessing), would be at the heart of the magical nuclear energy future, when nuclear power would be “too cheap to meter.”3 At that time, projections of nuclear power use were very high. In the early 1970s, the U.S. expected an installed nuclear capacity by the year 2000 of 1,000,000 megawatts. However, U.S. capacity is now only 10% of those projections (about 100,000 megawatts) and will not increase by the year 2000 (see Table 3 for additional data).

Theoretical arguments in favor of breeder reactors still provide inspiration to nuclear establishments all over the world. But technical, economic, political, environmental, and military realities have all combined to make a plutonium-based energy system economically impractical, environmentally dangerous, diplomatically difficult, and militarily risky.

Technical and economic complications

Discussion in this article focuses on the sodium-cooled breeder reactor (also called a fast neutron reactor)-the main breeder reactor design that has been developed. Tens of billions of dollars have been spent on research, development, and demonstration of this technology in a number of countries, including the United States, Russia, France, Britain, India, Japan, and Germany. But the technology has not yet reached the commercial stage of even moderately reliable power production and breeding of fuel. Breeder reactors total a capacity of roughly 2,600 megawatts, which is only 0.8 percent of the world's nuclear power capacity of about 340,000 megawatts (see pie chart).

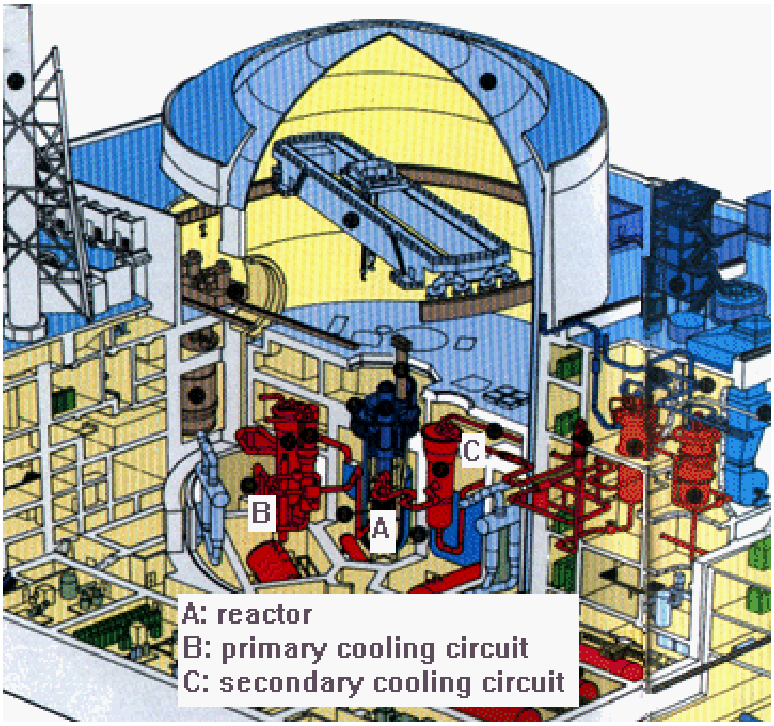


*Pressurized Water reactors (PWRs) account for 219,391 MWe and boiling water reactors (BWRs) for 75,519 MWe.
** A small amount of electrical capacity (less than 0.1%) is accounted for by other types of reactors.

Sources: Uranium Institute website (http://www.uilondon.org/reastats.html). The figure for fast breeder reactors is taken from Nuclear Power Reactors in the World (Vienna: international Atomic Energy Agency, April 1995). 280 MWe have been added to account for the Monju reactor in Japan which began operating in April 1995 but is now shut.

In turn, nuclear power plants account for 12 percent of the world's total electrical capacity. Not only have "breeder" reactors produced only a miniscule fraction of nuclear electricity; they have also failed to produce a significant amount of net fissile material. Indeed, it is possible that "breeder" reactors have so far been net consumers of fissile material.

Almost half of the world's breeder reactor capacity is in a single reactor, the Superphènix in France, which has faced serious operating problems and is not currently run as a breeder reactor. Rather, it is now a net burner of fissile material, used mainly as a research facility for studying the fission of plutonium and other similar elements called actinides. Another 10 percent of breeder capacity is in the 280-megawatt Monju reactor in Japan, which had an accident in December 1995, only eight months after its start up. (See graphic below.)



A cut-away view of the Japanese "Monju" fast breeder reactor. The two circuits contain sodium coolant with the secondary, non-radioactive loop drawing heat from the primary loop. The December, 1995 sodium leak occurred in the secondary circuit.

A number of problems have plagued the design and operation of breeder reactors:

- Breeder reactors are more difficult to control than light water reactors because runaway nuclear reactions (including complete loss of control, or "prompt criticalities") can occur far more easily in fast breeder reactors than in light water and other reactors that use slow neutrons for the chain reaction.

- Sodium, while it is an excellent coolant, reacts violently with air and explodes on contact with water. These and other properties raise severe safety issues, design complications, and operating difficulties. For instance, air and moisture must be kept out of the two necessary sodium loops.
- The presence of plutonium as a fuel in breeder reactors raises security risks that require more safeguards than are necessary with LWRs.
- Fabrication of plutonium fuel is far more costly than fabrication of uranium fuel due to higher radioactivity of, and safeguards requirements for plutonium.
- Extraction of plutonium from reactor fuel to enable its reuse in reactors (reprocessing), is costly and raises many safety, security, and environmental issues. [Reprocessing is covered in the January 1997 issue of Energy & Security.]
- The greater risk of catastrophic accidents and the more serious potential consequences of such accidents necessitate greater safety measures.

Most breeder reactor programs are now suspended or stopped due to the high capital costs and operating problems discussed above. They have been abandoned or cut back to a low-level research stage in the United States, Germany, and Britain. The Japanese program has had a severe setback due to the December 1995 sodium-leak accident at the Monju plant. The plant is not expected to be on line for several years, if ever. There are no current plans for new breeder reactors in France. Britain and Germany have pulled out of the European Breeder Reactor project. India's program has so far produced only a small pilot plant. Russian plans for breeder reactors are stalled for lack of money.

The expense and technical difficulties of breeder reactors, reprocessing, and plutonium fuel fabrication have led to far higher net costs for breeder reactors than for reactors that load only uranium as a fuel. Moreover, uranium is far more abundant than was presumed in the 1950s and 1960s. Instead of rising, uranium prices have, on the average, declined in real terms over the last several decades (table below).

Contract Price for Uranium Ore in 1995 Dollars

Year	Price U.S.$ per kg U
1960	100
1970	50
1980	90
1990	60

* We have used the producer price index for converting current uranium prices to 1995 dollars.

Furthermore, in the past ten years, spot market prices (the open market price at any given time) have been significantly lower than contract prices. For instance, in 1990 spot prices were about $30 per kilogram of uranium (in 1995 dollars)-just half of the contract price. In the past couple of years spot prices have ranged between $20 and $40 per kilogram. Low uranium prices are also partly due to reduced demand because the number of nuclear power reactors built has been far fewer than projected.

Value and cost of plutonium

While electricity systems based on breeder reactors have not been built, it is still possible to use plutonium as a fuel in light water and other power reactors not designed to breed plutonium. In any case, about one-fourth to one-third of the energy in an LWR is derived from plutonium created in the course of reactor operation from the uranium-238 in the fuel rods. Further, the spent fuel rods from LWRs typically contain about 0.7 percent fissile isotopes of plutonium. This plutonium, while far less than the amount of fissile material used in the reactor, can be re-extracted for use as fuel.

However, most reactors are not designed to operate on pure plutonium. The total amount of fissile material (uranium-235 plus fissile isotopes of plutonium) must be kept below the design level — in the vicinity of five percent for most LWRs. The plutonium is put into oxide form, mixed with depleted uranium oxide (mainly uranium-238 with about 0.2 percent uranium-235) to make a mixed oxide fuel ("MOX fuel"). Thus, it would appear that even without breeder reactors, plutonium can be useful as a nuclear reactor fuel.

While this argument is theoretically correct from the point of view of physics, it fails on economic grounds. To determine a practical economic value for plutonium, we must take into account the costs of processing and fabricating it into usable fuel and compare them to the costs of other fuels. The most detailed, recent independent analysis done on this subject was a study of reactor options for plutonium disposition published by the U.S. National Academy of Sciences (NAS) in 1995.

The NAS report estimated the cost of processing and fabricating low enriched uranium oxide reactor fuel (4.4 percent enrichment) at about $1,400 per kilogram in 1992 dollars, assuming a natural uranium price of $55 per kilogram. The costs of MOX fuel fabrication, assuming that the plutonium was free (that is, obtained as surplus from the nuclear weapons program), would be about $1,900 per kilogram in 1992 dollars, exclusive of taxes and insurance. 4 The higher cost of MOX means that annual fuel costs for a full MOX core would be approximately $15 million more than uranium fuel per year for a 1,000 megawatt reactor, or about $450 million over its operating life (in 1992 dollars), even if the plutonium were free. This amounts to about $500 millon in 1995 dollars. Further, the costs of disposing of MOX spent fuel are likely to be higher than those for uranium spent fuel because the MOX spent fuel will be more radioactive and contain two to three times more residual plutonium than uranium spent fuel.

It is clear that so long as uranium prices are relatively low, the use of MOX fuel is uneconomical even under the most favorable circumstances: when the plutonium itself is free and uranium is assumed to be more expensive than current spot market prices. The cost difference is even greater when the cost of reprocessing is taken into account, because reprocessing would add hundreds of millions of dollars to lifetime fuel costs for each reactor.

As the NAS pointed out in a 1994 study, the fact that plutonium has a fuel value in physical terms does not make it economically practical. The oil present in shale rock also has a physical fuel value. It is the cost of extracting oil from shale relative to petroleum in oil fields that precludes oil shale, like plutonium, from having an economic value as a fuel. In addition, plutonium poses some proliferation liability which, although difficult to quantify, is a serious cost.

Proliferation Dangers

Although civilian plutonium has a different isotopic composition from plutonium that has been produced for weapons, it can be used to make a nuclear explosive, as demonstrated in a successful 1962 test by the United States Atomic Energy Commission. Continued reprocessing and use of plutonium pose a two-fold proliferation danger. First, growing stockpiles of commercial separated plutonium undermine disarmament commitments under international treaties. Even if carried out for commercial reasons, reprocessing of plutonium can be perceived as simply adding to weapons-usable materials stockpiles. In the short-term, this could undermine effective global negotiations on a fissile material cut-off, and in the long-term, the Non-Proliferation Treaty, in which, under Article VI, signatories commit to “pursue negotiations in good faith on effective measures relating to the cessation of the arms race at an early date and to nuclear disarmament . . .”

Second is the danger of plutonium being diverted to a black market. The fuel value of plutonium is determined by the price of uranium. Assuming a price of $40 per kilogram of natural uranium, uranium-235 is worth about $5,600 per kilogram. Since the energy per fission from plutonium-239 and uranium-235 is about the same, the theoretical fuel value of fissile plutonium can be put at $5,600 per kilogram. Reactor-grade plutonium also contains non-fissile isotopes, reducing its value to about $4,400 per kilogram. 5 Six to ten kilograms of reactor-grade plutonium would suffice to make a nuclear bomb, making the fuel value of one bomb’s worth of plutonium between $26,400 and $44,000. However, the value of the plutonium would undoubtedly be far greater than this on a potential black market where the objective would be to make a weapon. The danger of plutonium diversion to a black market is particularly acute in Russia where the weakening of central control, combined with the rise of organized crime and poor economic conditions heighten the chances of diversion.

From Reactors to Weapons

- The size of the plutonium core in the bomb that exploded over Nagasaki would fit easily into an adult’s hand.
- The current amount of separated commercial plutonium is enough to make 20,000 to 30,000 crude but highly effective nuclear weapons.
- By the year 2000, the total amount of separated plutonium in the civilian sector is expected to surpass the total amount of plutonium in the world’s nuclear arsenals.

Long-term energy issues

The economic facts regarding plutonium are now so clear that they are not in serious dispute so far as short- and medium-term energy issues are concerned. But supporters of plutonium as an energy source cite long-term energy needs as a reason to create and maintain an infrastructure for the use of plutonium.

Current estimates of uranium resources at $80 per kilogram of uranium (still well below the price at which MOX fuel may be competitive) are estimated at about 3.3 million metric tons, enough for about six or seven decades of once-through fuel use at present levels of nuclear power production. These estimates do not take into account the intense exploratory activity that accompanies real increases in prices. The history of petroleum and natural gas exploration is instructive. The price increases in 1973-74 resulted from production-limiting and price-fixing policies adopted by the Organization of Oil Exporting Countries (OPEC). However, the price jump spurred new exploration activity, and the number of oil exporting countries and oil availability increased so substantially that the real price of petroleum is lower today than it was in 1974. Uranium prices have tended to decline in real terms (with the exception of a period in the 1970s, when uranium prices followed the upward trend of oil prices), and so current estimates of uranium resources may be biased downwards.

Whatever one’s views about the future of nuclear power, it makes little sense to invest huge amounts of money in using plutonium as a fuel today, when any potential economic use is many decades away, at best. Plutonium use makes even less sense when viewed in the context of scarce economic resources, which can be invested in areas with better environmental and security characteristics and a higher return, such as natural gas- or biomass-fueled power plants, natural gas-assisted solar electricity generation, and improved efficiency of energy use.