Why Recycle Plutonium?

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IN 1984, 250 KILOGRAMS OF PLUTONIUM OXIDE, SEPARATED in France from spent fuel from Japanese reactors, was returned to Japan by cargo ship. The ship carried only the plutonium; it made no intermediate stops; it was escorted partway by French and U.S. warships; and it was continuously tracked by satellite by officials in Japan (*1*).

If the nuclear industries of Europe and Japan continue with their plans to use plutonium in commercial reactors, they will, by the end of the century, have separated and placed into commerce more than 300,000 kilograms of plutonium (*2*) (Fig. 1). (For comparison, the Nagasaki bomb contained 6 kilograms of plutonium.) The extraordinary security measures applied to the French-Japanese shipment to protect the plutonium from theft and sabotage would need to be made routine on a vast scale.

This prospect derives from the decisions of several major countries, including France, Great Britain, the Federal Republic of Germany, Japan, Belgium, Switzerland, and Italy, to separate chemically the plutonium and uranium from the highly radioactive fission products contained in the spent fuel from their commercial reactors (a procedure called "reprocessing") and to recycle this plutonium and uranium into reactor fuel for breeder reactors and light water reactors. Such recycling differs from the "once-through" fuel cycle in use today in that material usable in weapons is not isolated in the latter process.

Barring a sharp turnaround in current programs, by the year 2000 or even earlier, more than 25,000 kilograms of separated plutonium may be placed in routine commerce annually (Fig. 2). Four countries—France, Great Britain, Germany, and Japan—will together separate most of this plutonium. Much will be separated from domestic fuel, but France and Britain also plan to reprocess fuel from West Germany, Japan, Belgium, Italy, the Netherlands, Spain, and Switzerland. Most of this plutonium, along with the nuclear waste, will eventually be returned to the country of origin.

After reprocessing, separated plutonium oxide will travel by truck, or a combination of truck and ship or plane in shipments across water, to fuel fabrication facilities in France, Great Britain, West Germany, Belgium, and Japan. If, on average, each shipment contains 100 kilograms of plutonium, more than 250 shipments of plutonium oxide annually will be required to transport the plutonium to these facilities. Slightly more than half of these shipments will be transported intracountry; the rest will travel from French and British reprocessing plants to other European countries and Japan.

At the fuel fabrication facilities, approximately two-thirds of the plutonium oxide will be blended with uranium oxide and fabricated into mixed-oxide (MOX) fuel elements and assemblies for light water reactors. Several hundred shipments of MOX fuel will be required each year to supply reactors in France, Germany, Japan, and elsewhere. The remaining separated plutonium will be fabricated into fuel elements for prototype breeder reactors in Britain, France, Germany, Japan, and Italy, and two Japanese heavy water reactors. The delivery of these fuel elements to the reactors will require an additional 100 shipments per year.

Neither the isotopic composition of the reactor grade plutonium nor its chemical form affords significant protection. Nuclear weapons designers have stated repeatedly that, despite its relatively high content of plutonium-240, reactor grade plutonium can be used directly in nuclear explosives. Similarly, plutonium oxide, the most common form of plutonium that leaves civilian reprocessing plants or that could be retrieved from unirradiated MOX fuels, could be used in nuclear explosives without reduction of the oxide to the metal. To guard against diversion of the material to weapons by terrorists, separated plutonium and fresh MOX fuel will have to be treated as virtually equivalent to weapon-grade plutonium (*3*). Given the scope of the commerce in separated plutonium, it is clear that stringent protection systems will be required.

Virtually any country engaged in plutonium recycling would have available large quantities of readily accessible fissile material. If a country had produced all the components of nuclear weapons other than the fissile material cores, it could reduce the time between a decision to build nuclear weapons and the achievement, on a potentially large scale, from years to weeks. Such "latent proliferation" would make it easy for governments to hide a nuclear weapons program within an ambitious civilian program.

Reprocessing and recycling are concentrated in countries that have nuclear weapons or support the Non-Proliferation Treaty. However, the emergence of a commercial market in MOX fuels, even if initially restricted to Europe and Japan, would allow other countries, some with dubious commitment to nonproliferation, to gain access to weapons-usable material. The emergence of a plutonium market would also make it extremely awkward for nuclear suppliers in the United States, Europe, and Japan to deny reprocessing and fabrication facilities able to produce such material relatively quickly to other countries.

One source of interest in reprocessing has been the view that reprocessing could improve the efficiency of radioactive waste disposal. This, combined with the willingness of France and Great Britain to reprocess foreign fuel, offered a politically attractive way for some countries to postpone dealing with their own waste disposal problems. However, the fission product contents of spent fuel and high-level waste from reprocessing are essentially identical, and the heat outputs per metric ton of original uranium are similar. Although reprocessing would separate much of the plutonium and perhaps some of the actinides from the spent fuel, significant amounts of plutonium and actinides would still end up in the reprocessing wastes. As a result, final disposal of unreprocessed spent fuel does not appear to represent a significantly greater

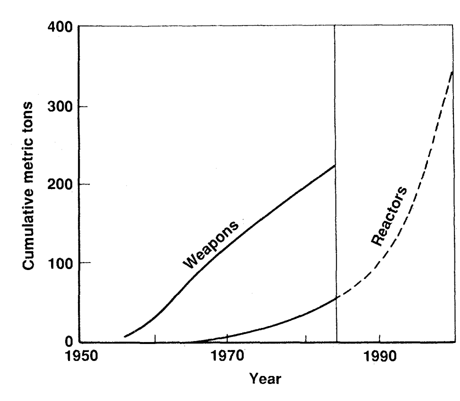

Fig. 1. The growing amount of separated civilian plutonium in noncommunist countries intended as fuel in civilian power reactors compared with the amount of plutonium in the nuclear weapons arsenals of the United States, the Soviet Union, France, and the United Kingdom at the beginning of 1984.

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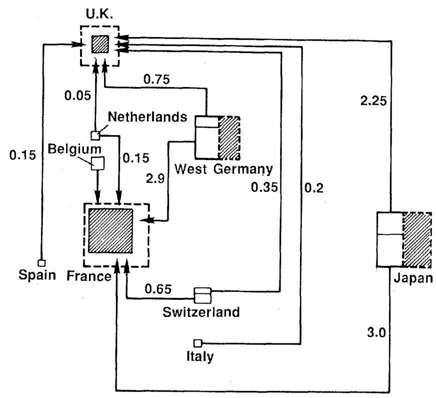

Fig. 2. Annual amount of plutonium to be separated from light water reactor spent fuel at the end of the century. Most of the separated plutonium will eventually be sent back to the originating country. A total of about 27 metric tons of plutonium per year is based on projected reprocessing capacities at the end of the century and already negotiated reprocessing contracts. The area of each country's square is proportional to the total plutonium that would be separated annually from spent fuel produced in the country plus, in the case of France and the United Kingdom, sent to it from abroad. The area of each dashed-outlined square or rectangle is proportional to the total plutonium that would be separated in the country's reprocessing plants. The shaded areas are proportional to the plutonium that would be separated from domestic fuel. The arrows represent international transfers of spent fuel to be reprocessed (in terms of contained plutonium).

environmental hazard than disposal of high-level wastes from reprocessing. Three countries with major nuclear programs—the United States, Canada, and Sweden—have decided to place their spent fuel in long-term storage without reprocessing (*4, 5*).

Although the waste disposal rationale for reprocessing appears to have weakened, a second motivation remains strong—that the energy content of the plutonium contained in the spent fuel must be captured. Until recently, the nuclear industries in the industrialized countries expected that this recycled plutonium would be used for the initial loadings of prototype and commercial plutonium breeder reactors. However, because of greatly reduced demand for electricity, the higher costs of breeder reactors compared to light water reactors, and larger than expected uranium resources, breeder reactor programs worldwide have slowed dramatically.

Breeder programs can thus absorb only a small portion of the plutonium scheduled or planned to be separated in this century. Unless current reprocessing programs are curtailed, there will be a surplus of separated plutonium of at least 100 metric tons by 1995 and 200 metric tons by the year 2000.

As the commercial viability of the breeder recedes and stockpiles of separated plutonium grow, the nuclear industries in Europe and Japan have initiated programs to use plutonium fuels in current light water reactors. Recycling would in practice reduce uranium feed and enrichment requirements by about one-quarter—the savings depending on the price of uranium and enrichment. At current uranium and enrichment prices, fuel cycles that use recycled uranium and plutonium would cost about 1 mill/kWh more than the normal once-through cycle. The price of uranium would have to more than triple from its present value of less than $83 per kilogram before the savings in uranium costs made up for the extra costs of reprocessing, of plutonium storage, and of MOX fabrication (*6*). Even if the costs of reprocessing are disregarded, the economic benefits of plutonium and uranium recycle are marginal or nonexistent.

Despite the poor economics, the nuclear industries in Europe and Japan often cite national energy independence as a reason to push ahead with reprocessing and thermal recycle. This goal draws mainly upon the persistent vulnerability of these areas to oil import disruptions. However, the uranium savings that could be gained by the recycling in light water reactors of all the plutonium and uranium planned for separation in this century would be only about 100,000 metric tons. For most countries, thermal recycling would lessen their dependence on foreign uranium only at the price of an increased dependence on a steady and assured flow of plutonium separated in foreign reprocessing plants. It would also make them dependent on the integrity of international safeguards and physical security arrangements to prevent the theft or diversion of the separated plutonium.

Countries concerned about the security of their uranium supply may, instead, find it cost-effective to reduce the consumption of uranium by higher burnup of reactor fuel or more complete recovery of uranium-235 from natural uranium at enrichment plants. In addition, uranium costs so little per unit energy-equivalent that it can be readily and economically stockpiled to provide a buffer against a supply disruption.

Reprocessing and recycling on the scale now envisioned would create a challenge of nightmarish proportions for those seeking to prevent diversion of plutonium to weapons. The reasons for European and Japanese interest in recycling are complex—for example, interest in Germany and Japan in postponing domestic debates on waste disposal and the drive in France to stay at the forefront of nuclear technology. But there do not appear to be any clear economic motives. Indeed, with the price of uranium low, and expected to remain so for several years at least, recycling appears to be an economically poor proposition.

It may not be too late for the international community to persuade the countries embarking on these critical activities to abandon plans for plutonium recycling and to defer indefinitely commercial reprocessing not devoted directly to research and development on breeder reactors.

REFERENCES AND NOTES

1. S. Spector, *The New Nuclear Nations* (Vintage, New York, 1984), pp. 237–238.
2. D. Albright and H. Feiveson, "Plutonium recycle and the problem of nuclear proliferation" (Research Report 206, Center for Energy and Environmental Studies, Princeton University, April 1986).
3. J. Mark, T. Taylor, E. Eyster, W. Maraman, J. Wechsler, "Can terrorists build nuclear weapons?" (paper prepared for the International Task Force on Prevention of Nuclear Terrorism, Nuclear Control Institute, Washington, DC, 24 May 1986).
4. Nuclear Energy Agency, *The Economics of the Nuclear Fuel Cycle* (Organization for European Cooperation and Development, Paris, 1985), appendixes 2, 3, and 10.
5. "Final report of the project group on alternative entsorgung" (KWA 2190/1, Karlsruhe Nuclear Research Center, Karlsruhe, Federal Republic of Germany, 1984).
6. The critical assumptions are: enrichment costs, $130 per kilogram separative work unit; uranium-oxide fabrication costs, $190 per kilogram of uranium (kg-U); MOX fabrication costs, $760 per kilogram of heavy metal (kg-HM); reprocessing costs including vitrification, $750/kg-HM; disposal costs of reprocessing wastes, $150/kg-HM; and spent fuel disposal costs, $350/kg-HM. The fuel cycle costs of a light water reactor on a once-through fuel cycle can be approximated by $4.3 + 0.03x$ mill/kWh, where x is the price of uranium in dollars per kilogram. The fuel cycle costs for a recycling reactor would be $5.6 + 0.024x$ mill/kWh. At a uranium price of $83/kg-U, recycling would cost about 1 mill/kWh more than a once-through system (*4*, pp. 15 and 60).
7. We wish to acknowledge the contributions of R. Socolow, F. von Hippel, and R. Williams.