

Economic Aspects of Nuclear Fuel Reprocessing

TESTIMONY OF
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MADAM CHAIRWOMAN AND MEMBERS OF THE COMMITTEE: It is an honor to be invited here today to discuss the economic aspects of nuclear fuel reprocessing. Together with colleagues at Harvard University, I recently completed an in-depth study of this issue,¹ the results of which were published recently in the journal *Nuclear Technology*.² In the course of this study we conducted an exhaustive search for information on historical and projected costs of reprocessing and other nuclear fuel-cycle services. We also examined previous studies of fuel-cycle economics by the Nuclear Energy Agency of the Organization of Economic Cooperation and Development (OECD), the governments of France and Japan, the U.S. National Academy of Sciences, the Massachusetts Institute of Technology, and others. Our conclusions are therefore well-grounded, and we have made our results transparent by documenting all of our assumptions and methods and by making spreadsheet versions of our economic models available on the web, so that anyone can reproduce and check our results. With this background, let me turn to the specific questions raised in your letter to me.

Under what conditions would reprocessing be economically competitive with the once-through fuel cycle?

In the once-through fuel cycle, spent nuclear fuel discharged from light-water reactors is placed in a deep geological repository, such as the one being built at Yucca Mountain in Nevada. The main alternative, as practiced in France and planned in Japan, is to reprocess spent fuel to separate the unburned plutonium and uranium from other radionuclides. The recovered plutonium is used to produce mixed-oxide (MOX) fuel for existing light-water reactors, and the high-level radioactive wastes are vitrified and stored pending disposal in a deep geologic repository. It is important to note that reprocessing does not eliminate high-level wastes or negate the need for a repository.

There is widespread agreement, in the United States and abroad, that reprocessing currently is significantly more expensive than direct disposal.³ This is because reprocessing itself is an

¹ Matthew Bunn, Steve Fetter, John P. Holdren, and Bob van der Zwaan, *The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel* (Cambridge, MA: Project on Managing the Atom, Belfer Center for Science and International Affairs, John F. Kennedy School of Government, Harvard University, December 2003), available at <http://www.puaf.umd.edu/Fetter/2003-Bunn-repro.pdf>.

² Matthew Bunn, Steve Fetter, John P. Holdren, and Bob van der Zwaan, "The Economics of Reprocessing versus Direct Disposal of Spent Nuclear Fuel," *Nuclear Technology*, Vol. 150, pp. 209-230 (June 2005), available at <http://www.puaf.umd.edu/Fetter/2005-NT-repro.pdf>.

³ See, for example, J-M. Charpin, B. Dessus, and R. Pellat, "Economic Forecast Study of the Nuclear Power Option," Office of the Prime Minister, Paris, France (July 2000); "Interim Report Concerning the Nuclear Fuel Cycle Policy," New Nuclear Policy-planning Council, Japan Atomic Energy Commission (November 2004),

expensive process, and also because the MOX fuel produced using the recovered plutonium is more expensive, at current uranium prices, than the low-enriched uranium (LEU) that is normally used to fuel reactors. Last year, operators of U.S. nuclear reactors on average paid \$33 per kilogram for uranium.⁴ At this uranium price, reprocessing would have to cost less than \$400 per kilogram of spent fuel in order to be competitive with direct disposal.⁵ For comparison, we estimate that reprocessing in a new U.S. facility, similar to those in the United Kingdom and France, would cost over \$2000 per kilogram.⁶ But even if reprocessing costs could be halved, to \$1000 per kilogram of spent fuel, the price of uranium would have to rise to nearly \$400 per kilogram in order to break even with the once-through fuel cycle. It is extremely unlikely that uranium prices will rise to this level in the next 50 years, even if worldwide use of nuclear power expands dramatically.

Substantial reductions in the cost of reprocessing would be needed even to achieve the \$1000 per kilogram mentioned above. The Plutonium Redox Extraction (PUREX) process used in existing facilities has been perfected over more than five decades, and it seems unlikely that dramatic cost reductions could be achieved using this or similar aqueous technologies, such as UREX+. Moreover, increasingly stringent environmental and safety regulations will put countervailing pressures on costs. The experience at the Rokkasho-Mura reprocessing facility in Japan, which has seen initial capital cost estimates triple to \$18 billion, should serve as a cautionary tale for any country contemplating going down this road.

A range of alternative chemical separations processes have been proposed over the years. Recently, attention has focused on electrometallurgical processing or “pyroprocessing.” A 1996 review by the National Academy of Sciences concluded, however, that “it is by no means certain that pyroprocessing will prove more economical” than PUREX. Indeed, recent official reviews have concluded that such techniques are likely to be substantially more expensive than PUREX.⁷

It is conceivable, of course, that at some point in the long-term future research and development could lead to a fundamentally different approach that might have lower costs. But it does not appear likely that the cost of reprocessing will be reduced to levels that would be economically competitive with direct disposal in the foreseeable future.

summary available at <http://cnic.jp/english/topics/policy/chokei/longterminterim.html>; *The Future of Nuclear Power* (MIT, 2003); available at <http://web.mit.edu/nuclearpower>.

⁴ Energy Information Administration, Uranium Marketing Annual Report, 2004 Edition, 29 April 2005; available at <http://www.eia.doe.gov/cneaf/nuclear/umar/umar.html>.

⁵ Computed with the spreadsheet available at <http://www.puaf.umd.edu/Fetter/programs/COE-LWR.xls>, using reference assumptions that are favorable to reprocessing, including a 50 percent reduction in waste-disposal costs.

⁶ Assumes a plant throughput of 800 tons of spent fuel per year for 30 years; an overnight capital cost of \$6 billion, repaid at interest rates appropriate for a regulated private entity with a guaranteed rate of return; annual operating costs of \$560 million per year, and standard assumptions about construction time, taxes and insurance, and contingency, pre-operating, and decommissioning costs. For a government-financed facility with very low cost of money, the corresponding cost would be \$1350/kg; for an unregulated private venture, the cost would be \$3100/kg. See Bunn, et al., “The Economics of Reprocessing versus Direct Disposal of Spent Nuclear Fuel,” p. 213.

⁷ Generation IV Roadmap: Report of the Fuel Cycle Crosscut Group, U.S. Department of Energy, Office of Nuclear Energy, Washington, DC (March 2001); “Accelerator-Driven Systems (ADS) and Fast Reactors (FR) in Advanced Nuclear Fuel Cycles: A Comparative Study,” OECD/NEA 03109, Organization for Economic Cooperation and Development, Nuclear Energy Agency (2002).

What would it cost to manage nuclear waste through a system that includes reprocessing, recycling, and transmutation?

Traditional approaches to reprocessing and recycle, as practiced in France and planned in Japan, do not significantly reduce the amount of repository space required for the disposal of high-level radioactive wastes. The required repository area is determined by the heat output of the wastes, not by their mass or volume. If the plutonium recovered during reprocessing is recycled in existing light-water reactors, the build-up of heat-generating minor actinides would result in a greater total heat output from wastes than if the same amount of electricity was generated using the once-through fuel cycle.

Substantial reductions in repository requirements can be achieved only if all of the major long-lived heat-generating radionuclides are separated from the spent fuel and recycled as fuel for fast-neutron reactors, which can transmute these long-lived radionuclides. This separation-and-transmutation system would, however, almost certainly be far more expensive than the direct disposal of spent fuel, per unit of electricity generated. This is because reprocessing is expensive, because the costs of fabricating and using the highly radioactive fuel would be high, and because the fast-neutron reactors required to transmute the long-lived radionuclides will cost significantly more than light-water reactors.

How much more expensive? The National Academy of Sciences examined this question in a 1996 report and concluded that the excess cost for a separation-and-transmutation system over once-through disposal would be “no less than \$50 billion and easily could be over \$100 billion” for 62,000 tons of spent fuel (the current legislated limit on Yucca Mountain).⁸ This conclusion remains valid today; there have no technical breakthroughs or dramatic cost reductions in either separation or transmutation technologies. Again, the separation-and-transmutation system would generate high-level wastes requiring geologic disposal and therefore would not eliminate the need for the Yucca Mountain repository.

What government subsidies might be necessary to introduce a separation-and-transmutation fuel cycle in the United States?

Today, nuclear reactor operators pay a small fee—\$1 per megawatt-hour of electricity produced (about 2 percent of the wholesale price of nuclear-generated electricity)—for the geologic disposal of spent fuel. This fee, which is deposited into the Nuclear Waste Trust Fund, is considered adequate to pay for the full costs of geologic disposal.

As noted above, a separation-and-transmutation system would be considerably more expensive than direct disposal. Because there is no commercial incentive to develop a more expensive system for the disposal of wastes, the U.S. government would, at a minimum, have to assume the entire costs of research and development, which would likely total several billion dollars. Given the lack of market incentives, the U.S. government might also have to build and operate the required separations and transmutation facilities. If the National Academy’s estimate is correct, the total extra cost would be \$50 to \$100 billion to process the 62,000 tons of fuel planned for Yucca Mountain. If the licenses of all currently operating

⁸ U.S. National Research Council, Committee on Separations Technology and Transmutation Systems, *Nuclear Wastes: Technologies for Separations and Transmutation*, National Academy Press, Washington DC (1996); executive summary available at <http://books.nap.edu/html/nuclear/summary.html>.

reactors are extended, the amount of spent fuel and the total extra cost would be about twice as large—\$100 to \$200 billion—and would be still larger if new reactors are built. These extra costs could be funded by tripling or quintupling the nuclear waste fund fee, thereby passing the extra costs—\$1.5 to \$3 billion per year at current levels of nuclear generation—along to the rate payer. Alternatively, Congress could create a legal framework that would require reactor operators to reprocess their spent fuel, thereby artificially stimulating a market for private reprocessing and transmutation facilities. The final result would be the same, however: nuclear-generated electricity would become more expensive.

How would a decision to reprocess affect the economic future of nuclear power?

No nuclear reactors have been ordered in the United States since 1978, and no reactor ordered after 1974 was completed. Although public concern about reactor accidents had a role in the stagnation of nuclear power, it was driven primarily by economic considerations: in particular, the high capital costs and high financial risk of nuclear power compared to alternative methods of generating electricity or managing demand for electricity.

Increasing natural gas prices, and especially efforts to mitigate climate change by reducing emissions of carbon dioxide from the burning of fossil fuels, will increase the attractiveness of nuclear power. But nuclear power will still have to compete with other alternatives, including wind power, biomass, and coal-fired power plants with carbon sequestration. Traditional reprocessing would likely add 3 to 7 percent to the wholesale price of nuclear-generated electricity, depending primarily on the cost of reprocessing;⁹ a full separation-and-transmutation system would add still more. This can only hurt nuclear power in the economic competition with alternative methods of generating electricity, and could make the difference between a revitalized industry and continued stagnation and decline.

Advocates of reprocessing often point to the difficulty in licensing Yucca Mountain as a barrier to the expansion of nuclear power. As noted above, reprocessing would not eliminate the need for Yucca Mountain. A separation-and-transmutation system could, however, greatly delay—and might even eliminate—the need to expand the capacity of Yucca Mountain or to build a second repository. (As a purely technical matter, it is likely that the Yucca Mountain repository could be expanded to hold all of the waste that will be discharged by current reactors, even with license extensions.) Advocates of a separation-and-transmutation system implicitly assume that it would be easier to gain public acceptance and licensing approval for a large number of complex and expensive separation and transmutation facilities than for an expansion of Yucca Mountain or a second repository. This assumption is likely wrong. Reprocessing of spent fuel has been fiercely opposed by a substantial section of the interested public in the United States for decades, and there would stiff opposition to having taxpayers or ratepayers subsidize this enterprise at the rate of several billion dollars per year.

⁹ Assuming reprocessing costs of \$1000 to \$2000 per kilogram of spent fuel, uranium at \$50 per kilogram, and other costs that are generally favorable to reprocessing, the additional cost of reprocessing and recycle is \$1.3 to \$3.5 per megawatt-hour; the assumed wholesale electricity price is \$50/MWh for direct disposal.