Reprocessing: How Necessary Is It for the Near Term?

Reprocessing has long been thought to be one of the technologies that would be incorporated into a mature nuclear power system, but the assumption that it should be used with the current generation of reactors is being critically reevaluated because of widespread concern over nuclear proliferation.

Given its history, reprocessing was a natural technology for the nuclear industry to pick up. It was born of the nuclear weapons program long before the first reactor produced electricity, and it has always been inextricably linked to the concept of a breeder reactor, since that historically favored option for multiplying uranium supplies cannot operate without it. It was available to the planners of civilian nuclear programs from the very beginning, and it was always projected to be part of the array of future nuclear technologies because breeder reactors were thought to be imminent for most of the last 30 years.

As the date for the introduction of breeders slipped from the 1950's to the 1980's and now closer to 2000, it became clear that the United States, Western Europe, and Japan would install a very large number of nonbreeder, light water reactors. Unlike the situation with the breeder, there is no technical necessity that mandates the use of reprocessing with these reactors. Instead, the benefits of reprocessing the spent fuel from light water reactors are argued to be three: an increase in the energy available from uranium resources, a reduction of the costs of nuclear power, and an easing of the problem of radioactive waste disposal.

Alarmed over the central contribution of reprocessing to proliferation (six of the seven countries that have tested nuclear weapons used the technique to acquire material for their first bombs), a number of federal agencies and private groups have reexamined the case for reprocessing in the present circumstances and found it to be remarkably weak. The arms control and environmental agencies have been lobbying against domestic reprocessing within the government for the last year, and reprocessing became one of the more sharply defined issues of the presidential campaign last fall, with both candidates expressing grave reservations. The Carter Administration's views on the issue are in considerable flux but an official position is due to be announced soon.

The case against reprocessing received unexpectedly strong support last week when a new Ford Foundation study recommended that the President should make "a clear-cut decision" to defer commercial reprocessing indefinitely.

Noting that the government's analysis shows only a 1 or 2 percent saving in the cost of electricity, the highly influential members of the Ford study group said some elements in the government analysis appear to be underestimates and "our own analysis indicates that any net economic benefit during this century is questionable."

Fuel Supplies Little Enhanced

The 21-member Ford group, which included the Nobel-winning economist Kenneth Arrow, Secretary of Defense Harold Brown, Carl Kaysen, former director of the Princeton Institute of Advanced Study, and physicist Wolfgang Panofsky (see p. 41), also discounted the benefit of the small uranium savings that would be achieved by reprocessing, and asserted it could aggravate rather than ease the problem of waste disposal. Underscoring the connection between domestic actions and the U.S. efforts to reach an agreement among the suppliers of plutonium technology, the report warned that a decision to go ahead with reprocessing "would accelerate worldwide interest in the plutonium fuel cycle and undercut efforts to limit nuclear weapons proliferation."

In the face of heavy opposition, the nuclear industry is vigorously defending the merits of reprocessing and the government's nuclear research arm is arguing that in addition to other benefits, reprocessing of light-water reactor fuel will provide a valuable store of plutonium and experience needed in preparation for the breeder.

As a practical matter, however, commercial reprocessing is at a standstill in the United States right now. Two relatively small plants that were built during the 1960's both failed—one for technical reasons and the other for economic reasons. A much larger plant (Fig. 1), capable of reprocessing the fuel from 50 reactors, has been built at Barnwell, South Carolina, but it is sitting idle while the Nuclear Regulatory Commission conducts hearings on the safety and environmental effects of recycling the plutonium that would be extracted at the Barnwell plant to refuel light water reactors. The first set of commission hearings, which are entitled GESMO hearings for Generic Environmental Impact Statement on Mixed Oxide fuels, are expected to last into the summer and a second round to consider safeguards will be held after that. No decision is likely before the middle of next year, and some observers do not expect the regulatory question settled before 1980.

In Europe, Britain, France, and West Germany are going ahead with commercial reprocessing but accidents, technical difficulties, and public opposition are slowing the plans. In 1971, Britain modified its military plant at Windscale to make it suitable for commercial reprocessing by adding on an extra unit. A minor criticality accident in 1972 pointed out a subtle design flaw and then a chemical explosion in the new unit caused it to shut down for major design changes in 1973. The improved unit is due to be working in 1978, and Britain plans to construct a completely new plant at the site by 1984 (*Science*, 7 January, p. 33).

France has similarly modified its military reprocessing plant on the English channel at La Hague. After a 2-year delay the plant is now operating on a small scale and the French are planning to build its capacity slowly to about 800 tons of fuel per year—about half the optimum size for a new commercial plant. The La Hague plant has probably the most advanced mechanical technology, some of which has been used in the idle U.S. plant at Barnwell, and it is the only commercial facility in the West presently in operation. West Germany is planning to build a large commercial plant with a capacity of 1500 tons per year by 1984. The recently selected site for this plant is Gorleben near the East German border, where antinuclear groups are likely to slow construction of it just as they have done for other recent nuclear projects.

The focus of the controversy is an esoteric chemical technology developed in the United States in the early 1950's, called the Purex process. It was specially tailored—after a series of less satisfactory processes were discarded—to produce plutonium in its purest form, suitable for weapons.

As spent reactor fuel rods enter the front door or the "head end" of a reprocessing plant, they are chopped up into small sausage-sized pieces by a large hydraulic shear located inside a massive

Fig. 1. Allied Chemical Company's $250 million reprocessing plant at Barnwell, South Carolina.

concrete "canyon." The pieces are dropped by remote control into diissolvers which are constructed so that the amount of plutonium cannot build up to a critical mass in any location. Nitric acid dissolves the fuel, leaving behind the metal cladding. At this point, highly radioactive fission products, as well as uranium and plutonium, are all in the one solution.

The radioactive liquid is then mixed with an organic solvent (tributyl phosphate or TBF) and the uranium and plutonium ions migrate into the solvent while the fission products do not. After repeated purgings, the fission products are removed and then the plutonium is separated from the uranium stream by an oxidation process that causes it to precipitate (in the form of plutonium nitrate). Thus, pure plutonium is the result.

All the new reprocessing plants, presumably including the ones that France and West Germany are planning to export to Pakistan and Brazil, are based on the Purex process, which was proved in the large U.S. military reprocessing plant at Savannah River, South Carolina. That plant has been operating quite successfully for more than 20 years. One Washington official familiar with the battle over reprocessing between the arms control agency and the Energy Research and Development Administration (ERDA) says, "For proliferation, you can't find anything worse than Purex. It was developed for bombs."

In spite of the dependability of the Purex method in the military plants, the commercial plants have had many breakdowns. The first U.S. commercial plant, built at West Valley, New York, as one element in Nelson Rockefeller's plan to give New York State a head start on futuristic technologies, was clearly premature. There were few power reactors when it opened in 1966, and fully two-thirds of the fuel it reprocessed until 1972 was military fuel supplied by the Atomic Energy Commission under an agreement that effectively subsidized the plant. The $30 million plant processed a total of 600 tons of fuel, at a price of about $30 per kilogram, and never broke even. A second plant of about the same size (300 tons per year) was built at Morris, Illinois, by General Electric when it was still thought that reprocessing would be cheap enough, compared to the cost of transporting spent fuel, that it would pay to put a small plant near a cluster of reactors. The Morris plant was within a stone's throw of Commonwealth Edison's reactors, but it never worked. General Electric had developed its own chemical process, called Aquaflor, and at a point where the GE process changed what would have been a liquid stream of uranium into a solid powder, the process got plugged up. The $64 million plant was effectively written off (*Science*, 30 August 1974, p. 770).

One of the reasons that commercial plants have had so much unexpected trouble is that light water reactor fuel resides in the reactor five to ten times longer than fuel for military production reactors. The additional residence time boosts the radioactivity and decay heat of the spent fuel and places more demanding requirements on a reprocessing plant. Among the problems are degradation of the organic solvent by the higher radiation and more difficulty in maintaining the equipment in the highly radioactive head end of the plant.

Another reason that commercial plants have been less reliable than military plants may be that the commercial plants were not as conservatively designed. The Savannah River plant was built like a Cadillac, with provisions for remote maintenance and much redundancy. In fact, it is really a twin facility. Two process lines have been built side by side in identical concrete canyons. The "hot" canyon is used for reprocessing and the "cold" canyon is available to test any modification before trying it in the contaminated area. Knowledgeable nuclear engineers estimatee that the Savannah River plant cost at least 50 percent more than a commercial plant of the same capacity would cost.

The plutonium and unburned uranium left over in spent fuel rods undeniably represent an energy value. But the amount of plutonium produced in a light water reactor each year (about 250 kg) is a very small fraction of what would be produced in a breeder. If plutonium and uranium were both recycled it would result in a uranium saving of only 20 to 25 percent by the end of the century. By contrast, reprocessing breeder fuel would multiply the energy obtainable from uranium reserves by 5000 percent or more. The uranium savings from recycling light water reactor fuel would be so small that the same effect could be achieved by small changes in other parts of the fuel system—such as by reducing the tails of uranium enrichment plants in the 1980's. Comparable uranium savings could also be achieved by changing reactor types—light water reactors are inherently less efficient at converting uranium to electricity than the Canadian CANDU reactor, for example. Alternative technologies will be discussed in a second article.

But if uranium and plutonium were recycled, there are already hints that new technical problems would appear. Uranium separated out of spent fuel contains a considerable amount of ^{236}U, which is not present in the natural ore and would add an economic penalty if not removed from the next load of fuel. Recycled plutonium fuel becomes increasingly plutonium-rich as it goes through repeated fuel cycles and plutonium oxide is considerably harder to dissolve than uranium oxide (except with agents that cause other problems to the Purex chemistry). The Barnwell license application now pending before the Nuclear Regulatory Commission is for reprocessing uranium fuels only.

Several detailed studies have projected what appear to be large economic benefits from reprocessing and recycle of mixed oxide fuel, but what the critics of these studies have found is that the uncertainties in the analysis are generally greater than the benefits. An ERDA cost-benefit study of the question, published in December, found that plutonium and uranium recycle would save $16.6 billion by the end of the century. Similar benefits were found by the GESMO study. The owners of the Barnwell plant, Allied General Nuclear Services (AGNS), found double that benefit.

One of the most important recycle costs is that of reprocessing itself, which depends heavily on the capital cost and reliability of the plant. The GESMO and AGNS studies put the cost of reprocessing at $150 per kilogram, but—as the Ford Foundation study notes—raising the reprocessing cost to $250 would practically negate the positive conclusion in the GESMO analysis. A thorough study of a commercial-sized plant by du Pont, which probably has the greatest reservoir of expertise in these matters since it designed and built the Savannah River plant, puts the plant cost at twice that of other estimates. Any of these estimates could turn out to be unrealistic if the plant were to process much less fuel than it was designed for. A survey of all commercial plants to date, including the two American ones, shows that none performed better than the West Valley plant, which during its 6-year life operated at only 35 percent of its rated capacity.

Although the government analyses find that reprocessing could yield a 1 to 2 percent saving in the cost of electricity, other critics rate the highest possible benefits even lower. Vince Taylor, a research economist with Pan Heuristics who has done a number of well-respected studies for the Arms Control and Disarmament Association, concludes that even if reprocessing were free, the reduction in the cost of electricity would only be 2 percent. His economic study of the problem concludes that there would be a net loss from plutonium recycle—a loss larger than the government's projected gains.

To forgo reprocessing would necessitate a drastic change in the prevalent approach to waste disposal—which is to partition wastes emerging from a reprocessing plant and then dispose of them in accordance with their different degrees of biological hazard.

Although nearly half the economic benefits projected by the ERDA and GESMO analyses depend on the assumption that reprocessing makes waste disposal cheaper, there have been virtually no detailed studies in the United States to support such a conclusion. Neither have there been studies of the relative safety hazards of the direct disposal of spent fuel. A 1976 report by the Nuclear Regulatory Commission* stated the situation quite clearly.

> It has been assumed in the past that the uranium and plutonium in spent fuel would be recovered and recycled. Therefore, detailed analyses of the technology of spent fuel disposal are not to be found in the literature.

Such studies would have been the responsibility of ERDA or its predecessor, but that agency remains one of the strongest proponents of reprocessing.

It seems clear that spent fuel can be disposed of in the form in which it leaves the reactor—that is, intact, with the fission products uranium and plutonium still sealed in the metal fuel cladding. The Canadian nuclear program has looked at this method rather thoroughly and found that it is quite cheap—less than $10 per kilogram of fuel. On the other hand, the GESMO study, which in five volumes devoted only a short paragraph to the matter, estimated the cost of spent fuel disposal to be somewhere between $50 and $150 per kilogram. The Canadian fuel is less radioactive than light water reactor fuel, however.

The Canadian cost estimate is roughly the same as the cost of doing what all U.S. nuclear plant operators are now doing with their fuel—storing it in facilities like swimming pools at the reactor sites. But the Canadians expect that their method—keeping the fuel in small dry concrete silos—will require less maintenance, and "it could be considerably cheaper because no operating costs are involved," says S. A. Mayman of the Whiteshell laboratory of Atomic Energy of Canada, Ltd.

The standard view in the past has also been that reprocessing reduces the risk associated with waste dispoal. This was thought to be the case because reprocessing reduces the amount of long-lived radioactivity by about a factor of 10 and reduces the volume of the most radioactive wastes by about the same factor. But reprocessing produces additional waste materials by converting the spent fuel into acidic liquid waste, cladding hulls, and process trash contaminated with plutonium. The volume of all reprocessing wastes would be from one to three times the volume of the spent disposal package. The high-level wastes from reprocessing would generate just as much heat as before, and disposal costs may depend more on heat than volume. The wide differences in disposal costs are apparently due to GESMO's base of costs on the volume of high-level wastes and the critic's base of costs on heat output.

Although the Ford Foundation report acknowledged that reprocessing could achieve a small reduction in the long-term risks from nuclear wastes, it found that the largest risks from nuclear wastes are in their interim management. In particular, the report cited the history of problems from reprocessed civilian and military wastes that have been put into temporary storage (*Science*, 18 February, p. 662). The report concluded that the reduction in long-term risks is small compared with the more immediate risks associated with reprocessing and plutonium recycle. Thus good waste management practice may weigh against reprocessing.

Even if—as the critics say—the uranium savings from reprocessing are small and the economic and waste safety benefits are marginal or negative, the nuclear interests argue that reprocessing is valuable in light of the breeder.

But the technology for reprocessing breeder fuel is not going to be the same as that for reprocessing present reactor fuel because breeder fuel will be irradiated three to five times longer. Just as light water fuel reprocessing has run into problems that did not occur in the military program, it is possible that breeder fuel will. "The technical issues involved in the breeder case are really quite different and rather extreme," says Thomas Neff at the Massachusetts Institute of Technology, because breeder fuel would have about 30 times the plutonium content of light water reactor fuels. As a consequence, a breeder reprocessing plant would have to be designed for different criticality standards, different dissolution problems, and higher concentrations of fission products. In fact, ERDA is planning to build and test a $600 million demonstration plant for reprocessing breeder fuel in the 1980's.

If the matter due to be decided in the United States just now were the benefit of reprocessing in conjunction with the breeder, the arguments for going ahead would be much stronger. But the critics of near-term reprocessing argue that the two cases are fundamentally different, and to tie them together now is a political move. The decision being taken about reprocessing, argues Taylor, is not whether to approve it or reject it forever. The actual choices, he argues, are either to approve it now or to defer a decision. In view of the great potential dangers of proliferation through reprocessing and its marginal potential benefits, to give up reprocessing now would appear to be a small sacrifice.—WILLIAM D. METZ

*"Environmental Survey of the Reprocessing and Waste Management Portions of the LWR Fuel Cycle," NUREG-0116.