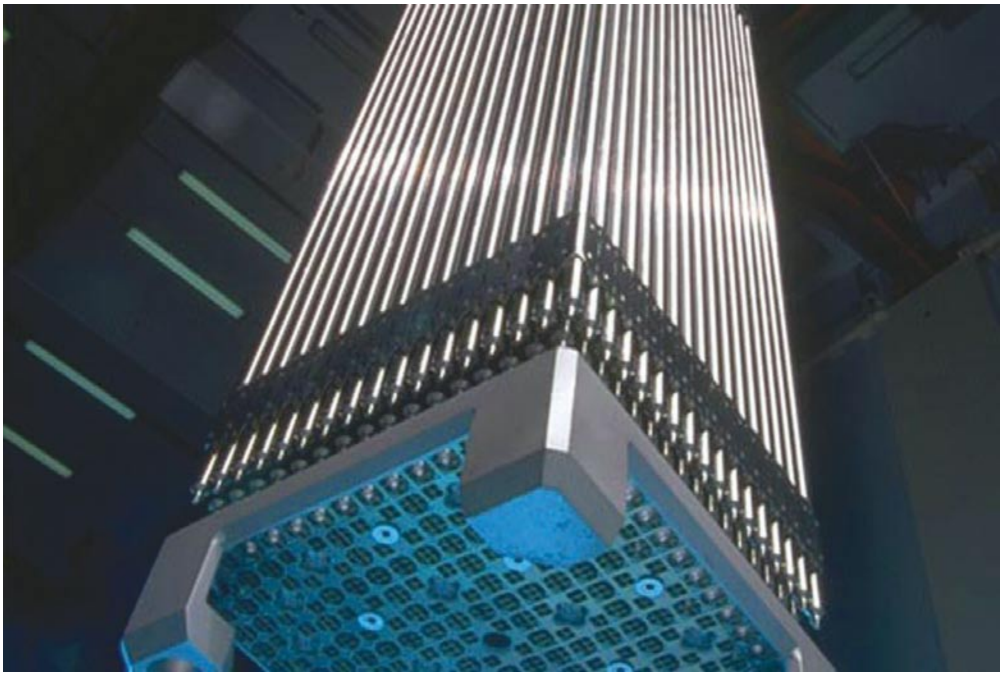
We Need to Reprocess Spent Nuclear Fuel,



P. Lesage/AREVA

And Can Do It Safely, At Reasonable Cost

by Clinton Bastin

A veteran nuclear reprocessing expert for the U.S. government recounts the little-known history of America's successful reprocessing program, and the unfortunate political decisions to thwart its progress.

Reprocessing is the chemical separation of energy-usable materials from used nuclear fuel. It permits full use of nuclear materials that would provide a virtually inexhaustible energy resource that does not add pollutants to the atmosphere. It is also needed to separate weapons-usable materials from nuclear wastes so that the weapons-usable materials can be transmuted to non-weapons materials for beneficial use, and the wastes disposed of without need for indefinite safeguards, which cannot be assured.

Nuclear power plants in the United States and most nations use less than 1 percent of the energy in nuclear materials. In the best possible reprocessing concept, essentially *all* of the products produced in nuclear reactors could be recovered and put to beneficial uses.

Above: Spent nuclear fuel can be reprocessed into new fuel like this mixture of uranium and plutonium oxides, called MOX, shown here at AREVA's MOX fabrication plant in France. One gram of MOX-recycled plutonium generates as much electricity as one ton of oil.

Decision-makers for every light water reactor built in the world to date had the full expectation that spent fuel would be reprocessed, the remaining energy values would be recycled for production of energy, and the weapons-usable plutonium would be destroyed in producing pollution-free electricity.

Reprocessing, integrated with mixed uranium-plutonium fuel fabrication in a well-designed, well-managed fuel recycle complex, would assure that weapons-usable materials would remain inaccessible until they were transmuted to non-weapons usable materials. Reprocessing and recycle are thus essential components of good nonproliferation practice.

I would like to explain how loss of reprocessing is largely the result of many years of mismanagement, misinformation, and misdirection by the Department of Energy and its predecessors, beginning in 1944. I would also like to set the record straight and make the case for restarting U.S. reprocessing on the successful model of the Savannah River Plant, which was operated for the U.S. government by DuPont, from 1950 to 1989.

Editor's Note: This highly informed description of the fiasco which befell nuclear fuel reprocessing in the United States, penned by one of the nation's leading experts in the field, should be known to every American and every person interested in the future of mankind. The reader should also be aware of a point, not addressed in this article, that more advanced scientific techniques, such as plasma isotope separation, based on new physical principles, will some day be applicable to both nuclear fuel enrichment and reprocessing. Although these more modern methods have not yet been brought to the development stage, that is only because of the continuing opposition to scientific innovation, which is part of the design for world population reduction and zero technological growth from powerful political and financial forces.

One of these methods, atomic vapor laser isotope separation (AVLIS), developed in the 1980s for uranium enrichment, was brought to fruition; a pilot facility was completed at Lawrence Livermore National Laboratory in 1997, which demonstrated industrial capability, using full-scale hardware over a several-month period. But under privatization, the program was shut down on the basis that the old enrichment technology would provide larger shareholder dividends in the immediate term. Another technology, the fusion plasma torch, conceived in the 1960s, despite great promise, has met a similar fate.

Savannah River vs. the Laboratory Model

The Savannah River Plant had a successful, safe, and efficient reprocessing history, on an industrial level, operated by the DuPont Company (Bebbington 1990). DuPont had also successfully managed reprocessing for the nuclear materials production programs of the Manhattan Project (Hewlett and Anderson 1972). Those experiences provide full assurances that reprocessing of used fuels from nuclear power plants in the United States, and those in other nations, could be done safely, successfully, cost-effectively, and without a credible threat of proliferation.

DuPont became involved in reprocessing in October 1942. Manhattan Project director, General Leslie Groves, recognized that the complexities of reprocessing needed to support a large nuclear program would be a difficult challenge even to the most experienced chemical engineering organization. He asked E.I. DuPont de Nemours and Company to design, build, and carry out experiments in a reprocessing pilot plant, and to design, build and operate production-scale reprocessing facilities.

Manhattan Project scientists were disappointed with the decision to use industrial corporations. They believed that they had earned the right to carry out their work to completion and were able to do so. But most of these scientists had no experience operating complex technology on an industrial scale.

Recognizing the importance of the Manhattan Project effort, DuPont accepted General Groves's request, but insisted that DuPont provide corporate management for the activity and engineering design for major projects, similar to those for its commercial activities. DuPont also requested that Manhattan Project scientists who had developed reprocessing processes participate in pilot plant experiments.

The reprocessing pilot plant built at Oak Ridge, Tennessee, was not configured for extended operation or maintenance; it was intended for only a few experiments to assure success in scaling up for production facilities. After a few experiments to confirm and improve process concepts developed by the scientists, DuPont left Oak Ridge to build and operate the Hanford Engineering Works in Washington, which included three large, canyon-type reprocessing plants.

The plant design was called a "canyon" because of the very large—60 feet high, 700- to 1,100-feet long—thick-walled, heavily reinforced concrete structure, in which remotely operated and maintained equipment was installed at the bottom to carry out the chemical processing. A large crane for rapid removal and replacement of failed equipment was at the top of the canyon, and there was room to move failed equipment out of the canyon space. From above the processing equipment, the structure looks like a canyon.

The canyons and processing equipment, piping, and instruments were configured for safe and high capacity operation; containment of radioactivity under all credible conditions, including fires and explosions; good material accountability; rapid, remote removal and replacement of failed equipment; and rapid move to full productivity after the start of operations.

The "T" canyon at Hanford was operated safely, successfully, and with minimal radiation exposure to workers to recover plutonium from irradiated natural uranium by a precipitation process (Hewlett and Anderson 1972).

The "U" canyon was used shortly after World War II to recover uranium not recovered earlier, using a solvent extraction process (Bastin A). The "B" canyon was used many years later to recover isotopes from nuclear waste.

After the war, in 1946, the General Electric Company assumed responsibility for operations at Hanford, but did not provide corporate management of the activity. Significant problems developed, particularly in the PUREX reprocessing plant. (PUREX stands for Plutonium and Uranium Recovery by Extraction.) Among the most severe problems was close coupling of process systems, which resulted in the plant taking a long time to reach full productivity after the start of operations.

There was also a lack of storage capacity for nuclear waste generated during startup, which resulted in the need to dispose of large amounts of nuclear waste to soils. This problem was most difficult during the initial attempt to start operations after completion of construction, in 1956, and resulted in a two-year delay in operations. In 1972, Hanford PUREX was shut down because it could not be operated without large releases of nuclear waste to soils, which was then a violation of AEC rules (Bastin E).

The Oak Ridge Pilot Plant. After DuPont left Oak Ridge, Manhattan Project scientists who had participated in experiments continued to operate the pilot plant and recovered 326.39 grams of plutonium (Jolley et al. 1994). However, the pilot plant managers believed they had recovered *several kilograms* of plutonium.

Completing the Nuclear Fuel Cycle

The concept of used nuclear fuel as "nuclear waste" is a fiction created by the opponents of nuclear energy. Used nuclear fuel isn't waste at all, but a renewable resource that can be reprocessed into new nuclear fuel and valuable isotopes.

When we entered the nuclear age, the great promise of nuclear energy was its renewability, making it an inexpensive and efficient way to produce electricity. It was assumed that the nations making use of nuclear energy would reprocess their spent fuel, completing the nuclear fuel cycle by recycling the nuclear fuel after it was burned in a reactor, to extract the 95 to 99 percent of unused uranium in it that can be turned into new fuel.

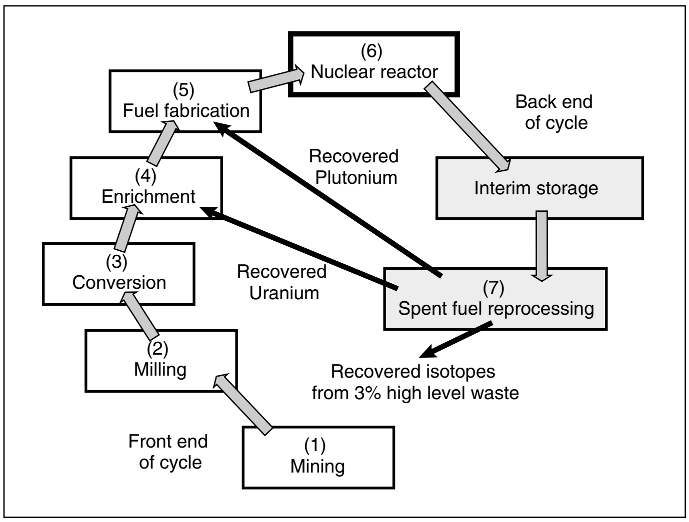
This means that if the United States buries its 70,000 metric tons of spent nuclear fuel, we would be wasting 66,000 metric tons of uranium-238, which could be used to make new fuel. In addition, we would be wasting about 1,200 metric tons of fissile uranium-235 and plutonium-239, which can also be burned as fuel. Because of the high energy density in the nucleus, this relatively small amount of U.S. spent fuel (it would fit in one small house) is equivalent in energy to about 20 percent of the U.S. oil reserves.

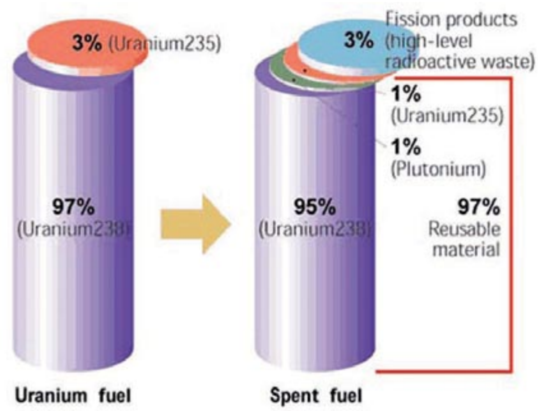
About 96 percent of the spent fuel the United States is now storing can be turned into new fuel. The 4 percent of the so-called waste that remains—2,500 metric tons—consists of highly radioactive materials, but these are also usable. There are about 80 tons each of cesium-137 and strontium-90 that could be separated out for use in medical applications, such as sterilization of medical supplies.

Using isotope separation techniques, and fast-neutron bombardment for transmutation (technologies that the United States pioneered but now refuses to develop), we could separate out all sorts of isotopes, like americium, which is used in smoke detectors, or isotopes used in medical testing and treatment. Right now, the United States must import 90 percent of its medical isotopes, used in 40,000 medical procedures daily.

The diagram shows a closed nuclear fuel cycle. At present, the United States has no reprocessing, and stores spent fuel in pools or dry storage at nuclear plants. Existing nuclear reactors use only about 1 percent of the total energy value in uranium resources; fast reactors with fuel recycle would use essentially 100 percent, burning up *all* of the uranium and actinides, the long-lived fission products.

In a properly managed and safeguarded system, the plutonium produced in fast reactors would remain in its spent fuel until needed for recycle. Thus, there need be no excess build-up of accessible plutonium. The plutonium could also be fabricated directly into new reactor fuel assemblies to be burned in nuclear plants.—*Marjorie Mazel Hecht*





Federation of Electric Power Companies of Japan

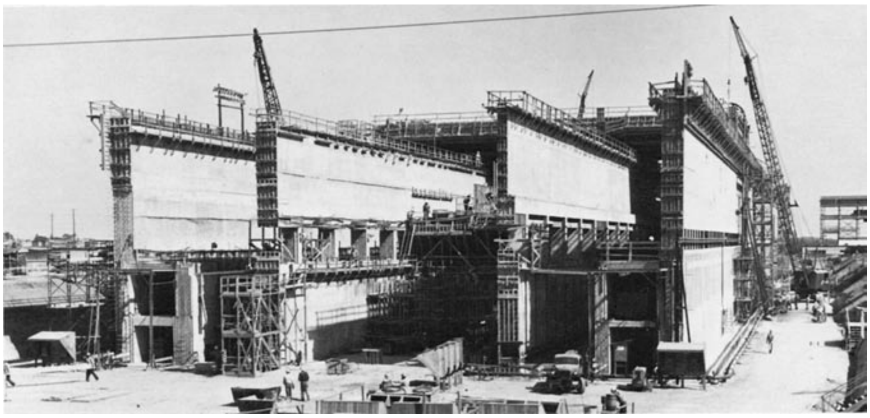
Ninety-seven percent of spent nuclear fuel is reusable!

Relying on the statements by Oak Ridge National Laboratory managers about their successful production campaign in the Oak Ridge pilot reprocessing plant, Atomic Energy Commission managers asked ORNL scientists and engineers to direct the design, construction, and start-up operation of the Idaho Chemical Processing Plant (ICPP), which was configured like the Oak Ridge pilot reprocessing plant. The ICPP was built to reprocess all highly enriched uranium irradiated in U.S. nuclear reactors, including those operated at the Savannah River Plant for production of tritium for the weapons program.

W.P. Bebbington, *History of DuPont at the Savannah River Plant*

Aerial photo of the Savannah River Plant, which operated from the early 1950s until 1989.

Problems at the Idaho Plant were apparent during early attempts at start-up, in 1952. Ventilation filters to prevent the release of radioactivity became plugged and were removed. Productivity for many years was only a few percent of rated capacity. The American Cyanamid Corporation had been selected to operate the Idaho Plant, but realized that the facility could not be operated safely or successfully, and left. Phillips Petroleum Company, which operated the Materials Test Reactor at the Idaho site, agreed to operate the Idaho Plant, but did not provide adequate corporate management (Jolley et al. 1994).



W.P. Bebbington, *History of DuPont at the Savannah River Plant*

A "canyon" reprocessing building in construction at the Savannah River Plant operated by DuPont. The key to the plant's success was the industrial production methods which focussed on safety and high capacity operation.

The Savannah River Success

In 1950, President Harry S. Truman emphasized DuPont's success in design, construction, and operation of the Hanford Engineer Works in a July 25 letter requesting that DuPont design, construct, and operate the Savannah River Plant (Bebbington 1990, Bastin C).

Again, operations by DuPont were highly successful. The Atomic Energy Commission reported that the company had achieved the best-ever safety for both construction and operation (USAEC 1975). Factors critical to successful operation in the Dupont reprocessing plants were the plant configuration, equipment and piping layout, type of equipment, remotability features, remote maintenance system, intersystem tankage, sampling systems, ventilation, containment, safeguards and accountability, and so on. It was demonstrated that significant differences in these non-process components could make as much as two orders of magnitude difference in operability or unit cost of operations—and could in some cases preclude operations.

The two reprocessing plants at Savannah River, "F" and "H" canyons, reached full-capacity operation within a few weeks after completion of construction, reprocessing irradiated natural uranium for production of plutonium for the weapons program. The plants used the PUREX system (see box, p. 14). Highly enriched uranium fuels irradiated in Savannah River reactors to produce tritium for weapons use were shipped to the Idaho plant for reprocessing.

But by 1957, the low productivity of the ICPP resulted in large accumulations of irradiated highly enriched uranium fuels from Savannah River reactors. To avoid a threat to tritium and nuclear weapons production, a decision was made to increase the capacity of the "F" reprocessing plant at the Savannah River Plant for reprocessing of natural and low enriched uranium fuels for production of plutonium, and to convert the "H" reprocessing plant to reprocess highly enriched uranium.

In October 1957, the Atomic Energy Commission issued its summary report, "AEC Reference Fuel-Processing Plant (WASH 743)," which it presented as a model for nuclear power plant fuel reprocessing. The model was based on the ORNL-built Idaho Plant, which the report indicated had operated *not at less than 3 percent,* but at 80 percent productivity—an overstatement by a factor of 30 (Bastin F)! The Atomic Energy Commission proposed to use the ORNL/ICPP technology for reprocessing U.S. nuclear power plant fuels, and also began to transfer the ORNL/ICPP reprocessing technology to many other nations, including India (Bastin I).

Earlier, the U.S. Atomic Energy Commission, as the first supply of "Atoms for Peace," had provided heavy water for use in reactors supplied by Canada. These reactors were similar to the one operated by Canada, under a mutual security agreement, to produce plutonium for U.S. nuclear weapons. Supply of the ORNL/ICPP reprocessing technology permitted recovery of the plutonium produced in these reactors. India used its plutonium from one of these reactors for a nuclear explosive test, in 1974, and later for nuclear weapons (Bastin I). Supply of the ORNL/ICPP reprocessing technology also undermined America's most important nonproliferation initiative, the policy for return of used fuel of U.S. origin or from reactors supplied by the United States (Bastin B).

The ICPP: A Failed Model

The use and export of ICPP reprocessing technology also led to the failure of commercial reprocessing in the United States, instead of the success it could have been, and to problems with reprocessing worldwide. The failure of nuclear and political leaders to recognize the difference between successful and failed reprocessing led to the myth that reprocessing was a proliferation threat and should be deferred. Its deferral precluded responsible disposal of nuclear wastes, an argument used to justify the long moratorium on new nuclear power plants in the United States.

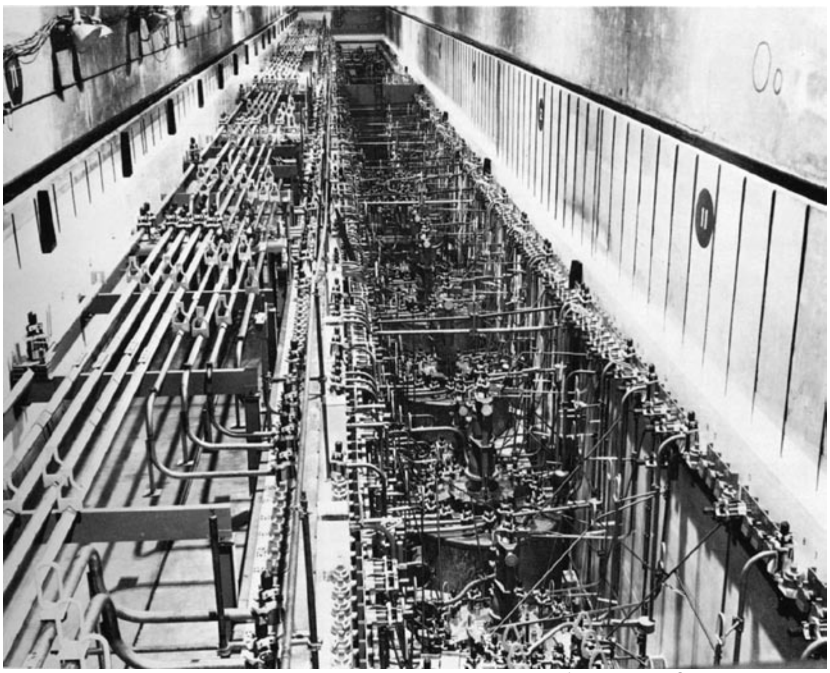
A good understanding of experience provides a basis for a better approach for reprocessing that will lead to more viable nuclear programs. Particularly important in reprocessing are:

- differences between laboratory-type reprocessing and that needed for nuclear power,
- the basis for decisions that led to successful and unsuccessful reprocessing, and
- the DuPont design for a "Spent LWR Fuel Recycle Com-

PUREX: How Reprocessing Works

Separation of uranium and plutonium from high-level waste and from each other in a nuclear fuel reprocessing plant is accomplished using mixer-settler chemical process equipment. Think of this operation as like a bottle of Italian dressing. The vinegar/water mixture on the bottom simulates the nitric acid/water solution of uranium, plutonium, and fission products in the feed to a mixer-settler. The salad oil on top simulates the tri-butyl-phosphate/kerosene mixture used to extract the uranium and plutonium.

Add the proper chemicals to the kerosene (oil) in the top of the bottle, shake thoroughly, and the plutonium and uranium are extracted into the kerosene, leaving the fission products (high-level waste) in the nitric acid/water at the bottom of the bottle. Pour off the kerosene containing the plutonium and uranium, add some different chemicals, then mix the kerosene with concentrated nitric acid. The plutonium is extracted into the nitric acid, leaving the uranium in the kerosene.



W.P. Bebbington, *History of DuPont at the Savannah River Plant*

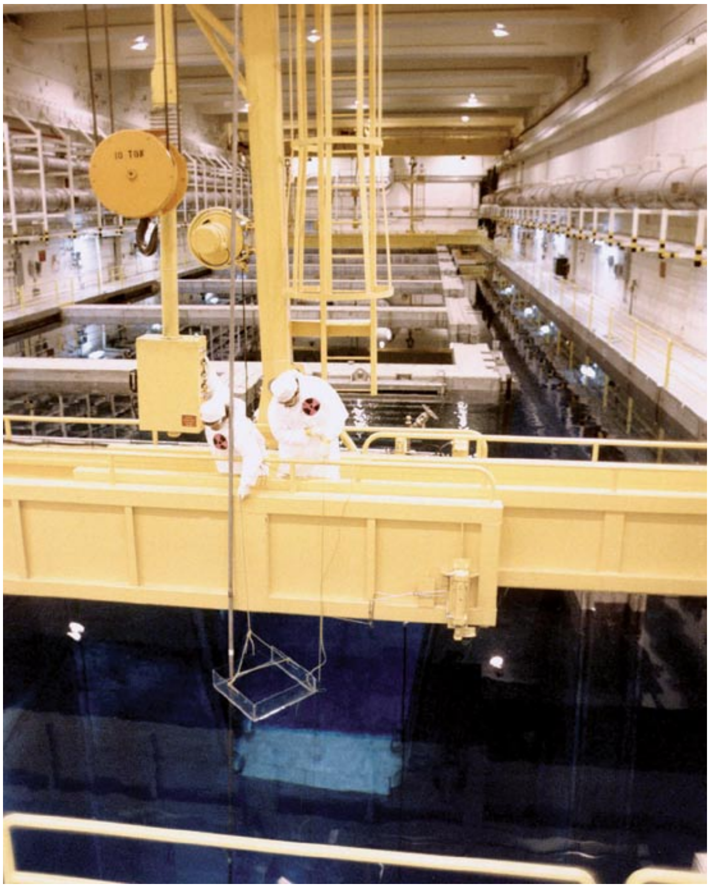
Looking down on a 60-foot high canyon cell, showing typical process vessels and connectors that separate uranium and plutonium from spent fuel.

Simple. Except not so simple in a radiation field where exposure for about 20 seconds would be a lethal dose of radiation. As the short-lived fission products in spent fuel decay over a period of time, the radiation is reduced, and after a few hundred years the process becomes almost as simple as described here.

plex" that would have avoided access to, and accumulations of, separated plutonium and resolved other problems and concerns (DuPont 1978).

The initial Atomic Energy Commission program for disposition of used nuclear power plant fuels was based on receipt, storage, and reprocessing at Savannah River Plant facilities, operated by DuPont (Bastin B). But some Atomic Energy Commission officials promoted the concept identified in the Atomic Energy Commission Reference Fuel Reprocessing Plant, cited above (USAEC 1957). The Industrial Reprocessing Group, composed of officials of early nuclear power plant vendors and operators, and Davison Chemical Company (a division of W.R. Grace and Company), with consultants from the Idaho plant, Oak Ridge National Laboratory, and Hanford (but *not* the Savannah River Plant), endorsed the ORNL/ICPP concept, and commercial reprocessing using this concept was initiated at West Valley, N.Y., in a facility destined for failure.

Problems at West Valley began immediately after start-up. Productivity of 30 percent was achieved, but process losses and radiation exposures to workers were more than a factor of 10 larger than those at the Savannah River Plant, and final products often failed to meet specifications. During the sixth and final year of operation, average radiation exposures to personnel were well above Federal standards and rising, and the release of radioactivity to surface streams exceeded technical specifications. In 1972, Atomic Energy Commission regulatory authorities ordered a halt of operations (Low 1972).



DOE

The Idaho Chemical Processing Plant was built on the model of the Oak Ridge National Laboratory pilot plant, and was plagued with failures and low productivity. Here, a view of the interior of the ICPP.

Operations at the Idaho Plant, meanwhile, continued at very low productivity, and by 1966, inventories of used highly enriched fuels at Idaho approached the total storage capacity. The Atomic Energy Commission carried out a review for reprocessing of these fuels, and some of the fuels were reassigned to the Savannah River Plant and delivered there (Bastin C). However, ICPP operators published a "Multiple Fuels Processing Program" report that showed an economic advantage for reprocessing of certain highly enriched uranium fuels at the ICPP, and the Atomic Energy Commission decided to continue operations there.

Subsequent annual Multiple Fuels Processing Program reports showed attractive economics for reprocessing at the Idaho Plant (USAEC 1968 and ff.). In 1967, the Allied Chemical Company accepted responsibility for operation of the ICPP. Allied Chemical managers reviewed the Multiple Fuels Processing Program reports which had indicated attractive economics for reprocessing, and, in partnership with General Atomics Corporation, as Allied General Nuclear Services (AGNS), decided to build the Barnwell Nuclear Fuel (reprocessing) Plant in South Carolina, at an estimated cost of $40 million (Bastin C).

More Failed Reprocessing Ideas

At the same time, the San Diego-based company General Atomics was attempting to commercialize its High Temperature Gas-cooled Reactors, which required reprocessing. General Atomics relied on the favorable fuel-cycle economics, based on reprocessing in a conceptual plant designed by the ICPP technical staff. Federal funding of $30 million was provided for modification of the Idaho Plant to permit demonstration of HTGR fuel reprocessing (Bastin C, D). (HTGR fuel consists of tiny particles of uranium, each encased in layers of graphite and special ceramics; these fuel particles are then formed into rods or tennis-ball size "pebbles.")

In 1974, Allied Chemical and General Atomics officials learned that:

• Statements of production in annual Multiple Fuels Processing Program reports, which indicated favorable economics for reprocessing at the Idaho Plant, were overstated by a factor of 5 (Bastin F).

• The costs of the conceptual HTGR fuel reprocessing plant were underestimated by a factor of 10.

• The cost for modification of the Idaho Plant to permit a demonstration of HTGR fuel reprocessing was underestimated by more than a factor of 10.

The Atomic Energy Commission then abandoned plans to demonstrate HTGR fuel reprocessing, and General Atomics abandoned plans to commercialize the HTGR (Bastin E). Officials of Allied General Nuclear Services, aware that the concept adopted for the Barnwell reprocessing plant was not valid, notified the Atomic Energy Commission that it would not operate the plant for commercial reprocessing and proposed that it be operated as a government demonstration.

During the same time period, General Electric built the Midwest Fuel Recovery Plant at Morris, Illinois. In an attempt to reduce size and capital cost, GE used much more complex processes for reprocessing than those used at Savannah River. Numerous equipment failures and problems were encountered in cold testing that made it impossible to operate the plant, and GE senior executives carried out a corporate review of the technical and operational capability of the plant, which identified many problems. Among the most significant was the following:

"It thus appears that the time required to stabilize the process and obtain useful output may well exceed the mean time between failure. If this should be the case, it would be difficult to be able to run long enough to obtain some output, and time operating efficiency (productivity) would be close to zero."

GE decided not to operate that plant (Reed 1974).

DOE

Despite the problems known with the Oak Ridge/Idaho Plant concept, the West Valley, N.Y. commercial reprocessing plant was built using this concept, instead of the successful method of the Savannah River Plant. It was a facility "destined for failure," Bastin says. Here, the fuel receiving and storage area at the West Valley plant in 1982.

Reprocessing in Other Nations

Nuclear program leaders in Britain, France, Germany, India, Japan, and the Soviet Union were aware of problems with the Oak Ridge/Idaho pilot plant reprocessing technology and the success of DuPont technology. In 1970, French reprocessors visited the United States with a promise of access to DuPont technology, but after their arrival, the Atomic Energy Commission denied them access (Bastin C).

The Soviet Union gained an understanding of DuPont technology through intelligence efforts, but in its own reprocessing plants, it did not provide adequate protection against accidents, contrary to the DuPont system (Bastin C).

Britain had access to DuPont technology through a classified cooperative agreement, but relied on a philosophy of "no maintenance"—again, contrary to the DuPont system—until there was a severe accident in an early British reprocessing facility in 1973 (Bastin C, E).

France attempted management of reprocessing by its Atomic Energy Commission and encountered serious problems. Its technology was based largely on the Oak Ridge/Idaho pilot plant reprocessing concept, with provision for rapid removal of certain more sensitive process equipment (Bastin 2007). Since the creation of a state corporation, COGEMA, France has improved reprocessing, and, in the absence of DuPont reprocessing technology, has dominated world reprocessing activities. However, the high cost and other features of the most recent French-built reprocessing plant, that of Japan at Rokkasho Mura, raise serious questions about the French technology.

After a thorough review of reprocessing successes and failures, and particularly of the failures and other problems with commercial reprocessing, the Atomic Energy Commission in 1974 reassigned responsibility for support of commercial fuel reprocessing to DuPont with its emphasis on safe, successful, cost-effective reprocessing. At a meeting at its New York offices in July 1974, the Edison Electric Institute Nuclear Fuel Cycle Committee expressed strong support for this reassignment.

The DuPont Facility That Was Never Built

DuPont carried out its own research and development and supported outside work focussed on conceptual design studies for a licensed fuel recycle complex. The design studies were completed in November 1978 and reports issued. Costs for the 3,000 tons/year integrated fuel reprocessing/fabrication facility were estimated at $3.7 billion. Special features of this facility included:

- no access to or accumulation of separated plutonium,

• total loss of plutonium to waste for fuel recycle would be about 5 percent of that lost in the U.S. commercial nuclear fuel recycle program,

• high-level nuclear wastes would be prepared for long-term isolation in a geologic repository and there would be no storage of liquid wastes in underground tanks,

• indefinite (hundreds of years) life of facility,

• flexibility for major changes, including processing other types of fuels,

• costs for reprocessing of about one-fourth of that of current reprocessing prices, and

• other features based on successful reprocessing experiences at the Savannah River Plant (DuPont 1978; Bastin E, G).

Many problems and concerns about reprocessing worldwide would have been resolved, if there had been a continuation of research and development by DuPont, the subsequent construction and operation of the DuPont facility, and a sharing of the technology with other nations which had large nuclear power programs and with the International Atomic Energy Agency (Bastin H).

But in January 1975, under the Ford Administration, programs of the Atomic Energy Commission were transferred to a newly created agency, the Energy Research and Development Administration. Nuclear program leaders in the new ERDA did not understand the complexities of reprocessing, set aside those who did, and transferred program responsibilities back to the Office of Nuclear Energy, successor to the Atomic Energy Commission Division of Reactor Development.

Presidents Gerald Ford and Jimmy Carter carried out major policy reviews of reprocessing *with no input from persons who understood the technology* and who knew what had happened that led to successes, failures, proliferation, and other problems. The indefinite deferral of efficient use of nuclear energy resources and responsible disposal of nuclear wastes resulting from these reviews were major factors contributing to the long mora-

The Reprocessing Facility

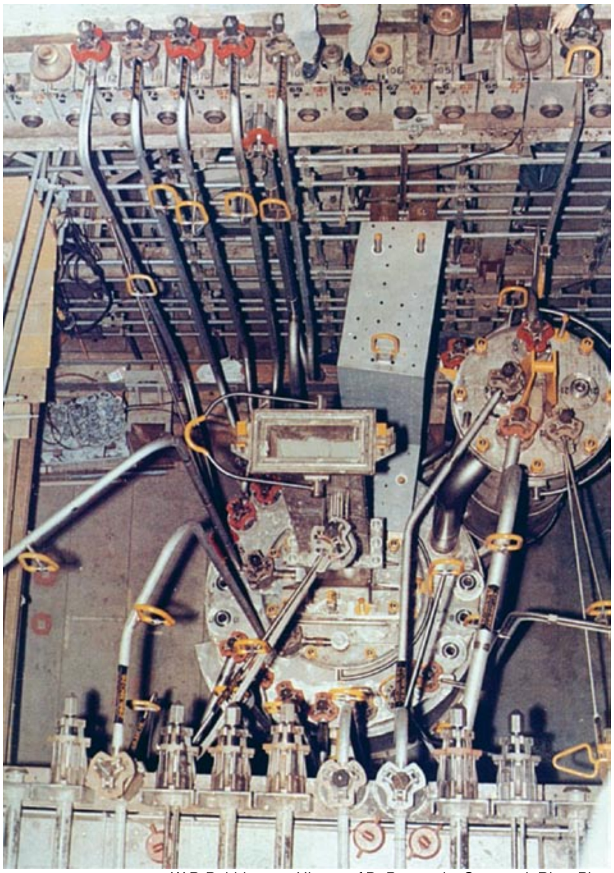
The chemical processes used in reprocessing are only one component of reprocessing “technology.” Also critical to successful operation are the plant configuration, equipment and piping layout, type of equipment, remote control features, remote maintenance system, intersystem tankage, sampling systems, ventilation, containment, safeguards and accountability, and so on.

Significant differences in these non-process components could make as much as two orders of magnitude difference in operability or unit cost of operations—and could in some cases preclude operations.

During the mid-1950s to mid-1970s, the Idaho Chemical Processing Plant and the reprocessing facilities at the Savannah River Plant used similar processes, but operability (and many other important parameters) were vastly different.

On-stream time during periods of product demand were more than 80 percent at Savannah River, and only about 2 to 3 percent at the Idaho Plant. Failure of a major piece of equipment resulted in one day of lost operating time at Savannah River, and up to one to two *years* at the Idaho Plant. Return to equilibrium (that is, productive operation) after shutdown for maintenance, accountability, or other reasons at Savannah River would take a few minutes; it would take about 30 days at the Idaho Plant and about 8 days at the Hanford PUREX facility.

The DuPont plant was designed with more safety protections for plant workers. For example, equipment maintenance at the Idaho Plant resulted in large radiation exposure to personnel, because personnel were required to enter process cells for direct maintenance of equipment. Average radiation exposures to operating and maintenance personnel at the Idaho Plant were about a factor of 3 higher than at Savannah River and Hanford on an overall basis, and a factor of some 50 to 100 times higher on a unit of production basis.



W.P. Bebbington, *History of DuPont at the Savannah River Plant*

Looking down on a 60-foot high canyon cell, showing typical process vessels and connectors that separate uranium and plutonium from spent fuel.

torium on new nuclear power plants in the United States. Under President Carter, ERDA was dissolved and the Department of Energy was organized to take its place in 1977.

Nuclear program leaders in the DOE set aside information from DuPont about reprocessing that would have resolved problems, and instead they supported use and development of laboratory concepts that had no potential for success. No information about the success-based concepts was provided to Presidents Carter or Reagan.

President Reagan was elected in 1980 on a platform of support for reprocessing, but was unwilling to support operation of the Barnwell Plant.

The DOE funded the development of an Oak Ridge National Laboratory concept for reprocessing with the PUREX process, but incorporating a very complex, in-place maintenance system, until a cost estimate based on detailed design indicated an exceptionally high cost. The ORNL program continued as a collaborative development with Japan, and the complex maintenance system was incorporated in the very expensive Japanese reprocessing plant at Rokkasho Mura.

In 1990, the Oak Ridge program was phased out, in order to fund development of an Argonne National Laboratory pyroprocessing concept for separating uranium, plutonium, and other heavy elements from highly radioactive waste in fast reactor fuel. The pyrometallurgical process is claimed to be proliferation-resistant. An evaluation by DOE staff knowledgeable about reprocessing revealed that the concept was neither proliferation-resistant nor appropriate for reprocessing (see box, p. 19). There was no disagreement with this evaluation by Department of Energy or Argonne National Laboratory officials, but support for the concept continues.

Advanced Reprocessing Technologies

The DOE now proposes funding for so-called "advanced reprocessing technologies" as part of its Global Nuclear Energy Partnership (GNEP) initiative, but the processes proposed — UREX+ and pyroprocessing—are neither advanced nor appropriate for reprocessing of used nuclear fuels.

Decisions of Manhattan Project Director Gen. Leslie Groves in 1942, and President Truman in 1950, that resulted in successful reprocessing in the past provide a model today for successful reprocessing of nuclear power plant fuels. Similar decisions of Atomic Energy Commission leaders in 1959 and 1974 would have led to success and avoided many problems. Note also that

The Cost of Reprocessing

The costs for reprocessing in the DuPont-designed LWR Fuel Recycle Complex would have been about $250 per kilogram of uranium. This compares to about $1,000 per kilogram charged by the British and French for reprocessing, and $5,000 to $15,000 per kilogram for reprocessing in the French-built facility at Rokkasho Mura in Japan.

The major reason for the differences in cost is that there is much higher productivity with the DuPont design because of its shorter time for replacement or repair of failed process equipment, piping, and instruments, and the shorter time to full productivity afeter the start-up of operations.

The much higher cost of reprocessing at the Rokkasho plant is the result of a much more complex—and expensive—laboratory-type, in-place remote maintenance system. In-place maintenance results in greater loss of operating time, compared with the much more simple, rapid, remote equipment replacement system of DuPont, followed by hands-on repair at leisure.

Atomic Energy Commission of Japan

The now-operating Rokkasho Reprocessing Plant in Japan, when it was under construction. Its operating costs are higher, Bastin says, because it did not incorporate the successful concepts of Savannah River.

The Cost of Not Reprocessing

Of course, the greatest difference in cost is that between reprocessing and not reprocessing.

Without reprocessing, highly radioactive wastes in used fuel cannot be permanently disposed of without indefinite assurance of safeguards for weapons-usable materials in the used fuel—which is impossible. The moratorium on new nuclear power plant orders in the United States began in the same year—1974—that commercial reprocessing stopped.

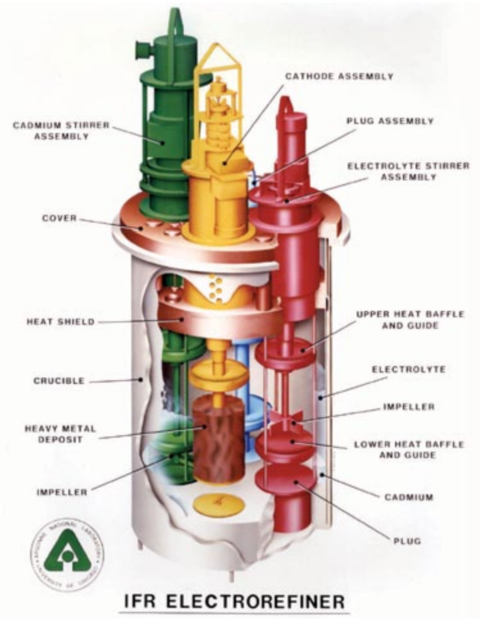
This moratorium is the greatest reason for America's energy crisis and resulting economic challenges, including the huge budget deficits in California.

Pyroprocessing and the Integral Fast Reactor: A Case Study of So-called Proliferation-Resistant Fuel

by Clinton Bastin

In 1991, I was assigned by DOE's Office of Nuclear Energy to develop criteria for evaluation of a planned demonstration of DOE's Integral Fast Reactor (IFR) "proliferation-resistant," "pyroprocess-based" fuel cycle. I visited DOE sites in Chicago and Idaho to inspect process equipment and details of planned demonstration operation, and learned that DOE plans were for a demonstration of a *process,* not technology, and that questions of operability, maintainability, safeguardability, and containment of radioactivity—major problems with commercial reprocessing—would not have been resolved.

Of greatest concern were great difficulties for material balance measurements and high plutonium losses. These findings led to a conclusion that the safeguards challenge would be difficult and the process as planned would not be proliferation-resistant nor viable for commercial nuclear fuel recycle.



DOE

Artist's drawing (1989) of an electrorefiner for the Integral Fast Reactor, which would recycle the reactor's spent fuel, returning the high level wastes to the reactor to be burned as new fuel. Bastin's evaluation was that the prcess was not commercially viable.

Concerns about the planned demonstration were reviewed with DOE and DOE laboratory management and technical staff without significant disagreement, and are summarized here:

(1) Processes to be used were similar to those used for plutonium *metal* processing in the Atomic Energy Commission weapon programs. Much greater difficulty was experienced in plutonium metal processing than in properly designed aqueous reprocessing. Large accumulations of scrap were normal at all plutonium metal plants, except for those at the Savannah River Plant where scrap was immediately redissolved and returned to reprocessing.

In earlier, similar fuel cycle experiments, large amounts of scrap were shipped to the Idaho Chemical Processing Plant for recovery.

(2) Equipment proposed for the DOE fuel cycle was much more complex than that used in aqueous reprocessing (the PUREX system) and would have been very difficult to maintain for reasonable on-stream time. In-situ manipulator-type maintenance would be needed. The rapid, remote equipment-replacement system used in successful reprocessing would not be appropriate.

(3) Material measurement in the electrorefiner was extremely difficult under cold, development conditions and was performed only about every year or two in the development facility. Measurement of fully irradiated fuel in a remote environment would be far more difficult; thus, material accountability and safeguards would be virtually impossible.

(4) High process losses (10-20 percent) were experienced, particularly in the fuel fabrication step, and high process losses would have been likely in electrorefining. This, combined with measurement difficulties, makes significant diversion detection impossible.

(5) Operations in a remote environment are about three times as difficult as operations in glove boxes; operations in an inert environment are similarly more difficult. The combination contemplated for the IFR fuel cycle might be ten times as difficult as those in glove boxes, or about three times as difficult as those in aqueous reprocessing, without consideration of the more complex equipment planned for the IFR process. High temperatures would further increase difficulties.

(6) The IFR process requires use of exotic materials that are not available in forms/shapes needed. Research for materials was under way, but there was no experience base for use of these materials.

(7) Inter-process transfer of nuclear materials requires physical movement of containers of nuclear material as opposed to transfer through piping in reprocessing plants that have operated successfully. The containers are not fully sealed. Thus, there is significant potential for release of contamination into the cell atmosphere.

(8) Fissile plutonium is in weapons-usable form and in concentrations usable for a significant nuclear explosive. Some reviewers argued that in-process materials may not be directly usable for weapons suitable for military stockpiles, but clever operators of electrorefining equipment might be able to produce fairly pure plutonium metal directly usable for military type nuclear explosives.

(9) The requirement for inter-process transfer by physical movement by manipulators of containers of nuclear material instead of through pipes would limit applicability of the IFR fuel cycle process to research, or production of small amounts of plutonium.

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DuPont's exceptional core values of safety, health and the environment, ethics, and respect for people were major factors in the success of reprocessing and other programs for the Manhattan Project and Atomic Energy Commission.

America needs real advanced reprocessing technologies, and a competent chemical engineering organization to manage reprocessing. I propose a "U.S. Energy and Nuclear Technology Board," or a similar organization, that will:

• implement and support policies and programs on the basis of need, determined through careful, competent assessment based on lessons learned from experiences,

• provide full and accurate information to Americans about energy and nuclear technology,

• carry out collaborative research and development with other nations for use of the best systems and technology for beneficial, efficient, and safe use of nuclear technology.

The President, leaders of Congress, and leaders of nuclear power programs should ask DuPont and others with extensive experience in successful reprocessing and other uses of nuclear technology to help create organizations to resolve long-neglected energy and nuclear technology challenges. Recent French experience in certain reprocessing techniques will be important for U.S. programs, but the French facility design should be examined carefully by those with experience in the best reprocessing technology. This nation has demonstrated successful reprocessing of spent nuclear fuels in the past, and if we are to move forward as an industrial nation, we need to do it again!

Chemical engineer Clinton Bastin, now retired, was responsible for the Atomic Energy Commission's reprocessing plutonium, and plutonium scrap operations, plutonium-238 production, transuranic materials processing, tritium and deuterium production for weapons programs, radioactive waste management, and related activities at the Department of Energy's Savannah River Plant. He was also involved in the diplomatic side of U.S. international nuclear efforts, and he was president of the Federal Employees Union at the Department of Energy headquarters.

Upon his retirement, Bastin was recognized by the DOE in a Distinguished Career Service Award as "the U.S. authority on reprocessing and initiator of total quality management and partnering agreements." Bastin served as a U.S. Marine in World War II and was an instructor in chemistry for the Marine Corps Institute.

He has many published papers on the topics in this article.

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Clinton Bastin personal experiences:

(A) Participant in summer seminar for chemical engineering professors at Hanford on fuel reprocessing, including studies for disposal of nuclear wastes in soils at Hanford, June-August, 1958.

(B) Atomic Energy Commission technical leader for the initial, success-based program for disposition of used fuel from nuclear power plants in the United States and other nations, 1959-1962.

(C) Atomic Energy Commission technical leader at the Savannah River Plant and AEC/ERDA headquarters for reprocessing, plutonium processing, and studies for disposal of nuclear wastes, 1962-1976.

(D) Participant in monthly design reviews for reprocessing projects, DuPont corporate offices, Wilmington, Del., 1964-1972.

(E) Technical leader and task force chair at AEC headquarters for resolution of problems in AEC and commercial reprocessing facilities, and reduction of reprocessing-related proliferation threats, 1972-1974. Effort led to recommendations that reprocessing program direction and management be reassigned to those who had directed and managed successful reprocessing programs and understood reprocessing technology

(F) Compared Atomic Energy Commission accountability records with production data in 1968 through 1972 annual reports of Idaho Chemical Processing Plant Multiple Fuels Processing Program; learned that production was overstated in these reports by a factor of 5; and notified Atomic Energy Commission and Allied Chemical Company authorities of the discovery, 1973.

(G) Technical leader in Energy Research and Development Administration for nuclear power fuel reprocessing and recycle, until ERDA leaders reassigned reprocessing program direction and management to those who had directed, managed, and proposed failed reprocessing, and did not understand reprocessing technology, 1975-1976.

(H) Lead technical consultant to the International Atomic Energy Agency for its study of "Regional Fuel Cycle Centers," which had been proposed by the United States to reduce proliferation threats from reprocessing.

(I) Technical leader for major non-proliferation initiative with the Government of India.

(J) Instructor for "Worldwide Reprocessing Experiences and Plans" for CIA and NSA, 1968-1996.

(K) Technical leader for U.S. nonproliferation initiatives and proliferation threat assessments, 1970-1983.

(L) U.S. coordinator for reprocessing development and technology exchange with other nations, 1962-1993.

(M) Determined that an Argonne National Laboratory pyroprocessing process which was claimed to be proliferation-resistant was neither proliferation-resistant nor appropriate for reprocessing, and advised DOE and ANL officials of that determination, 1991 (see box).

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