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Spent nuclear fuel casks in dry storage at the Idaho National Laboratory.

Spent Nuclear Fuel Is An Abundant Source of Energy

by Dale E. Klein, Ph.D.

The world today is moving to the "closed fuel cycle" by recycling spent nuclear fuel. France, Japan, the United Kingdom, Russia, India, and China reprocess spent fuel. There are two reasons. First, reprocessing recovers significant energy value from spent fuel that contributes to energy security. Second, reprocessing substantially reduces the volume and radiotoxicity of high-level nuclear waste.

These distinct advantages are currently driving international research efforts and likely will influence national decisions on the establishment of domestic and regional nuclear waste repositories.

U.S. leadership in this area has been lost, and the underlying

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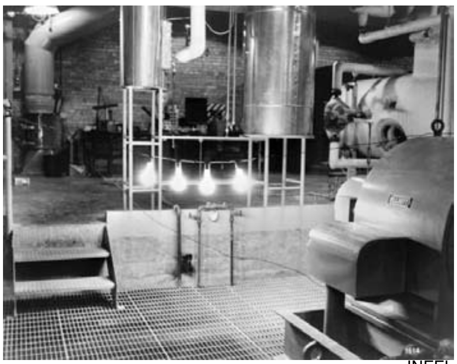
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The Experimental Breeder Reactor No. 1 located at the National Reactor Testing Station near Arco, Idaho, produces the first electric power from a nuclear reactor, December 1951.


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President Lyndon Johnson, with nuclear scientist Glenn Seaborg, at the 1966 ceremony making the EBR1 a National Historic Monument. Johnson is holding one of the original four light bulbs.


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Visitors at the EBR1 today.

technological capability and intellectual capital needed to compete internationally have diminished to near irrelevance.

Establishing domestic infrastructure to recycle nuclear fuel will require a public-private partnership that operates outside normal appropriations and has a charter to manage the fuel over a period of decades.

Table 1
FUEL NEEDED FOR A 1,000-MW ELECTRICAL POWER PLANT

Fuel	Quantity (Metric tonnes)	Volume
Coal	2.6×10^6	2,000 train cars
Oil	2.0×10^6	10 supertankers
Uranium	30	1 reactor core

Table 2
WORLD COMMERCIAL SPENT FUEL REPROCESSING CAPACITY

Reactor Fuel Type	Facility	Processing Capacity
	France - La Hague	1,700
LWR	U.K. Sellafield (THORP)	900
	U.K. Sellafield (Magnox)	1,500
	Japan - (Rokkasho)	800*
	Russia - Ozersk (Mayak)	400
PHWR	India (4 plants)	330
	Total all fuel types	5,630

* Japan's facility is expected to start operations in 2012

Energy from Spent Fuel: 60 Years Ago

Later this year, the United States will celebrate the 60th anniversary of a major accomplishment in the history of science and technology: the production of electricity using nuclear power. On Dec. 20, 1951, in a remote part of eastern Idaho, scientists and engineers from Argonne National Laboratory started a small electrical power generator attached to an experimental reactor that created enough energy to power four 200-watt electrical bulbs.

The next day, they were able to increase the power to illuminate the whole building. It was one of the great demonstrations of the peaceful use of nuclear energy, and it gave birth to today's global commercial nuclear power industry. But what is often lost in the history of this event, is the simple fact that the first nuclear-powered electricity was produced using reprocessed plutonium.

What Is in Spent Fuel?

The news media often refer to spent nuclear fuel, which includes a small amount of plutonium, as "waste." It is not waste. Rather, our failure to reprocess, or recycle (the two terms are used interchangeably) spent fuel is a waste of an extremely valuable resource.

How much uranium comes out of a nuclear reactor? Let's start with a typical fuel reactor fuel that has been enriched to contain 4 percent U-235, and the rest 96 percent U-238. While in the reactor, the U-235 is consumed and plutonium is both created and consumed. In the end, the typical used fuel bundle will have about 5 percent mixed fission products and a mixture of about 93 percent U-238, and 1 percent each of U-235 and mixed plutonium isotopes. Basically, this means that 95 percent of the uranium and plutonium, and therefore 95 percent of the potential energy value of the used fuel remains.

Ninety-five percent is an astonishing figure when you consider that the current practice in the United States is to use the fuel once and then store it at the reactor for eventual disposal in a geologic repository. Idaho Rep. Mike Simpson captures the illogic of failing to recycle spent fuel. He says it is like mining gold and throwing nine pounds out of every ten back in the ground.

The energy density of uranium is remarkable when compared to other fuel types. Table 1 gives a few comparisons among fuel types for a 1,000-megawatt-electric power plant.

The once-through nuclear fuel cycle, which is our practice in the United States, is an enormous waste of potential energy. The math is straightforward, and certainly this is the reason why so many advanced nuclear countries are developing the technology and infrastructure to capture that energy.

Proliferation Concerns

To get to the energy value contained in that used fuel requires reprocessing. President Jimmy Carter stopped spent fuel reprocessing during his administration on the grounds that it would lead to the risk of proliferation of weapons-grade plutonium. However, other nuclear nations did not follow his path.

Now, more than three decades later, six nations have major commitments to reprocessing their spent fuel. The arguments against reprocessing as a proliferation concern are not compelling and obviously, other nations interested in extracting the energy value from their spent fuel do not align with U.S. policy.

A typical commercial nuclear power reactor will generate about 20 tonnes of spent fuel every year. Contained in that spent fuel is about 200 kilograms of reactor-grade plutonium. Often misunderstood, or misrepresented by opponents to recycling, the isotopic mixture of reactor-grade plutonium makes it unsuitable for nuclear weapons.

Weapons-grade plutonium is approximately 95 percent Pu-239, whereas reactor-grade is only about 50 percent Pu-239. The cost and complexity of the technologies required to purify reactor grade to weapons grade makes it impractical for use in nuclear weapons.

In fact, we know of, or strongly believe, that nine nations have developed nuclear weapons. Looking historically at the origins of the fissile materials used to develop those weapons, we know that the sources were either through enrichment of uranium or with the use of graphite or heavy-water-

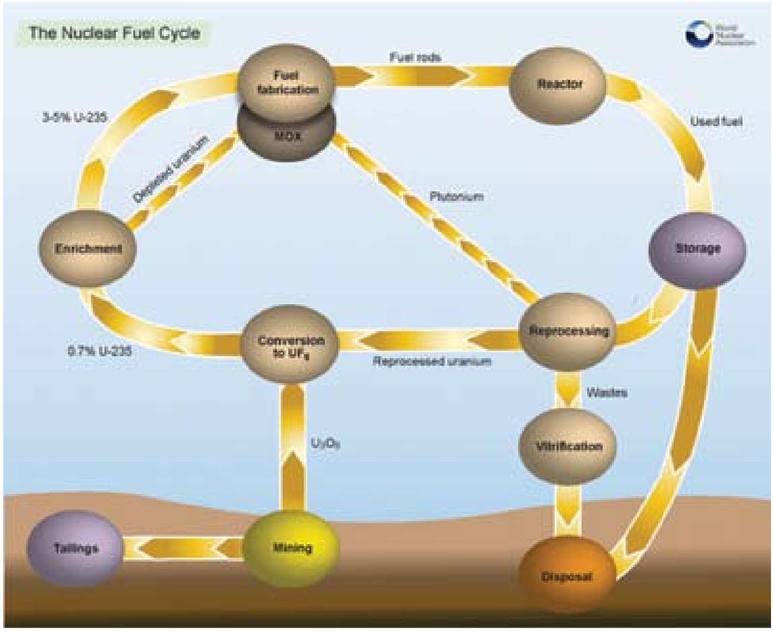


Figure 1
CLOSED NUCLEAR FUEL CYCLE

moderated production reactors, but not commercial reactors.

Israel, India, Pakistan, and North Korea are believed to have produced weapons-grade plutonium from the diversion of their heavy water research reactors to irradiate target materials. No nation has ever tried to produce nuclear weapons from the type of spent fuel discharged by commercial power reactors.

Global Reprocessing Capacity

In total, the current global capacity for reprocessing spent nuclear fuel is about 5,600 metric tonnes (Table 2), or almost three times the current annual production of spent fuel from U.S. reactors. That fact alone demonstrates the failure of the Carter policy.

In the next two decades, the World Nuclear Association estimates that 400,000 tonnes of used fuel will be generated by operating commercial reactors worldwide. This number could change, based on the number of new reactors built, and some decommissioned, but one fact is known: The inventory will increase over time, as more nations look to nuclear power to meet their energy demands and obligations to reduce greenhouse gases. With 95 percent of the total energy still remaining in spent fuel, energy-starved nations are already beginning to look at this as an asset, not a "waste."

Converting Waste to Energy

There are two basic paths to converting spent fuel to energy. The first, and most common is to use reprocessed material to make fuels for existing light- or heavy-water reactors. The second, and more efficient method, is to use fast reactors, as we did 60 years ago, to produce the first electricity from a nuclear reactor.

Mixed Oxide Fuel. The simplest way to obtain energy value from spent fuel is to extract the reactor-grade plutonium through reprocessing, re-blend it with uranium, and use it in fabricating fresh fuel assemblies. Otherwise known as a mixed oxide fuel or MOX, a typical MOX fuel is composed of about 93 percent U-238, and 7 percent reactor-grade plutonium.

MOX fuels assemblies are used to replace typical enriched uranium fuel in light water reactors. Currently, about 30 reactors in Europe (Belgium, France, Germany, and Switzerland) are using MOX, and Japan expects to use MOX in about 20 of its reactors. No U.S. nuclear plants use MOX fuel, although there is some growing interest in doing so, particularly as the price of uranium increases.

Advanced Fast Reactors. According to the IAEA, there are five operating fast reactors and three under construction, for a total of about 2 gigawatts-electric when fully operational. The distinct advantage of fast reactors over today's light water reac-

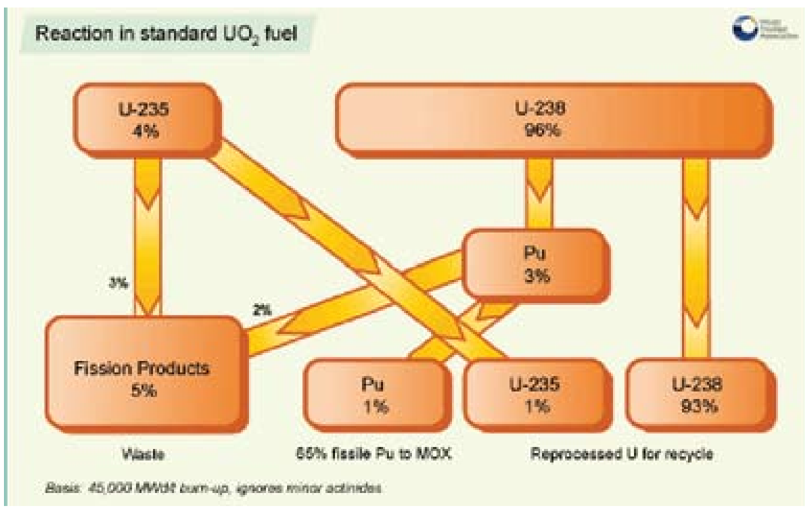


Figure 2
NUCLEAR REACTION IN URANIUM OXIDE FUEL

tors is that they can convert both plutonium and uranium to energy.

In a fast reactor, plutonium can be produced and fissioned to produce more energy and make new fuel at the same time. Fast reactors are often designed to be "breeder" reactors, and can convert U-238 to additional fuel. Fast reactors can also be "burner" reactors, and can utilize as fuel, or transmute, many of the long-lived actinides that cannot be fissioned in a commercial light water reactor. This gives the fast reactor the advantage of being capable of destroying the major source of long-lived radiotoxicity in spent fuel, while also making new fuel and producing energy.

A cutaway model of Russia's BN-600 fast reactor.

The existing U.S. inventory of used fuel from commercial reactors (more than 60,000 tonnes), if reprocessed for use in fast reactors, would be more than sufficient to supply the nation's energy needs for several hundred years.

Russia's BN-800 fast reactor in construction.

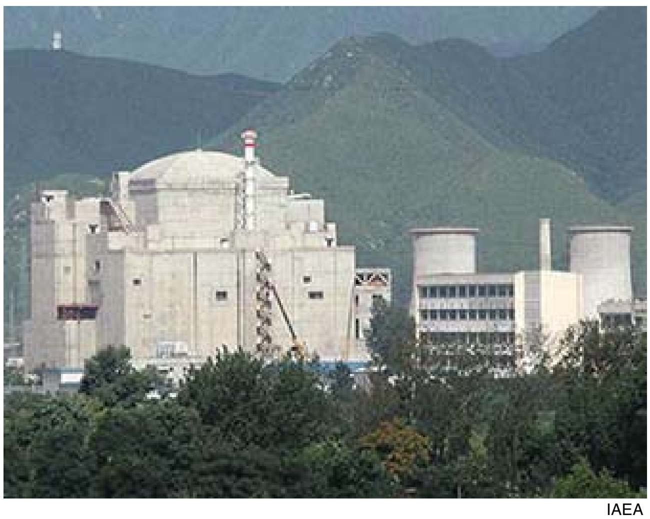
It is very clear that several nations are rapidly moving forward to develop commercial fast reactors. For example, Russia has been working on fast reactors for several decades. The Russian concept of plutonium management (both civil and weapons) is based on the principle of a closed fuel cycle to enhance fuel efficiency, and decrease the radioactivity of disposed long-lived wastes. Their BN-600 reactor had its first criticality in 1986 using MOX fuel and they are in the process of finishing their BN-800 reactor, which will be fueled using excess weapons-grade plutonium.

India, too, is in the process of finalizing construction of its 500-MWe prototype fast reactor, which it has stated it expects to have deployed extensively by mid-century. France, China, Japan, and Korea are all actively engaged in developing fast reactor designs.

Barriers to Reprocessing

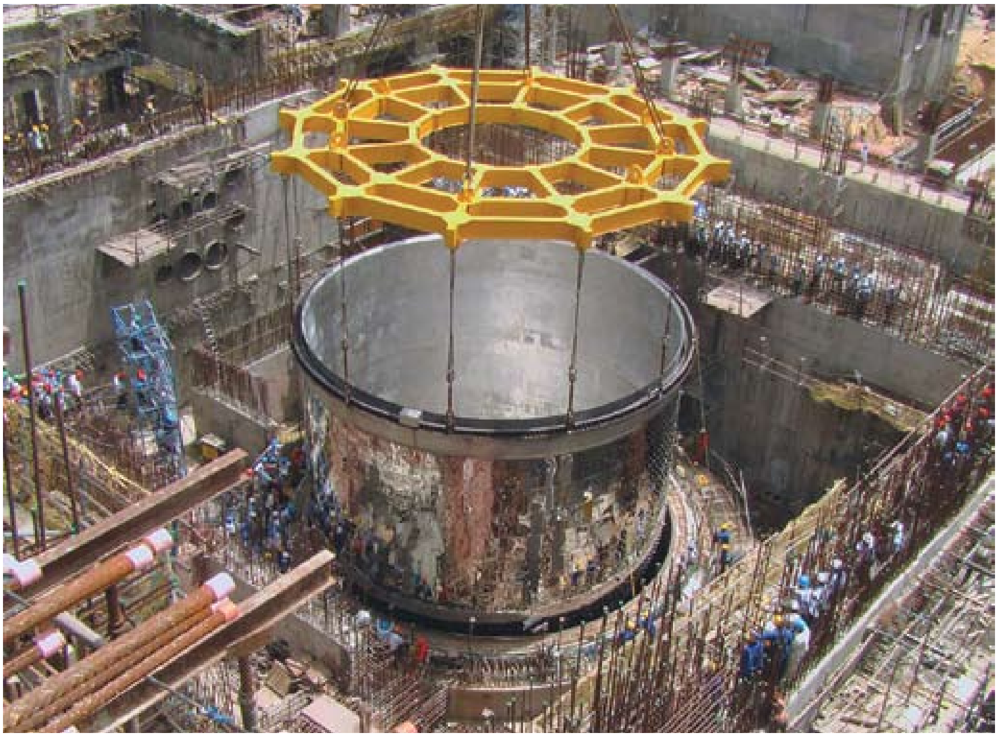
There is no broad agreement that re-starting spent fuel reprocessing in the United States is the right way to go. The nuclear industry itself has been ambivalent, and the low cost of uranium fuel has not warranted the investment in the infrastructure need to reprocess.

Recent efforts by the Department of Energy (DOE) to revive interest in reprocessing were perhaps overly ambitious, given that the United States has only recently re-started building



IAEA

China's experimental fast breeder reactor.


Government of India

The huge main vessel of India's indigenously designed 500-MW fast reactor, being lowered into place at the Kalpakham nuclear site.

new nuclear power plants after a 20-year hiatus. The DOE's Global Nuclear Energy Partnership (GNEP) proposed to build a three-part system composed of spent fuel recycling, advanced fuel fabrication, and fast reactors. While technically feasible, the challenge for GNEP was funding and, perhaps more important, it failed to make the case for an integrated spent fuel policy. Unlike other advanced nuclear nations, the United States has never linked or required reprocessing as a means of managing spent fuel and treating it prior to disposal.

There were also objections from sources that had significant influence in Washington. In 2007, the National Academy of Sciences reported to Congress, relative to the GNEP program, that, in its view, R&D for spent fuel reprocessing should be stopped altogether. Instead, the academy said, R&D funding should be redirected to develop new reactor designs in a Department of Energy program called "Generation IV."

In 2010, the Massachusetts Institute of Technology updated its interdisciplinary study of the future of nuclear energy. It found that uranium supplies will not limit the expansion of nuclear power in the United States or around the world for the foreseeable future. The new study suggests an alternative to fast reactors. The authors of the study cited their preference for this approach because it also addresses their concerns about proliferation of nuclear materials.

While I respect the findings in the reports from these groups, I think circumstances are changing that will lead to new interest in reprocessing.

The Value of MOX and Reliable Fuel Services

Nations with commitments to nuclear energy recognize the value in recovering the energy value in commercial spent fuel. In fact, some nations may even compete for it in the future.

For instance, both Turkey and South Africa have told reactor vendors bidding on new projects that they want to see a portion of the revenue stream come from the recycled fuel. These demands in planned contracts for new reactor projects clearly illustrate the case for reprocessing spent fuel, which are energy value and energy security.

In effect, these countries will lease the fuel from suppliers. They will receive some relief on price because the supplier will recover uranium and plutonium from the spent fuel to make MOX fuel and sell it to other customers.

Countries building new reactors will want guarantees of reliable fuel supplies, without having to make their own. This approach lifts the financial and environmental burdens of building local uranium enrichment and fuel reprocessing plants. The United Arab Emirates adopted this model in its award in December 2009 of a $20 billion contract to South Korea for four new 1,400-megawatt reactors.

We are beginning to address the recycling issue here. The


Areva

The MOX fuel facility under construction in at the Savannah River Site (SRS) near Aiken, South Carolina. The plant design is based on AREVA's MOX facilities in France. The French have used MOX technology for almost two decades and currently supply MOX fuel to over 30 reactors worldwide.

The U.S. facility will be able to turn 3.5 metric tons of weapon-grade plutonium into MOX fuel assemblies annually.

DOE

Brent Scowcroft, co-chair of the Blue Ribbon Commission on American's Nuclear Future, at a full commission meeting in Augusta, Georgia, in January 2011.

United States is building a $4.5 billion MOX fuel plant in South Carolina, which will convert 34 tons of weapons-grade plutonium into MOX fuel and is expected to be operational by 2016. While no U.S. utilities are currently using MOX fuel, it is expected that when this new plant becomes operational, there will be a growing interest in using MOX to supplement fuel supplies.

Blue Ribbon Commission to Address Reprocessing?

The likelihood that the United States will build a commercial reprocessing plant in the next decade depends on many political factors. But perhaps one of the most important factor will be the recommendations of the Blue Ribbon Commission on America's Nuclear Future. Chartered by the Department of Energy, the Commission was created to fill the policy vacuum created when the Administration, for political reasons, abandoned the Yucca Mountain project and the mandates of the Nuclear Waste Policy Act.

The 15-member Commission is chaired by former Congressman Lee Hamilton of Indiana and former national security advisor Brent Scowcroft. Its goal is to make recommendations for the safe, long-term management of spent fuel. Its draft report is due this Summer, with a final report to be completed in January 2012.

Many in the industry have hopes that the Commission will chart a reasoned path for spent fuel management which will include reprocessing. Equally important, there are high hopes that the Commission will recommend that the United States develop a public-private partnership, a quasi-governmental agency formed with industry, to take over management of spent fuel from the DOE and de-politicize the process.

The Case for Institution Building

What is needed is a long-term political commitment and the institution building to carry it out. Last Summer, then-Senator George Voinovitch (R-Ohio) proposed legislation to create a Federal corporation like the Tennessee Valley Authority (TVA) to manage spent nuclear fuel and to build facilities to reprocess it. Here's a brief outline of what it would look like.

• As a Federally chartered corporation, like the TVA, it would be self-governed by a Congressionally appointed board that focusses on long-range strategy that looks far beyond the needs of the next election cycle.

• It would have the authority to manage spent fuel, recycle it, and bury the remaining high-level waste.

• It would use the money in the nuclear waste fund, which would not be subject to annual appropriations.

• It would implement U.S. nonproliferation policies as part of its management of spent fuel.

• It would be subject to environmental regulations issued by Federal agencies, including the Environmental Protection Agency and the Nuclear Regulatory Commission.

The concepts in the bill have support from the Nuclear Energy Institute, which is the main trade association of the nation's nuclear utilities. For instance, on May 25, 2010, the Institute's CEO, Marvin Fertel, told the Commission, "The Federal government's used nuclear fuel program should be transferred to an entity with a management and financing structure that is able to function in the presence of inevitable political and policy uncertainty."

Opponents of nuclear energy have used the lack of a comprehensive solution for spent fuel as a cork to bottle up future development of new nuclear reactors. A three-decade ban on construction of new nuclear reactors in several states is based on this concept.

Senator Voinovitch said in 2010 that the passage of his bill would resolve that issue and create thousands of jobs not only for the new reactors that the nation needs, but also to manage the spent fuel. The difference would be management based on science as a prevailing paradigm rather than politics as usual.

In summary, reprocessing of spent nuclear fuel should be on the agenda in the United States because of the energy value it contains and the security of energy supply it provides, relative to future needs for uranium, and becuse it significantly reduces the volume of material to be disposed as high level waste. By adopting a path to reprocessing spent fuel, we will remove uncertainties in these critical areas and set our nation on a sustainable path to cleaner energy futures.

An Afterword on Fukushima

The nuclear community continues to analyze the tragic events of the earthquake and tsunami that crippled the reactors at Fukushima Japan. Many lessons will be learned from this unprecedented event that will further improve the safety of nuclear power.

While it is too early to say how this event might affect the global expansion of nuclear power, one issue brought to the world's attention was the storage of used fuel at reactors. Several governing bodies have now called for decreasing the amounts of used fuel stored in reactor cooling pools by transferring it to interim storage or recycling facilities. Fukushima has clearly brought attention to the need for robust international and domestic used fuel management programs.

—*Dale Klein*