A Short Case for Recycling Used Nuclear Fuel – Steve Curtis / Tom Dolan

https://texas-recycles-unf.com/

Nuclear energy is absolutely necessary to attain air pollution and carbon goals stated throughout the world. However, although the rest of the world is moving strongly into nuclear power, the United States has lagged over the last 40 years in nuclear energy development. To move this along, it will take leadership and education to the public. In this respect, nuclear advocacy has been conspicuously silent. This has been interpreted by the public that the anti-nuclear forces are right and that we should eliminate anything nuclear. This is the exact opposite of the truth, but perception is truth to each individual.

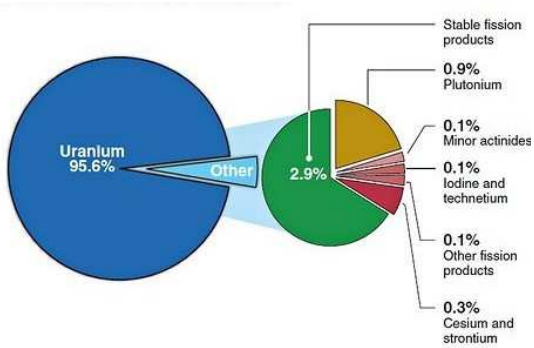
The biggest complaint in the anti-nuclear community is the inability of the nuclear industry to deal with used nuclear fuel. While it is clearly being handled safely, it is also clear that no long-term solution has emerged. This is (or should be) embarrassing to the professional nuclear community. The simplest part of the fuel cycle is the “back end” and our community has allowed political rhetoric to overshadow logical solutions to the problem. The existing nuclear community is being dominated by the long-standing ideas developed in the early days of the industry. The idea of throwing away a resource when only 1% of it has been used is completely against the modern-day idea of preserving the earth’s assets through recycling. So, part of the problem is getting the nuclear industry to reevaluate their thinking through the eyes of the 21st century.

Recycle Facility in France

Recycling is being conducted in France, and has been conducted since the beginning of their nuclear energy program. France supplies about 75% (down from 80%) of their electricity from nuclear power. In addition, the UK, Russia, China, Japan and India have programs to recycle their used nuclear fuel. So, what happened to the United States where nuclear power was born? One issue is the stated fear that recycling will unleash plutonium that may end up being used to make a bomb. However, except for a demonstration project to illustrate that it was possible, no country has taken this route. Not even North Korea. If any country wants plutonium suitable for a bomb, they simply design a reactor for this purpose and leave the fuel in for far less time than commercial reactors do. The reason is that plutonium is way too contaminated by higher isotopes of plutonium which make it difficult to produce a bomb. It is simply better to start from scratch as North Korea did. So, the issue of proliferation of plutonium from commercial used nuclear fuel, while an issue of concern, is not a major problem. Another issue is the massive misinformation left unanswered in the public’s eye regarding nuclear power. Eisenhower and Kennedy were outspoken on the benefits of nuclear power. Since Johnson, however, the issue has either been ignored or criticized by our leaders. Strong leadership would greatly help advance the cause, but there are enough grass-roots efforts in play that nuclear energy is slowly becoming “cool” again.

There are two different types of recycling for used nuclear fuel: aqueous (chemical) and non-aqueous (electro-chemical) pyroprocessing. Aqueous recycling is the method being used in the world today and involves dissolving all the fuel rod materials in a strong nitric acid bath and using chemistry to separate the different parts. Pyroprocessing uses molten salt as the solvent and electroplating as the separation method. Pyroprocessing has been around for almost 60 years, but only in the experimental prototype stage. Each has advantages and disadvantages like everything else, but either should be considered superior to discarding used nuclear fuel. I also find that the public does not accept “waste” burial, but loves the idea of recycling and the fact that there is a tremendous amount of energy left to produce carbon and pollution-free power.

Separation of used nuclear fuel means, basically, separating four distinct chemical groups in the fuel rods. The vast majority of the material is uranium. New fuel is about 96% uranium-238 and about 4% uranium-235. These are different isotopes of uranium and uranium-235 is the material that fissions and produces energy. When the used fuel is removed, the four basic categories of material remaining in the fuel material are:



Fission Product Mix for Used Nuclear Fuel

Uranium – 95% of uranium entering the reactor never changes. Only about 1% of it is uranium -235.

Plutonium – about 1% of the used nuclear fuel. Plutonium is actually bonus energy. Some of the uranium-238 transforms into plutonium-239 which can also fission and produce energy. When the reactor fuel is removed, there is some left that has not fissioned yet, but could be used for energy in the future.

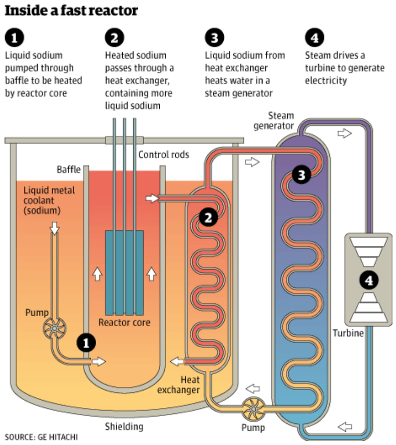
Minor Actinides – less than 1% are higher isotopes of elements heavier than plutonium. Together with plutonium, these are called transuranics, or “TRU” because they are heavier than uranium.

Fission Products – This is what is left after a nucleus fissions – two atoms per fission. They emit heat and radiation, but they remain inside the fuel material. This comprises 3% of the material in used nuclear fuel, but is the major reason used nuclear fuel must be handled carefully and shielded from people.

While either recycling method would be preferable to burial, the method used mainly depends on which kind of reactor the fuel is to be recycled into. These fall into two main categories, although there are several types in each group. With only a handful of exceptions, our current reactors in the US and around the world use water to slow down the fission neutrons to lower energies where they are more likely to cause more fissions in the neutron chain reaction. Some advance reactors (and there is a long history of these) are fast neutron reactors in which the neutrons are not slowed down. The group of nuclear reactions that fast neutrons cause is quite different than those that slow neutrons cause. Fast neutrons actually extract energy from and change plutonium and the higher transuranics far, far more effectively than do slow neutrons. From a used nuclear fuel toxicity perspective one could view a water-cooled reactor with recycling as a trash compactor, while a fast reactor takes the role of incinerator.

Using water-cooled reactors to recycle used fuel, as France currently does, means that mixed oxide (MOX) fuel, a mixture of uranium oxide and plutonium oxide, is the resulting recycled fuel form. The U.S. does not do this. To recycle the plutonium in used fuel, the French use an aqueous chemical process involving large volumes of concentrated nitric acid in very large, expensive piping systems. They separate plutonium to re-mix with uranium oxide to make MOX. Each recycle reactor is only partly fueled with MOX, the rest being the usual uranium oxide. The drawback with this system is that the same material can be economically recycled only once or possibly twice. Further recycled fuel material contains increasing fractions of plutonium isotopes that (1) make obtaining and controlling a chain reaction more difficult, and (2) presents worker radiation protection challenges during fuel fabrication.

So the regular commercial water-cooled reactors in use today can only reduce the waste volume somewhat, but do not eliminate enough of it to be considered a solution to the used fuel disposition problem, nor do they extract much more than 1% of the nuclear energy stored in the original uranium.



SOURCE: GE HITACHI

Fast neutron reactors offer important advantages and special capabilities. They use uranium far more efficiently than water-cooled reactors, and can convert useless uranium-238 (over 99% of the uranium mined) to plutonium-239, which is a fine reactor fuel. In water-cooled reactors, nearly all of the uranium-238 is wasted (an additional 80% of it was wasted during the uranium-235 enrichment process required for water-cooled reactors, so this is a vast untapped energy resource). Unlike water-cooled reactors, fast reactors can consume fuel that has been recycled many times. This is how it is able to extract nearly all the energy sequestered in uranium fuel – like increasing an SUV's gas mileage from 30 MPG to 3,000 MPG. Perhaps more importantly, experience shows that there is no limit to the number of times fuel material can be recycled in metal-fueled fast reactors, unlike water-cooled reactors. This means that the final residue waste after multiple recycles consists almost entirely of fission products. Their radioactivity disappears after a few hundred years, so a geologic repository for them need not last for more than, say 1,000 years. This is enormously shorter than the current 300,000-year requirement.

The most advanced fast neutron reactor designs, especially those of the US, use a metal fuel form, not an oxide, for a number of technical reasons including safety, ease of recycling, simple fuel fabrication, robust fuel performance, and high neutron efficiency. Pyroprocessing is naturally suited to metallic fuels because metallic fuels are easily fabricated in heavily shielded hot cells using remote technology.

Pyroprocessing, however, employs a different method of recycling than the aqueous chemistry used in recycling oxide fuels from water-cooled reactors. Pyroprocessing is used in non-nuclear industries, so there is US industrial experience, albeit with different materials. It dissolves used nuclear fuel using electrical current that partly, but adequately, separates the fission products from the uranium and plutonium in the used metallic fuel. A rough analogy is the operation of a battery, where electric currents force the movement of materials. This is a more compact process than the aqueous processing used for water-cooled reactor fuel. Early indications are that it will be a good deal less expensive. Both the characteristic facility size and cost make this a technology that can be deployed at regional locations that are already reactor sites, rather than at one gigantic national center as France does. With one additional step, used water-reactor fuel can be reduced to metallic form suitable as feed for pyroprocessing then directly into fast reactors.

Argonne's EBR-II in Idaho

No pyroprocessing facilities exist outside the prototype stage, but Argonne National Laboratory successfully operated such a reactor/recycle system, called the Experimental Breeder Reactor II (EBR-II), for 30 years in Idaho. The process used the system described in the last paragraph to power a 20 MWe sodium-cooled fast reactor during that time while constantly recycling the fuel. No incidents were experienced. In fact, two extreme accident failure experiments were conducted to test the safety of the system. This was done to test the passive safety of the system (the reactor fuel remains undamaged, even if there is no intervention by operators or by any back-up or safety systems). In one, a total loss of power to the system (a Fukushima-like scenario) was inflicted by the operators. In the second, the operators turned off the cooling pumps. In both instances, the reactor shut down with no damage and was able to be quickly restarted for normal operations. Both of these experiments were conducted on the same day.

The prototype system, called the Experimental Breeder Reactor at Argonne-West in Idaho, was shut down in 1994 for political reasons and has now been decommissioned, but the Department of Energy is about to build a larger, similar test reactor using the same concepts. This project will provide much more accurate cost projections for fast reactors.

The Argonne scientists have designed two capacities of facilities suitable to commercialize this process. One is a 100 tons per year facility at a cost of $500 Million. This could feed a 1 GW fast reactor power plant which could replace an existing coal or natural gas facility or an existing light water reactor complex. There also exists a design concept for a full-scale commercial 2,000 Tons/year facility that would cost $7 Billion. Based on only fees collected from the DOE for reprocessing used nuclear fuel, the facility would run at a minimum of 18% profit per year.

Fast reactors would be necessary to work in tandem with pyroprocessing, but the additional revenue of power production would cover much or all of the reactor costs. Commercial fast reactors may or may not be more expensive than our current commercial reactors. It is possible to show quite a profit margin for the pyroprocessing system. The basic model below does not include costs related to "First-of-a-Kind" production and getting licensing approval for the design. However, there is some wiggle room in the figures which will still show a profit, especially given the expected 80-year life cycle of a plant.

Here is a calculation of the possible profit lines from a pyroprocessing/fast reactor system at the 2,000 tons per year level:

Potential Annual Sources of Income
from Pyroprocessing/Fast Reactor Technology

Recycling:

a.	Charging $1,200 per kg @ 2,000 T/year	$	2,400,000,000
b.	5 GWe fast reactors power sales @ $0.10/kWh	$	4,400,000,000
c.	Fuel reserve for U and Pu @ $30/lb – 1,000 T	$	66,000,000
d.	Process Heat 15 GWth @ $5/MMBTU	$	2,200,000,000
	Total	$	8,866,000,000
	Operations and Maintenance	$	1,000,000,000
	Net Profit	$	7,866,000,000

Bottom Line:

We have a unique opportunity to provide clean energy to a world that is in short supply of that commodity and is struggling to move in that direction. Splitting a single atom releases 50,000,000 times more energy per molecule than burning coal does, and 20,000,000 times more than methane (gas). This is certainly an advantage we need to develop. All this is possible with material that is already in our inventory and is considered "waste" right now. In fact, there is no consensus long-term solution to this waste (in the United States) after 40 years of political intrigue and $15 billion drained from the treasury. The United States Congress has collected fees from electricity rate payers enough to have built a fund of $40 billion (including interest) for the purpose of securing a used nuclear fuel long-term solution. The main objection to this process is the anti-nuclear lobby which seems to be well-funded, but very misguided in its advertising.

A lot more work needs to be done on this project, but, as with all energy business economics, billions of dollars of profits are there for the taking. If a Governor would agree to accept used nuclear fuel, his/her state could demand huge benefits. At a minimum, they could negotiate for a Carbon-Free National Laboratory as well as research facilities to explore next-generation nuclear reactors, fuel types, microgrid technology, military reactor applied research, and a prototype pyroprocessing/fast reactor system. All of these are at the very beginning of development, but ready to supply the world with efficient, carbon-free, affordable energy with the least volume of waste among all other sources; and the waste is recyclable. It will be a large part of the energy future in the United States just as it is for the rest of the world. But we need to catch up to the rest of the world, most prominently China and Russia since they seem to be our greatest adversaries, both militarily and commercially.