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The Nuclear Alchemy Gamble: An Assessment of Transmutation as a Nuclear Waste Management Strategy

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Transmutation for waste management will necessarily involve nuclear reactors. This is because the process of converting long-lived radionuclides to shorter half-life ones is accomplished by irradiating the nuclei of the long-lived elements with neutrons generated in a nuclear reactor.

Current commercial reactors would not be effective tools for transmutation because they rely on low energy neutrons to maintain the chain reaction. Such neutrons can fission uranium-235 and plutonium-239 in the reactor and keep a chain reaction going, but they cannot fission many isotopes like plutonium-240 and -242.

Reactors that use high energy (or fast) neutrons can be more effective in reducing the mass of long-lived radionuclides in waste. However, these reactors pose severe safety and other problems, as will be clear shortly.

When a typical light water reactor is fuelled with MOX, a mixture of plutonium and uranium oxides, there is as much plutonium produced as destroyed. The leftover plutonium is also a different mixture of plutonium isotopes which makes its reuse in the reactor difficult and unsafe. Other more toxic transuranic radionuclides, notably americium, are also produced making, MOX spent fuel more radiotoxic than ordinary spent fuel. The difficulty in reducing the inventory of plutonium and the creation of more radioactive higher mass actinides means that light water reactors do not have a significant role to play in transmutation, a conclusion that has also been reached by transmutation proponents

This leaves fast neutron reactors as the option for transmutation. I will cover critical fast reactors, the most developed of which is the sodium-cooled fast breeder reactor. Hisham Zerriffi will discuss sub-critical fast reactors.

France and Japan have long had breeder reactor programs that have proven to be costly, technically unreliable, and environmentally problematic. They also raise serious proliferation problems. After five decades of intensive effort and tens of billions of dollars of expenditures worldwide, these reactors still have not been made to work reliably and consistently. Several large fast reactors with capacities of more than 100 megawatts electrical have been built. The largest breeder reactor in the world, the French Superphénix, which represented over 40 percent of the entire breeder reactor capacity in the world, was prematurely and permanently shut in 1998 due to persistent operating problems.

Technical operating problems have been rife, and there have been several accidents. The very first fast reactor, the Experimental Breeder Reactor 1 built in Idaho, suffered a partial meltdown in 1955, as did the larger Fermi reactor in 1966. The most recent accident was a major leak in 1995 of liquid sodium and subsequent fire that occurred in the Japanese Monju fast reactor, not long after it had been commissioned. It remains shut.

Finally, sodium-cooled fast reactors pose huge safety issues. Besides meltdown accidents, which can also occur in light water reactors, sodium-cooled fast reactors can suffer from sodium leaks and fires, failures of cooling equipment handling liquid sodium, and catastrophic super-criticality accidents.

These well-known concerns with fast reactor safety would be complicated further by the introduction of minor actinides as well as fission products in the form of target rods. It seems strange that France and Japan are laying so many plans for the use of fast reactors with exotic fuel and target core configurations, when even the operation of these reactors with the fuel for which they were designed, MOX fuel with about 30 or 40 percent plutonium content, has not been successful on a routine, reliable basis.

If the schemes to use fast reactors for transmutation are implemented, they will also require repeated reprocessing to separate the elements to be transmuted. Although fast neutrons can fission more plutonium and minor actinides than slow neutrons, the same problems associated with light water reactors will still be present, albeit in theory they would be less pronounced. Multiple recycling will be necessary with their associated reprocessing between each pass.

Commercial reprocessing is already one of the most polluting parts of the nuclear power business. Several European governments are asking France and Britain to shut down their commercial reprocessing operations. Reprocessing is also a principal element in concerns about proliferation. The use of fast reactors, which can be used to breed weapons grade plutonium, and of commercial reprocessing, which will result in the separation of large amounts of nuclear weapons usable materials, will be necessary features of the use of critical reactors in a transmutation system.

In conclusion, the existing LWRs cannot be used to implement a transmutation program due to the limitations of the technology itself. The use of fast reactors for transmutation could reduce the amount of transuranic elements now present in spent fuel, but this would require many passes through the reprocessing-fuel fabrication-reactor components of the transmutation system, raising severe safety, environmental, and proliferation concerns. Even so, a substantial amount of long-lived materials will remain and they will have to be disposed of in a geologic repository.