MORE THAN ONE WAY TO CONTROL NUCLEAR WASTE UPSTREAM

Studies are in progress to explore not one, but a whole range of options for eliminating the most radiotoxic part of nuclear waste. At the industrial-facility level, CEA research teams are comparing them, taking into consideration the entire cycle of nuclear materials and how they change over time. Many scenarios for different types of facilities, some of which might be dedicated to waste processing only, have been studied to learn the advantages and drawbacks of the different decisions that could be taken.

Claude Pauquet/EDF

The Phénix reactor at Marcoule (Gard). Fast-neutron reactors offer the best neutron balance for transmutation purposes.

Why study different scenarios?

The nuclear power cycle involves a variety of facilities that make, use, and reprocess **fuel** to recycle potentially energy-rich nuclear materials, such as plutonium and uranium, and manage waste. The performance of **transmutation** processes with regard to waste management can only be analyzed by considering this cycle as a whole, and not in light of the performance of just one of its phases. The basic options presented in this issue of *Clefs CEA* must therefore be examined within the context of a complete system of industrial nuclear-power facilities (i.e. reactors and fuel-cycle plants), and taking into consideration how these facilities change over time. Various scenarios are studied to this end.

Selected scenarios

The scenarios considered for transmutation purposes involve reactors integrating current technology, such as **pressurized-water reactors** (**PWRs**) or sodium-cooled, **fast-neutron reactors** (**FNRs**), and innovative systems such as gas-cooled reactors (**GCRs**), i.e. with a gas **coolant**, or hybrid systems combining a **subcritical** reactor with an **accelerator**-driven external neutron source (see *From the critical reactor to the subcritical hybrid system: transmutation tools*, box E, ***What is a hybrid system?*** and box F, ***PWR, FNR, and GCR***).

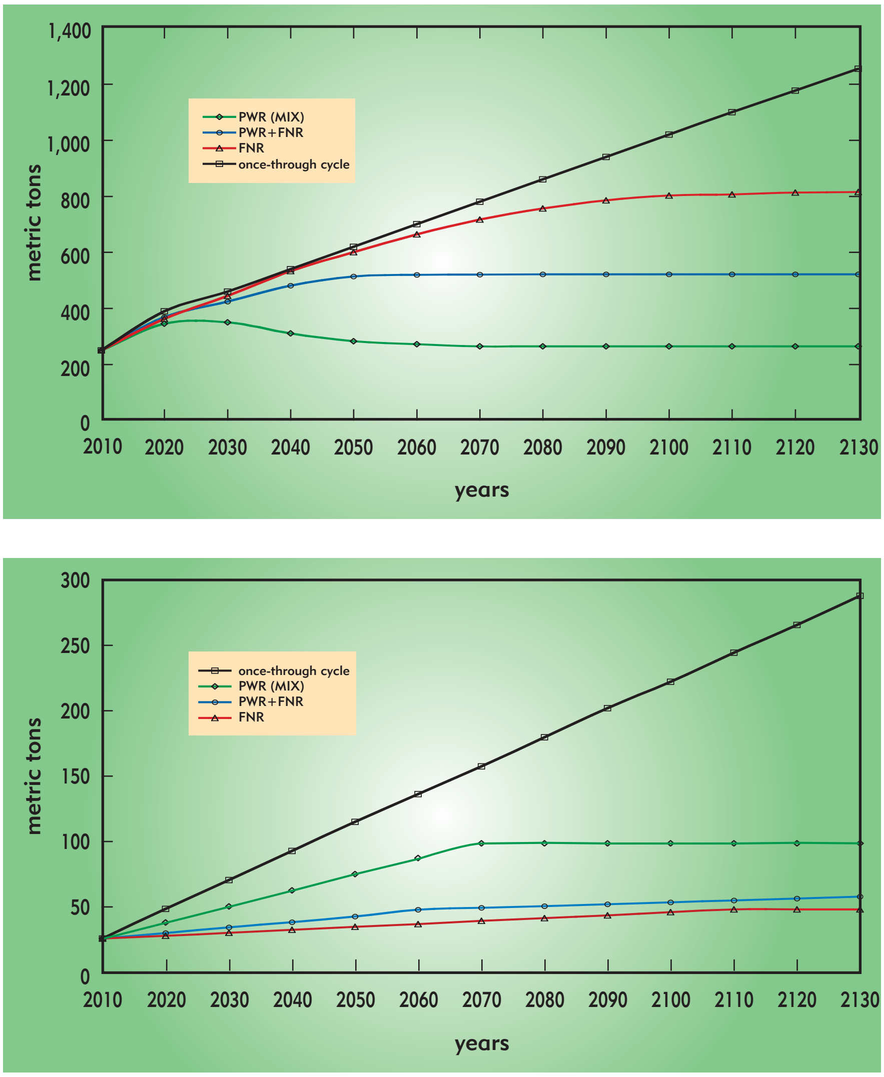
Three categories of nuclear-reactor systems using current technologies

The results of R&D work carried out in recent years have revealed scientifically feasible options to **recycle** plutonium and **minor actinides** (neptunium, americium, and curium) in facilities integrating current technologies: oxide fuels (uranium oxide **UOX**, or mixed uranium and plutonium oxides **MOX**), PWRs, and sodium-cooled FNRs. The selected scenarios have a common period until 2010, the date by which transmutation is supposed to be implemented. Two alternatives are studied for each type of nuclear power system: recycling plutonium alone, and recycling plutonium and minor actinides. These alternatives correspond to three categories of nuclear reactor system.

The two pressurized-water reactors (PWRs) of the EDF Chooz-B plant. Slow-neutron reactors such as PWRs could play a part in transmuting minor actinides, and in recycling plutonium.

Marc Morceau/EDF

Figure 1. Changes in total plutonium (top) and minor-actinide (bottom) inventory, in three categories of reactor system for a once-through cycle.



The first category consists of PWRs that (multi)recycle plutonium and minor actinides, uniformly mixed in a MIX fuel, i.e. plutonium with a uranium support enriched with uranium-235 (see *From the critical reactor to the subcritical hybrid system: transmutation tools*, and the box *"Controlling the plutonium inventory in a PWR"*).

The second category is made up of PWRs loaded with standard UOX fuel, and FNRs, recycling plutonium and neptunium in homogeneous form in MOX fuel, and all of the two most important minor actinides (americium and curium, accounting for 90% of these) in capsules (or "targets"), irradiated in a single pass in the reactor, after which the actinides are treated as waste.

The third category consists of FNRs in which plutonium and minor actinides are (multi)recycled in homogeneous form in MOX fuel.

The overall performance of these alternatives is compared with that obtained in a "once-through" cycle, where UOX fuel from PWRs is not reprocessed and simply sent as is to waste facilities.

Transmuting as from 2010 and stabilizing the actinide inventory?

For each scenario, the nuclear power system (total electrical generating capacity of 60 GWe) maintain its present structure until 2010. As from that date, the addition of different types of reactors and recycling options is simulated, meeting the objective of a con-

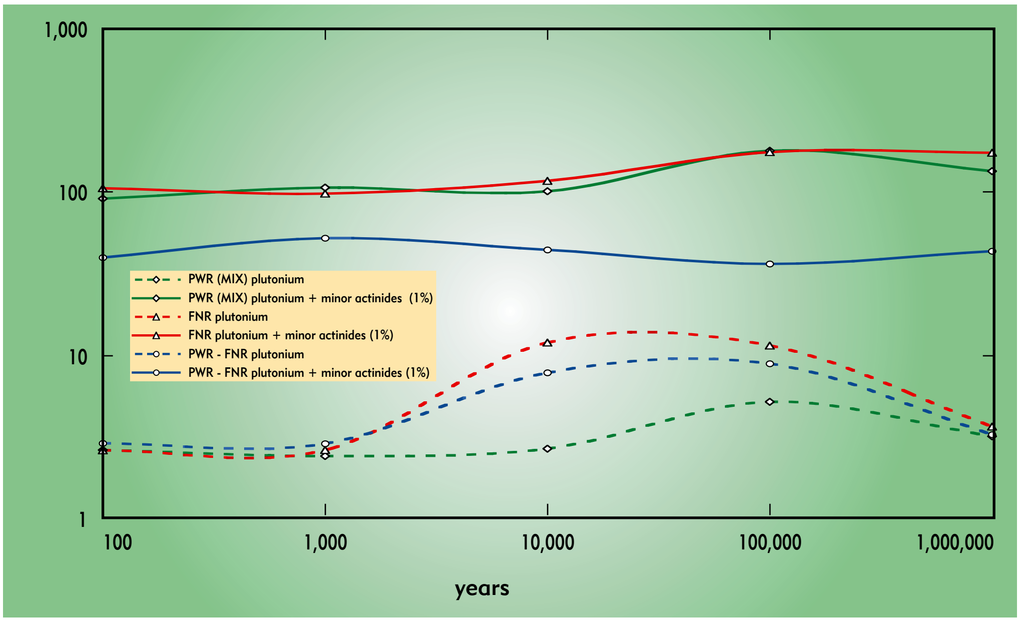


Figure 2. Radiotoxic inventory gain (evaluated in terms of intaken radionuclides according to ICRP 72) in six different reactor systems.

stant electrical-power output of 400 terawatthours). The number of reactors required to stabilize the mass inventory of actinides is reached within 20 years with a system comprising 100% MIX-fuel PWRs, 60 years with a mixed system (comprising 45% UOX-fuel PWRs and 55% MOX-fuel FNRs), and 100 years with a system comprising 100% MOX-fuel FNRs.

In the selected scenarios, stabilization is reached in the different systems at 250–800 metric tons for plutonium, and 50–90 metric tons for minor actinides. The “once-through” cycle, which by definition is not “stabilized”, produces 10 metric tons of plutonium and 1.5 metric tons of minor actinides per year (figure 1). The system composed of MIX-fuel PWRs offers the lowest plutonium inventory, but the highest minor-actinide inventory (with 50% curium, compared with 20% for the other scenarios).

Taking the waste generated by all nuclear facilities every year, the gain in terms of **radiotoxic inventory** can be assessed, as a function of cooling time (figure 2), from the ratio of the radiotoxicity of the “once-through” scenario to that of the scenario under study, and assuming a reprocessing recovery rate of 99.9% for plutonium and 99% for minor actinides.

Two types of curve emerge. In the first, where only plutonium is recycled, the gain varies between a factor of 3 and 10, and the “FNR-only” scenario seems the most effective. In the second, where plutonium and minor actinides are recycled, the average gain varies between a factor of 130 (“FNR-only” and “PWR-only”) and 60 (“PWR + FNR” scenario). The last scenario is less effective in terms of waste radiotoxicity because of the 10% of actinides remaining in the “targets” after a single pass in the reactor. However, it succeeds in concentrating americium and curium, which are the most difficult actinides to handle in terms of radiological protection and from the thermal point of view. These materials would only represent a flow of 1.6 metric tons/year in fuel-cycle facilities, compared with 850 metric tons/year in the MIX-fuel PWR scenario, and 340 metric tons/year for the MOX-fuel FNR scenario.

Possibilities offered by innovative technologies

Studies relating to scenarios implementing innovative technologies show trends that must be confirmed by R&D programs under way with regard to both fuels and systems.

Innovative fuels such as the Advanced Plutonium Assembly made up of standard uranium-oxide (UO_2) rods and plutonium-oxide (PuO_2) rods in an inert matrix (APA or Duplex) could be used to consume more plutonium and transmute minor actinides in existing PWRs. The transmutation efficiency of a system of PWRs operating on fuel containing 40% of these new fuels would equal that of PWRs using 100% MIX fuel.

Innovative systems (**GCRs**, **hybrid systems**) can be used to contemplate transmutation according to two different strategies. The first, which is equivalent to those discussed above, is based on the use of PWRs and GCRs to recycle plutonium and minor actinides. The second is based on a “double-strata” configuration. In this case, the first stratum consists of nuclear power reactors (PWRs + GCRs or GCRs only), used to recycle plutonium and neptunium in GCRs, while the second stratum consists of hybrid systems dedicated to transmuting the other minor actinides and long-lived fission products.

In both cases, the gain achieved in terms of waste-inventory radiotoxicity is roughly the same (factor of 300). The “double-strata” strategy restricts transmutation to 5% or 10% of the nuclear power system in terms of overall electrical generating capacity.

Industrial feasibility studies under way

After ensuring that current PWR or FNR technologies are capable of producing nuclear power sytems that will achieve the stabilization of the plutonium and minor-actinides inventory, with significant gains regarding the radiotoxic inventory of waste generated, research teams have begun detailed studies of the industrial feasibility of each type of facility. This involves assessing the impact of transmutation on the environment (gaseous and liquid radioactive releases) and on cycle economy. The same type of study will then be started for scenarios implementing Corail-type fuels (mixture of standard uranium-oxide and MOX rods) to simplify plutonium recycling using current technologies, innovative fuels (APA), which raise hopes of effective recycling in PWRs, and innovative systems such as GCRs and hybrid systems, offering better performance in terms of reducing the radiotoxic inventory of waste. ●

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