PRODUCTION AND RECYCLING RESOURCES FOR NUCLEAR FISSION

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Summary

Owing to the production of plutonium 239 by the fuel's uranium 238 support, the energy produced from a certain mass of natural uranium can be considerably increased.

Similarly, owing to the production of uranium 233 by the fuel's thorium 232 support, the energy produced from a certain mass of thorium can be considerably increased.

1. In the case of incinerator reactors, the savings are small, ranging from a few tens of percent to a factor of 2

2. In the case of self-generating or breeder reactors, the multiplication factor for the energy available is very high, in the region of 200. It is sensitive to fertile material losses, which must remain low in comparison with the consumption of these same materials (100 kg/TWhe).

Breeder reactors are only necessary if one wishes rapidly to increase the installed power.

1. Introduction

Through a process of radioactive decay, all heavy nuclei (HN) and all fission products (FP) tend naturally towards a stable state, at various rates.

During radioactive decay, the nucleus transmutes into another chemical substance or another isotope (figure 1). This transformation is accompanied by the emission of a particle, which can be a helium nucleus (we then talk of alpha emissions), an electron (we talk of beta emissions) or a photon (we talk of gamma emissions).

Figure 1 : Radioactive decay of heavy nuclei.

When a heavy nucleus is bombarded with neutrons, two major types of reactions occur:

– fission, which leads to fission products, most of which are radioactive but most of which have far shorter half-lives than the initial heavy nuclei. These reactions are preponderant on a few nuclei, including uranium 235 (U 235), plutonium 239 (Pu 239) and plutonium 241 (Pu 241), americium 242m (Am 242m), curium 245 (Cm

245). We will talk of incineration for this type of reaction;

– neutron capture, which leads to higher isotopes with different half-lives and thus activities. Figure 2 gives an example of the evolution of the main heavy isotopes under the influence of flux. These reactions which transform a heavy nucleus into another heavy nucleus can be referred to as transmutation.

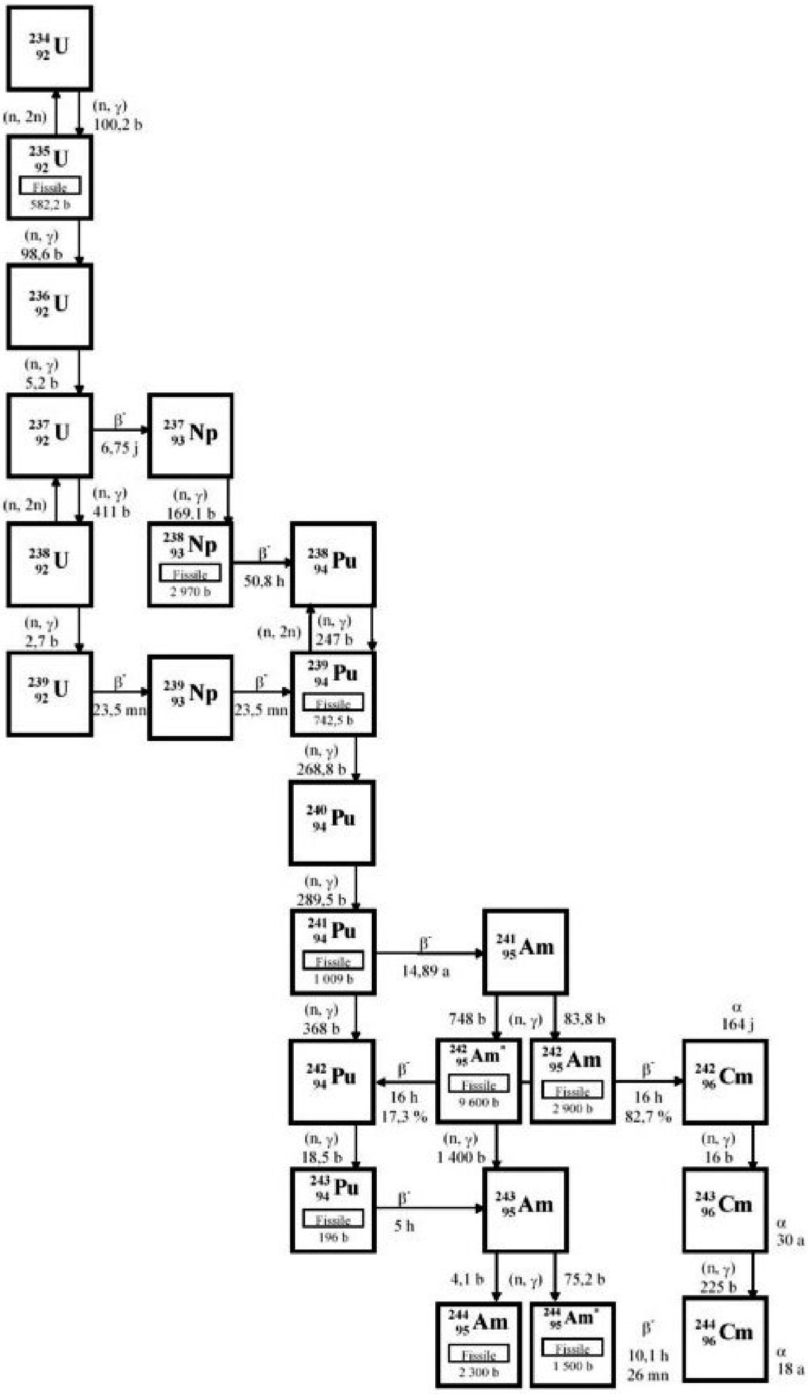

Figure2: An example of the evolution of the main heavy isotopes under the influence of flux

Thus, in a Pressurized Water Reactor (PWR), with standard fuel (uranium oxide enriched with U235), we will encounter these two types of reactions:

- fission of U 235, which is the only fissile material introduced into the reactor at the beginning of its life,

- -successive capture reactions which occur either from the U 235, or the uranium 238 (U 238). One of the most important captures for the rest of this article is that of U 238, which gives rise to Pu 239.

- then fission of the fissile isotopes thus formed (Pu 239, Pu 241).

In a standard fuel, a large part of the energy (about 30%) is produced by fission of plutonium (Pu) which was created from the U 238.

After an initial passage through a Pressurized Water Reactor (PWR), the spent fuel assemblies are unloaded. The fuel is not completely burned and still contains fissile isotopes.

In the spent fuel, we find:

1. the fissile materials initially loaded (U235)

2. new fissile materials arising from support captures. The support is a chemical substance used to dilute the fissile material. It can be U238 which, by capture, gives Pu 239, thorium 232 (Th232) which, by capture, gives U 233, or a light substance giving rise to no fissile isotopes.

3. and fissile substances arising from successive neutron captures on the previous isotopes (mainly Pu 241, Am242m, curium 245 (Cm245))

4. We also find all the even number isotopes arising from successive capture on the previous isotopes: uranium 234 (U234), uranium 236 (U236), for uranium; Pu238, Pu240, Pu242, for Plutonium; Cm244, Am243, Cm246 for the Minor Actinides, noted MA and comprising neptunium, americium and curium.

5. Finally, we find fission products (FP)

Using an appropriate process, it is possible to separate the heavy nuclei (uranium, plutonium and minor actinides) from the fission products. This is reprocessing as practiced in France, England, Russia and Japan.

Uranium and plutonium are easily reusable materials, and the minor actinides are, at present, dealt with as waste and vitrified. Some have a very long life and storage of them is therefore problematical.

It should be noted that some minor actinides are highly fissile.
Then, using the materials recovered in this way, we can manufacture new fuel for burning

in the reactor. The fuel is then said to be recycled.

By recycling spent fuel, we can increase the energy produced without using new uranium resources.

Uranium, plutonium and the minor actinides can be recycled together or separately. The number of possible scenarios is thus particularly large. Nevertheless, three main families are usually identified:

1. Scenarios in which only the uranium 235 present in the reprocessing uranium is recycled;
2. Scenarios in which plutonium is recycled on a uranium support
3. Scenarios in which uranium is recycled on a thorium support

Recycling of the minor actinides, although essential in order to reduce long-life waste, offers only little savings in natural uranium, when it does not increase consumption. It is linked to the problem of the back-end nuclear fuel cycle and management of nuclear waste. We will not therefore examine the savings brought about by this type of recycling.

The quantity of fissile nuclei contained in the spent fuel depends on the reactor in which the fissile substances are recycled. There are three distinct cases:

1. if it is less than the quantity present in the new fuel, the reactor is said to be an **incinerator,**
2. if it is equal to the quantity present in the new fuel, the reactor is said to be **self-generating,**
3. if it is greater than the quantity present in the new fuel, the reactor is said to be a **breeder.**

The incinerating power of a reactor is expressed in kg per TWh (billion kWh)

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