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The solutions for nuclear waste

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The subject of nuclear waste is often discussed in public debates on energy, and is used by some environmental groups to oppose nuclear energy. Such opposition is not backed by any solid scientific facts. This article proposes a new insight, from an environmental perspective, on the nuclear waste issue. Nuclear waste has undeniable environmental benefits: it is produced in relatively small amounts. It is not disposed of in the open and is almost totally confined. It is very easy to ensure protection from identified sources of radiation. Unlike with other highly toxic stable chemical and industrial waste matter, the toxicity of reprocessed radioactive waste decreases very rapidly in an exponential manner with time, returning to the natural level of radioactivity of the original ore after only 5000 years. Safe, simple and efficient solutions exist to make nuclear waste inert by vitrification and to isolate the waste from the biosphere until it is no longer toxic. The natural nuclear reactors of Oklo in Gabon, which self-ignited two billion years ago, are a source of essential information today which shows the absence of migration by the waste, which has not migrated more than three metres even after being left for two billion years without any confinement. The recurring question of nuclear waste therefore appears to be technically and ecologically entirely solved by combining the use of reprocessing technology, confinement, vitrification and geological disposal, but still faces the issue of social acceptance, which implies a need for better information for the public, and especially the environmentalists, about these questions.

Keywords: nuclear waste; radioactivity; confinement management; reprocessing; environment; natural radioactivity; Oklo; plutonium; transmutation; geological disposal

Your fate is not imposed by the future; you make it yourself.
Georges Bernanos (French critic, 1888 – 1948)

1. Introduction

When we speak of nuclear wastes, we distinguish on the one hand the short-lived waste, which is no problem because it disappears quickly by radioactive decay, and weakly radioactive waste, with intensity comparable to the natural backgound which is not dangerous because it emits very little radiation; and on the other hand high-level and medium-level long-lived radioactive nuclear waste, whose disposition is still undecided. Most of that waste is produced in nuclear power plants, and much of it is in temporary storage. In particular our concern is for spent fuel elements recently removed from reactors, not yet reprocessed and held in cooling pools. In addition there is an accumlation of separated radioactive material cast in glass, encased in stainless steel cylinders and held in dry storage at La Hague in France and at Sellafield in the UK.

The results of research carried out by scientific and engineering teams in several countries, and notably in France [1], show that the three paths under study – transmutation of long-lived isotopes to stable or short-lived isotopes, temporary storage on the surface or not too far underground, and permanent deep underground storage – are complementary. The only remaining question now is how best to implement these solutions.

In other words, we need not seek the SINGLE solution: SEVERAL options are available.

Spent fuel elements as they come out of the reactor are still rich in energy. The spent fuel consists of 95% unburnt uranium and 1% plutonium, as well as 4% fission products and transplutoniums (the latter are often called actinides). If the spent fuel element is reprocessed, then the uranium and plutonium can be recovered and exploited. Since the energy resources of our planet are limited, it would be a great shame not to recover these materials. Reprocessing and recycling, as practised at the La Hague plant in France, at Sellafield in UK and at Rokkasho-mura in Japan, is ecologically sound, for it greatly reduces the volume of the waste and confines the toxic material so extracted in a glass matrix where it is chemically inert and almost completely unalterable.

When vitrified, the highly radioactive nuclear waste produced per capita in a typical nuclear country during an entire lifetime would have a volume no greater than a golf ball (figure 1)

Figure 1. © Photo credit IBC

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2. A million times less waste.

The fission of one gram of uranium provides as much energy as burning one tonne of oil, whence the famous factor of a million. After fission there remains only a fraction of a gram of radioactive waste which is, in any case, not released into the environment but very carefully confined, eventually to be reprocessed and recycled. This small fraction, which is of no further use, is totally isolated from the environment. Nuclear energy has thus the virtue that the volume of waste is very small – small enough to be readily stored away – and completely confined. This is not the case for other kinds of industrial waste.

Because radioactivity is unfamiliar to us, nuclear waste is disturbing; and some people tend to exaggerate the danger. And because nuclear waste is at first strongly radioactive, certain precautions must indeed be taken when handling it. But the radioactivity falls off rapidly with the passage of time.

Over 90% of the initial radioactivity of the spent fuel disappears spontaneously in the first ten years after leaving the reactor (see figure 2). After about 5000 years – which is no time at all in geological terms - the radioactivity of spent fuel is no more than the radioactivity of the original uranium mineral from which it was obtained (see figure 3).

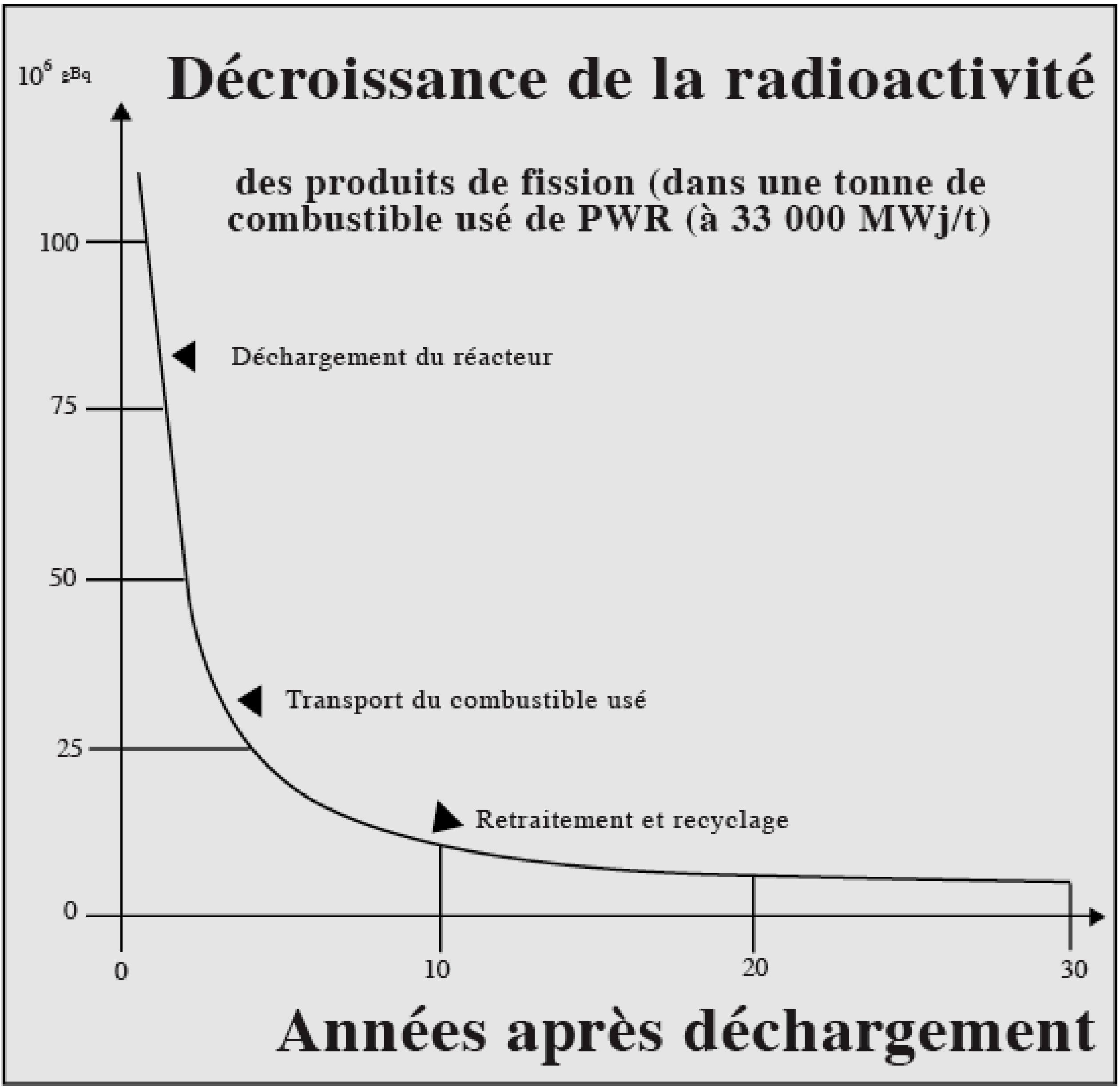
10_{6} gBq = 10 ^ 15 Bq

Radioactive decay

of fission products in one tonne of spent fuel
(33 000 MegaWatt days per tonne)

Unloaded from the reactor
Transportation of used fuel elements
Reprocessing

Figure 2. Radioactive decay of fission products in one tonne of spent fuel (unloaded after providing 33 000 MegaWatt-days per tonne)



Years after discharge

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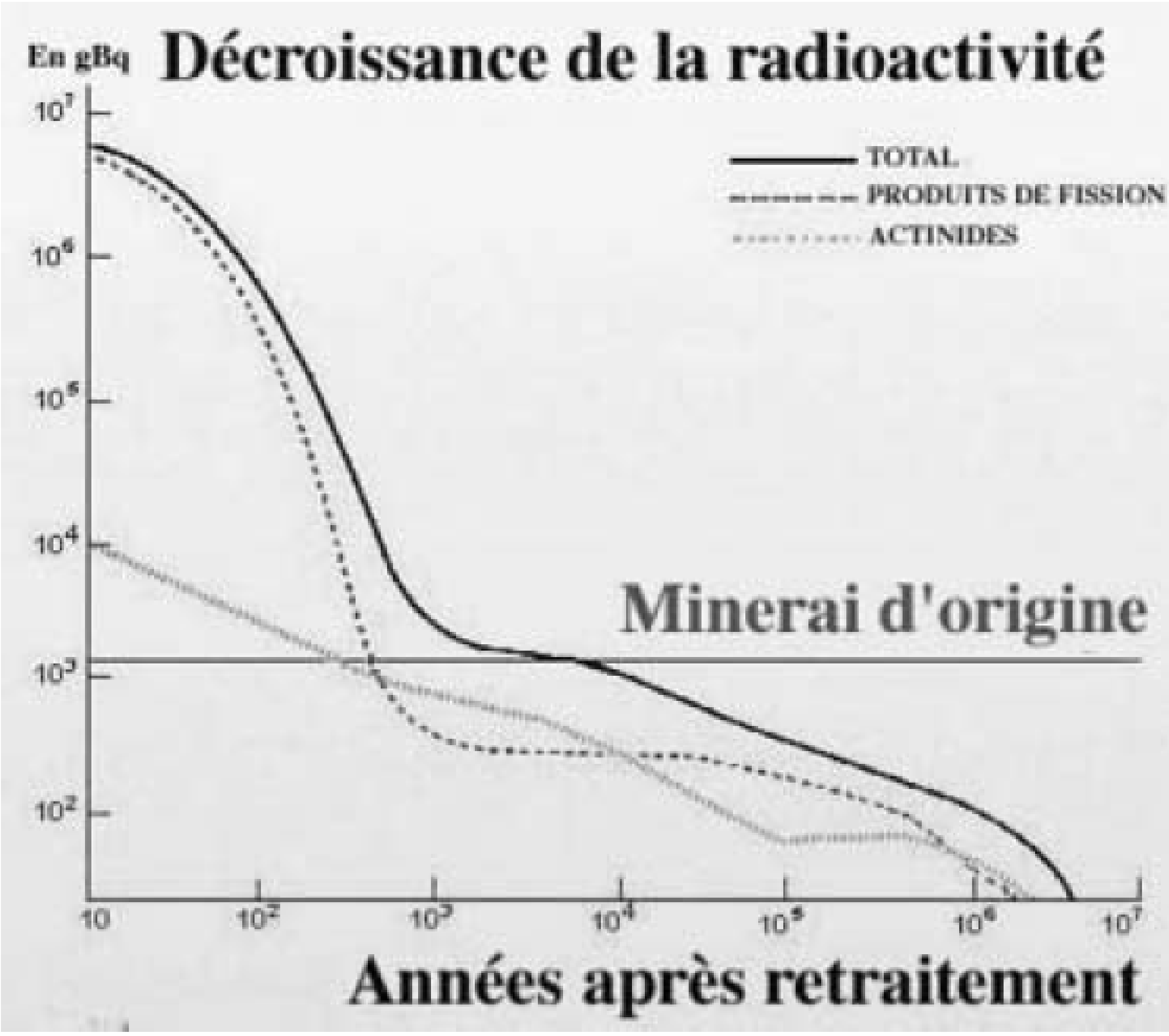

legend   en gBq --> ? gBq per tonne?

Original uranium mineral

Total
Fission products
Actinides

When we speak of high-level long-lived radioactivity, we should always say that it is INITIALLY highly radioactive. The high-level does not persist forever, but it diminishes rapidly, especially at the beginning, because of the characteristic exponential decay. The elements which remain after a long while are only weakly radioactive. And most of the very long-lived radioactivity consists of alpha-ray emitters from which we can easily protect ourselves.

Furthermore, nuclear waste consists mostly of elements which form solids – by their nature they are easy to confine. And they are self-degrading, by reason of radioactivite decay. In contrast, most chemical wastes are stable and do not degrade. From the point of view of public health and toxic waste, nuclear energy is by far the least polluting of all the sources of energy we have [2].

Moreover, the relatively small volume of nuclear waste permits us to let decades pass without having to decide what to do with it. During this time, mankind continues shamelessly to release each year over 25 billion tonnes of CO2, a greenhouse gas, as well as millions of tonnes of highly toxic industrial waste – in addition to sulfur dioxide, the source of acid rain, ashes, heavy metals, nitrogen oxides, pathogenic and cancer causing particles, etc. Our civilization also produces vast quantitites of household and industrial waste, some of which – so-called special wastes – are very poisonous and they will be with us forever, since they are chemically stable [3].

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Although the danger due to nuclear waste decays rapidly and progressively, we cannot justify an indefinite delay in finding a final resting place for it. It would be irresponsible of our generation to ask future generations to deal with the problem of our unmanaged and badly packaged nuclear waste, even if it is not very voluminous. Especially since we already know that simple and effective solutions are at hand.

We can easily protect ourselves from radiation. We don't need to call upon sophisticated technology – simple shielding will do (see figure 4).

From an environmental point of view, an important advantage of radioactivity is that its activity diminishes spontaneously as time passes – the well known law of exponential decay. One need only wait for the radioactivity to fade away of its own accord. On the other hand, many toxic chemical wastes are stable and last forever; one might say they have an infinite life. DDT is a notorious example.

Mankind did not invent radioactivity. It is found in nature everywhere around us. The weak doses of natural radioactivity, to which we have been exposed since time began, are not dangerous. It is worth noting that this natural background radiation is highly variable, varying by a factor of nearly a thousand from one place to another. In certain places, for example the city of Guarapari in Brazil, one finds a natukral radiation background which would be considered dangerous for workers at a nuclear reactor or at a nuclear waste storage site. Yet the inhabitants are perfectly healthy. This background radiation, mainly due to uranium and thorium, diminishes slowly in time as these elements decay, for their lifetimes are comparable to the age of the earth. Human activity on the surface of our planet has not increased the level of ionizing radiation except in a relatively few places. On the other hand, one might say that in burning uranium we accelerate (to a minuscule extent, of course) its natural disappearance from the environment. The Earth was much more radioactive when life first appeared, and natural radiation has not stood in the way of evolution and development.

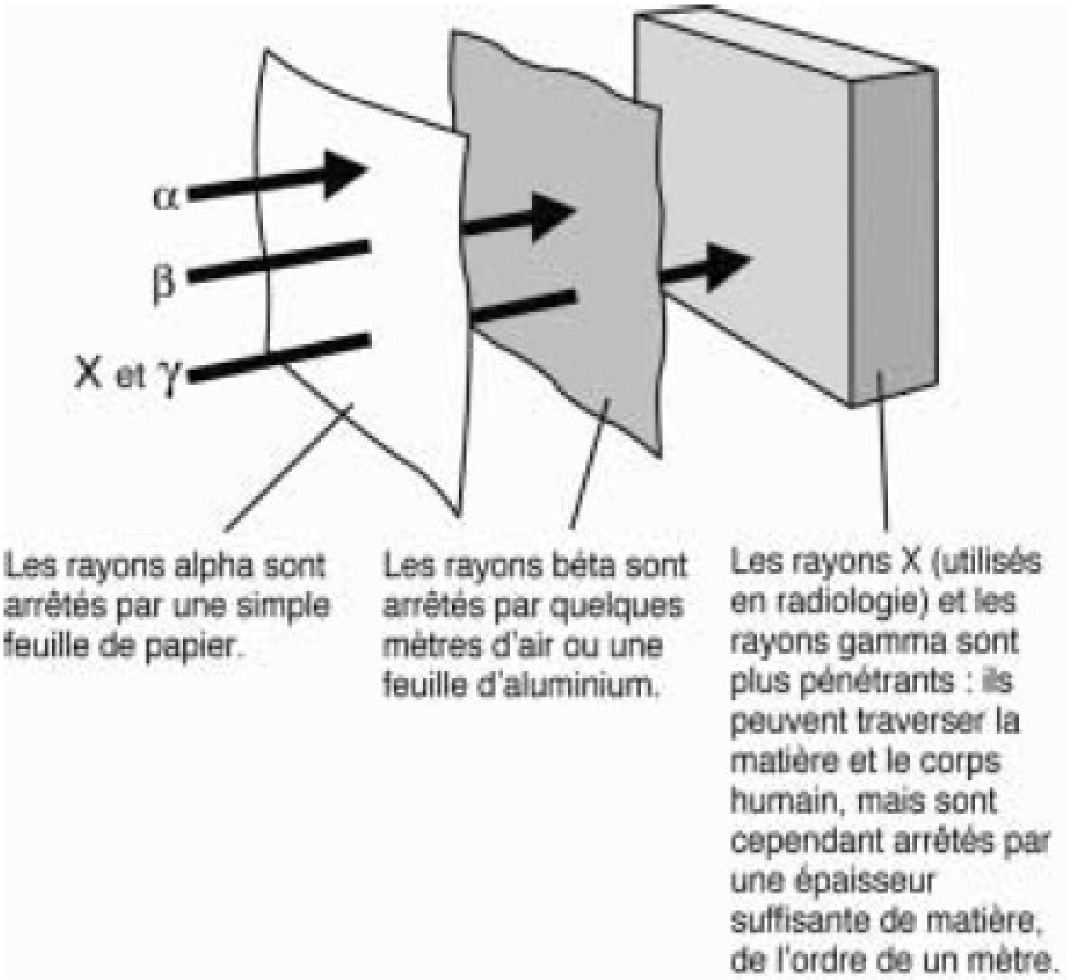

Figure 4. Protective screens

Legends for figure 4

Alpha particles are stopped by a simple sheet of paper

Beta rays can penetrate several meters of air, but can be stopped by a sheet of aluminum.

X-rays (used in medical radiology) and gamma rays are more penetrating and their absorption follows a different law. They pass through solid matter and the human body, but they are absorbed by a sufficiently thick layer of matter – lead or concrete.

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Figure 5 The Oklo uranium mine in Gabon, central Africa.

About 2 billion years ago, at Oklo in south-eastern Gabon (see figure 5) nuclear chain reactions just like those which we produce in reactors occurred spontaneously in several deposits of natural uranium mineral.

For over a million years, about fifteen natural nuclear reactors operated with power levels of up to 100 kiloWatts [4]. None of the fission products remain radioactive today – they have completely decayed. However, one finds their stable (non-radioactive) descendents in their place.

The nuclear waste which we produce now is carefully confined, which was certainly not the case at Oklo. Yet after two billion years we find that the plutonium and the fission products, left to their own, have not migrated more than a few meters, perhaps three meters at most. That "waste" remains in the sedimentary rocks, in or near each natural reactor, without even being dispersed or carried away by the ground water which was necessarily present as the moderator to produce the chain reaction. Most of the fission products form solid compounds and they are not at all mobile.

Our knowledge of the natural reactors of Oklo eases our concern about the long term behavior of our radioactive waste. In addition, the radioactive fission products we produce today are to be stored under conditions much more restraining than Oklo. Cast in glass and encased in stainless steel, they will in the end be deposited in carefully selected underground strata, surrounded by clay impermeable to water, which was certainly not the case at Oklo. We have every right to feel reassured that they will not migrate very much. Elaborate simulations sponsored by the European Commmission, and studies carried out in underground laboratories in Belgium, Finland, Sweden, Switzerland and the United States have confirmed these conclusions, with a large safety factor.

Figure 6. Waste storage at Mol in Belgium (© Photo Bruno Comby Institute, www.comby.org)

Scientific and engineering research in several countries has demonstrated the feasibility and the safety of long-term geological storage of nuclear waste (see figure 6). The public would never be subject to significant doses of radiation. At the beginning, the waste would be well confined and inoffensive. After some thousands of years, most of the radioactivity would have decayed, and a tiny fraction of what remains might leak and migrate, but Oklo shows that it wouldn't go very far. Meanwhile the radioactive isotopes would have almost totally decayed, so the deposit would be equally inoffensive. Even in the worse case and in the very long term, people living on the surface would be subjected to insignificant doses of radiation, much less than the natural radioactivity to which we are all exposed.

3. Radioactivity and ionizing radiation are natural.

When we speak of radioactivity, it is well to put things in perspective; radioactivity has existed since the beginning of time. Professor James Lovelock, who was in the 1960s one of the historic founders of modern ecological thought, puts it this way :

> "Perhaps the strangest thing about the Earth is that it formed from lumps of fall-out from a star-sized nuclear bomb. This is why even today there is still enough uranium left in the Earth's crust to reconstitute on a minute scale the original event.
>
> "There is no other credible explanation of the great quantity of unstable elements still present. The most primitive and old-fashioned Geiger counter will indicate that we stand on the fall-out of a vast ancient nuclear explosion. Within our bodies, half a million atoms, rendered unstable in that event, still erupt every minute, releasing a tiny fraction of the energy stored from that fierce fire of long ago.
>
> "I hope that it is not too late for the world to emulate France and make nuclear power our principal source of energy. There is at present no other safe, practical and economic substitute for the dangerous practice of burning carbon fuels." [5]

We even find a certain (infinitessimally small) amount of plutonium in nature. It appears spontaneously in the crust of the Earth as a consequence of the continuous bombardment of uranium by cosmic radiation arriving from space. Thus one may find a few million atoms of plutonium in a pot of flowers or in a kilogram of earth taken from our garden, or anywhere else in the crust of the Earth. Which has led Jacques Pradel to say "Plutonium, why, it's natural!" [6].

In view of its energy content, we ought to consider plutonium as a first-class source of energy rather than waste. In this respect, we can only evoke our support for the return to operation of the MONJU fast neutron reactor in Japan and our sorrow at the premature closing of the Superphenix reactor in France. At this very moment, a number of industrial countries, including France, are engaged in the development of future nuclear reactors in the Generation IV International Forum (GIF). The environmental virtues of fast neutron reactors (FNR – sometimes called the breeder reactor) are recognized by GIF which includes sodium-cooled reactors like the Superphenix in its program.

The actinides, at present considered waste, can be separated and burned in the FNR. In this case there is nothing left but the fission products whose life-time is much shorter. Furthermore, the FNR produces up to 100 times more energy from a given quantity of natural uranium. This fact is well appreciated in China, in India, in Japan and in Russia, countries which are actively developing reactors which produce even less waste than ours.

Figure 7. Professsor James Lovelock (© Photo Bruno Comby Institute, www.comby.org)

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4. Nuclear waste requires good management

After fifteen years of thought and study of the three paths mentioned above, it seems to us that the ecological management of long-lived high-level and medium-level nuclear waste consists of the following:

4.1. **To confine and reprocess spent fuel**, as is done in France today, in order to recover and recycle the unburnt uranium (95%) and the plutonium (1%). We would thus recover 96% of the spent fuel for recycling. The remaining 4% (the ultimately non-recoverable waste) would be cast in glass (vitrified) to render it inert and insoluble in water, then encased in stainless steel containers (figure 8). This would render it immune to chemical deterioration for a period of time long compared to the life of the radio-toxic elements.

One might eventually separate the minor actinides (americium, curium, neptunium, etc.) further reducing the volume and shortening the length of time during which the waste is radioactive; it would be advisable to continue research on transmutation of these transplutonium elements. The use of geological repositories for expended fuel elements as proposed by several countries, including the USA, Sweden and Finland is not an ecological approach; these countries should seriously reconsider their position. In any event, other paths should be explored, including long-term temporary storage before reprocessing as well as deep permanent storage after reprocessing.

Figure 8. Stainless steel container (© Photo Bruno Comby Institute www.comby.org)

4.2. **To reduce the quantity and volume**: new fuel cycles might lead to reduced quantities of waste and even to some transmutation. Research in this direction should therefore be continued. Just as the Russians have built BN600 and are planning BN800 and the Japanese continue their work at Monju, we too should be looking forward to a European project for the construction and exploitation of a fast neutron reactor of the EFR [7]

4.3 **To store nuclear waste temporarily on the surface or in shallow repositories**, as practiced at La Hague, Sellafield and Rokkasho-mura, for a few decades at most. This solution is not as safe as long-term disposal in a deep repository. Temporary storage on the surface or in shallow repositories is suitable for spent fuel awaiting reprocessing, and to allow freshly produced vitrified waste to cool before transfer to permanent storage. The lower the temperature, the easier the task of transfer to permanent storage, and the better the long-term conditions of storage.

4.4 **To store the final waste in deep geological strata**. This relatively simple, useful and ecologically necessary procedure would ensure that these radioactive substances are isolated from the biosphere long enough for their radioactivity to decay to a level comparable to that of the mineral from which they were originally extracted. This is the solution recommended by all international authorities. Life on Earth is concentrated in a very thin surface layer and in the atmosphere surrounding it, and cannot be affected in any manner by deep underground disposal of nuclear waste. Such storage might be designed to be reversible, at least for a certain period of time – some decades, say. But we must certainly not bury spent fuel elements before they are reprocessed; they will constitute a valuable strategic energy resource and will be much sought out by followng generations.

5. Conclusion

Since these safe solutions are now available, we have no right to transmit unprocessed nuclear waste to future generations in an open-ended way. It would be well if the interval between the service provided to our citizens – that is, a supply of clean, abundant and inexpensive electricity – and reprocessing and underground storage of the waste not exceed forty years. In other words, the generation which benefits from nuclear energy should bear the burden of reprocessing the corresponding spent fuel and storing the waste in a safe manner. This is all the more imposed upon us by the fact that the funds to implement these solutions are available.

If we put off such action, we run the risk that the funds may be diverted to other ends. It is thus imperative that the countries now using nuclear energy decide TODAY upon a definitive solution to the question of nuclear waste.

In public debate, an essential aspect is that the public be informed. And the information provided must be as complete, straightforward and objective as possible, avoiding the usual clichés. Toward this end, our association of Environmentalists For Nuclear Energy, which gathers over 8000 members and supporters in more than 50 countries, will continue its work of providing better information to the public on the question of nuclear waste. It is our purpose to construct, collectively and with the participation of every one of us, a world offering the best of opportunities to all, and especially to the developing countries where demand for energy can only increase.

To summarize, there is not *one* solution, but rather *several* complementary solutions to the problem of managing high-level and medium-level long-lived radioactive nuclear waste. We must pursue research on transmutation, continue to reprocess spent fuel and immediately begin work on underground storage. Failure to act now would be irresponsible; otherwise, our children will blame us for our negligence, and with just cause.

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