Position Paper

Irradiated Fuel and Waste Management: the Achille's heel of the nuclear industry?

ENS Higher Scientific Council Position Paper[1]

The management and final disposal of irradiated fuel and nuclear waste is often presented by the media and perceived by the public as an unsolved problem, which hampers the future of nuclear energy. However, the nuclear industry took care of this problem very early on, and has developed proven technical solutions.

Technical solutions and political advances for irradiated fuel and waste management

Whereas large volumes of short lived radioactive waste are already handled by the nuclear industry in surface storage facilities, the management mode of high activity, long lived waste has not been decided in detail and is still under study in all countries using nuclear power. Scientific knowledge is in progress, technical solutions are emerging, in a context where science and technique interact strongly with social and economical issues. Many technical advances have been made during the last twenty years in fields as varied as partitioning, transmutation, waste conditioning, storage and underground disposal.

The main principles of nuclear waste management

Reducing the dangers induced by waste, decreasing its volume, partitioning the waste into homogeneous categories: these principles that are familiar to domestic waste management also apply to nuclear waste.

With a closed fuel cycle, waste management from its production to its final destination looks like a chain whose links are treatment-recycling, conditioning, storage and disposal of the final waste. With the open cycle option, the first link is absent.

Recycling, the first link of the irradiated fuel management chain

The first option is thus to close the fuel cycle. This option has a very important influence on the nature of the waste produced, as well as on its ulterior management.

The alternative options (direct storage of spent fuel or specific conditioning of separated actinides) have been studied throughout the world. These options may have distinct advantages for the nuclear industry considered as a whole, but as far as the waste management is concerned, the closed fuel cycle is clearly more favourable, because it offers the possibility of considerably reducing the radiotoxic inventory, and of putting the waste into a stable and safe form. Recently, the economy of this option has been further reinforced by the rise of the price of natural uranium, which provides a powerful incentive to save on fissile matter.

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In the long run, the probable development of fourth generation nuclear power plants will make the closed fuel cycle more widely implemented. With these new plants, one can hope to reduce further the waste toxicity by transmuting actinides.

Indeed, the nature of the final nuclear waste (by definition non recyclable) depends on the nuclear technology at hand: final waste in 30 years may well be different from the present final waste. For example, it may be possible to further reduce the radiotoxicity of vitrified waste by eliminating some radionuclides (eg minor actinides) from the inventory. The exclusion of these radionuclides from the waste would also reduce the exothermicity of the waste, with a subsequent simplification of the waste management. This objective of a cleaner and cooler waste is the main stake for the research on partitioning and transmutation. However, in order to gain a substantial benefit in terms of radiotoxicity, one needs to transmute the separated radionuclides. The technology is already at hand for recycling plutonium, but research is still needed to make the recycling of other radionuclides viable on the industrial scale.

Transmute, recycle: where is the limit?

It is already clear that fission products are not readily transmutable, neither with the present nuclear reactors, nor with the fast reactors envisaged for the future. Whatever the nuclear system, fission products will therefore remain present in the final nuclear waste. The issue of actinides is less certain, since the future of these radionuclides depends on the nuclear reactors available, as well as on the policy of fuel cycle chosen. With the present reactors, plutonium can be recycled under a MOX form, but minor actinides tend to accumulate in the waste. Fast reactors might offer the possibility of transmuting these radionuclides, but this transmutation will remain slow and difficult. Moreover, putting minor actinides in the fresh fuel complicates both fuel fabrication and reactor operation, and one can doubt that those responsible for operating the facilities will be very enthusiastic about taking on this burden. The actinides are very insoluble and immobile in geological media, and could go in an underground repository without compromising its safety. The only important stake for the transmutation of actinides is the relief of the waste thermal loading and toxicity, with the associated reduction of the size and cost of the repository.

The two first links of the irradiated fuel management chain: fuel processing and waste conditioning work well together, and are implemented already in some countries (e.g. France, at the La Hague facility, or Japan at Rokkasho-Mura). Once conditioned under the form of a canister, one still has the problem of deciding what to do with this object. Thanks to their chemical and mechanical stability, the present conditioning forms (concrete, metallic compacted waste, glass) are well adapted to storage, eventually followed by an underground disposal for long-lived waste. These links of the waste management chain are coherent, and this coherence will be kept with the development of fourth generation fast neutrons nuclear systems, since future reactors will call for a closed fuel cycle with processes of treatment of the spent fuel that will complete rather than replace the existing process.

Waste conditioning, the essential second link in the chain of waste management

The industrial processes for the conditioning of nuclear waste are already ripe and operating. Basic research has permitted a good understanding of the physico-chemical mechanisms at play during both the fabrication and the ageing of the conditioning matrixes, glass, concrete or bitumen. The safety study of waste management relies on this scientific knowledge of the long-term behaviour of the confinement matrixes.

Suitable conditioning forms have been developed for all types of waste.

Solutions of fission products and minor actinides, which possess by far the highest radiotoxicity, are vitrified in facilities which work on the industrial scale. The quality of the glass obtained is well established. For instance, the R7T7 glass developed for the confinement of fission products from the processing of light water spent fuel has become a world reference. There are probably more scientific articles on this glass than on any other industrial glass!

Metallic waste from the spent fuel bundles is compacted and introduced in steel canisters identical to the ones used for glass casting. The radiological impact of this waste form in a geological repository would probably be very small.

Technological waste associated with the exploitation of nuclear facilities is conditioned in concrete. Most of this waste is short-lived, low or medium activity. In many countries, including France, this waste is already stored in dedicated surface or subsurface facilities. A wide spectrum of concrete formulae has been developed to fit the diversity of the waste to be conditioned, solid or liquid. These concrete packages are well characterised, and a sufficient knowledge of their alteration mechanisms enables one to guarantee their confinement properties.

What to do with the "final" waste?

Radioactivity possesses two important characteristics, which might somewhat mitigate the fear it inspires: first it is easy to detect, even at very low levels. A unique disintegration can be detected, whereas billions of billions of molecules must be present to detect chemicals. Second, once detected, it is relatively easy to protect oneself from the radioactivity, by combining shielding, distance, limitation of the exposure time, and radioactive decay.

The problem of the final nuclear waste then boils down to confining the radionuclides in an isolated, shielded installation, during a time long enough for radioactive decay to operate. This is the idea behind both storage and underground disposal facilities.

Interim storage, a temporary solution that gives flexibility for the management of waste

Whatever the fate envisaged for irradiated fuel, it must at first be stored temporarily. Countries which have chosen the open fuel cycle option must store the spent fuel before its disposal; the ones which have opted for the closed fuel cycle option must store it a few years, in order to let it cool before its processing. The vitrified final waste is then stored temporarily. In all cases, storage is a temporary solution which provides flexibility for the management of waste, because it permits to let the waste cool down, thereby decreasing its thermal load before its ulterior loading in the disposal facility, and therefore the cost of the installation. However, the safety and security of storage facilities is less well assured than that of an underground disposal facility, because these installations demand active maintenance, and are more vulnerable to human intrusions. Even if economical arguments plead in favour of a long-term interim storage, public policy would be well advised to limit the duration of this storage to a reasonable maximum, of the order of the duration over which maintenance of the installation can reasonably be guaranteed.

Underground disposal, the last link of the chain. A final place for the final waste

Last but not least, one has to find a final place for the final waste. The deep geological underground disposal seems to be the only long-term solution which does not require a continuous control by society. A general consensus has been reached on this issue, under the aegis of the International Agency for Atomic Energy (IAEA) and of the Nuclear Energy Agency of OECD. No better alternative solution has appeared.

Disposal in a geological repository will always be an expensive operation, hence the need for reducing the volume and the thermal power of the waste as much as possible. These two parameters largely determine the repository capacity, and therefore, its duration of exploitation and its cost. The processing of spent fuel is already a major step towards this reduction, since it involves the removal of the uranium (which represents 90 % of the mass of the spent fuel) and the removal of the plutonium (which represents the major contribution to the total waste radiotoxicity). The American Advanced Fuel Cycle Initiative (AFCI) is exemplary in this respect. After more than 20 years of efforts leading to the project of disposal of spent fuel in the Yucca Mountain repository, the US Department of Energy is reconsidering the optimisation of its use, and the nature of the objects that will be disposed of.

Underground disposal: a simple and robust concept

The safety of the underground disposal relies on its capacity to confine radionuclides within an underground facility, until radioactive decay has brought their radiotoxicity down to an acceptable level (usually a level equivalent to that of a natural uranium deposit). The safety demonstration of such an installation will rely *in fine* on the confidence that the installation will behave as foreseen. Studies have thus been made to better understand the evolution of the waste packages in an underground environment, and the migration of radionuclides through the man-made and geological barriers that isolate them from the biosphere. Removing from the waste the long lived radionuclides which contribute most to its long-term radiotoxicity could significantly shorten the duration over which the waste will remain dangerous. This could also reduce the scientific uncertainties associated with very long timescales. This option will only be open if and when one is able to separate and transmute minor actinides.

The concept of underground disposal is flexible. Initially designed with the idea of definitively and irreversibly getting rid of the waste, the underground disposal concept has evolved in all nuclear countries towards the concept of reversibility (which means being able to retrieve the waste from the repository after some time). That approach seems to have become a prerequisite for public acceptance of these installations. It contributes to modifying the image of underground repositories, without changing their general conception too much.

Thanks to the efficiency and the redundancy of its barriers, underground disposal is also a robust concept. The radiological impact of a deep geological waste disposal evolving normally should remain very small, local and delayed. However, the altered scenarios of the evolution of the repository, which are by definition unpredictable (especially those associated with human intrusions), can have a larger impact.

Strictly speaking, the safety of a deep geological repository cannot be *demonstrated*, because the very long timescales make direct experiments inaccessible. Therefore, the objective must be more modest: showing by means of partial experiments that the main physical and chemical phenomena at play are understood and mastered, and therefore validating the main pieces of the modelling of repository long-term evolution. The study of natural and archaeological analogues contribute to this process of confidence building, showing that in sites like Oklo, radionuclides have been confined over extremely long durations.

All national and international studies show that the impact of a repository on Man and on the Environment will remain negligible, even in the very long-term. In order to convince, it will be necessary to build confidence with convergent indications showing that all the possible events liable to affect the repository have been envisaged and are found to be within acceptable limits… in short, that the repository conception is well mastered.

This confidence is already there among most of the specialists, but not in the public. And, as long as public opinion doubts, the politicians will tend to postpone their decisions. The example of Finland and Sweden, two countries which decided democratically to build geological repositories for nuclear waste, shows that it is possible to overcome this obstacle.

Let us behave responsibly, let us try to be sensible

We have inherited nuclear waste from our predecessors, and we produce some waste ourselves. We cannot transmit this burden to our children, that is why we must put all our efforts into minimizing final waste, and managing this waste in the best safety conditions, with the technologies available today (which is why the concept of "retrievability" is so important??). The technologies exist, their implementation requires a political decision. Contrary to a view widespread within the public, much progress has been made towards technically and socially acceptable nuclear waste repositories. Most of the experts agree, but the public and the political circles are still reluctant, and must be convinced by a faultless process of confidence-building. In any case, one thing appears very clear to the authors: it would be an irresponsible attitude to store this waste for a long time, awaiting a hypothetical scientific advance. Science also has its limits!

As has been shown above, even if one considers only the scientific and technical aspects, waste management is a multidisciplinary challenge. Knowledge in reactor physics is needed, because the nature of the waste produced depends on the reactors used; knowledge in chemistry, to determine which radionuclides are left in the waste after the processing of the fuel; in physico-chemistry and material science to understand waste conditioning and the long-term behaviour of waste; in engineering, to master the thermal phenomena at play in the storage installations; in mining engineering to design the underground repository; in earth sciences like geo-chemistry to understand and predict the long-term evolution of these installations; in radioprotection to evaluate the impact of all the processes and installations on Man and Environment.

Nuclear energy will continue its development in the world, despite the Fukushima accident. Even in the European countries which decided the phasing-out of nuclear energy, there is a legacy of nuclear waste that must be dealt with. The adequate scientific and technical background for waste management already exists. Management decisions must be taken. Now comes the time for political courage.