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High Level Waste and Spent Fuel: Tackling Present and Future Challenges

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The future of nuclear power depends on several factors, such as competitiveness, the non-proliferation regime, and its social acceptance in industrialised countries as well as in emerging economic areas. The social acceptance issue encompasses several topics such as safety, communication, and management of high level waste and spent fuel. The latter is a particularly key issue which will help shape the global environment surrounding nuclear power.

A consistent answer to the waste and spent fuel management question will undoubtedly pave the way for an expanding reliance on nuclear power throughout the world. Conversely, mismanaging waste and spent fuel could interfere with the development of major national nuclear programmes.

Seizing the waste and spent fuel management question is a primary imperative for nuclear countries, as most nuclear programmes are now mature in terms of the number of operating nuclear units, while the volumes of waste and spent fuel are increasing accordingly. For instance, in 1997 alone, 10 500 tonnes of spent fuel were discharged worldwide[1] from the 427 nuclear power plants in operation. However, one must draw a distinction between spent fuel and the different types of nuclear waste which countries have to deal with.

First, it should be noted that the treatment of spent fuel differs from one country to another.[2] For some countries, engaged in once-through cycles using the direct disposal option, spent fuel will be packaged and disposed of in underground storage sites after a sufficient cooling period in surface-based facilities. For these countries, spent fuel is labelled as high level waste. To date, the direct disposal option is the reference back-end strategy of countries such as Canada, Finland, Sweden, South Africa and the USA. But no country has completed the direct disposal of spent fuel. Research and development, studies and viability assessments are still underway.

On the other hand, for countries that have embarked on the recycling strategy, valuable materials contained in the spent fuel – uranium and plutonium – are separated and reused in conventional nuclear fuels, while the ultimate residues are properly treated and conditioned before being stored and eventually disposed of.

The recycling path has been selected and implemented by several countries, such as Belgium, France, Germany, Japan, the Netherlands, Russia and Switzerland. This strategy has led to the setting up of a dedicated industrial structure including reprocessing plants, mixed oxide (MOX) fuel fabrication plants, reprocessed uranium conversion plants, waste treatment and conditioning workshops, etc.

In such countries, the categories for nuclear waste directly pertain to the non-recoverable materials to be disposed of after being properly treated and conditioned. Wastes are subdivided into low level waste (LLW), intermediate level waste (ILW), and high level waste (HLW), according to their level of radioactivity and their life span. Examples of LLW are gloves, protective clothing and minor equipment used in the daily operation of nuclear installations. ILW includes, for example, metal components making up the structure of a reactor. Residue from fission products produced by the reprocessing of spent fuel comprises HLW.

From a purely technical perspective, the management of waste does not pose any particular problem, as shown by years of successful and safe operation. LLW and ILW treatment, conditioning, storage and disposal is a routine activity in most of the leading nuclear countries in the world. For instance, LLW and ILW disposal centres have been commissioned in France at Soulaines, in South Africa at Vaalputs, in Spain at El Cabril, and in other countries. The HLW issue is more sensitive, as HLW management demands specific industrial answers due to the high radioactivity of these waste, both during the treatment/conditioning phase and during the interim storage/final disposal step.

Yet, whatever the back-end choice of nuclear countries, waste and spent fuels management must conform to a series of requirements set by contemporary decision-making processes. In that respect, ethical considerations, public acceptance, and political and economic dimensions are the pivotal questions shaping the way nuclear energy is perceived by the public at large and by policy-makers.

This paper intends to present the main international trends affecting the management of waste and spent fuel, taking into account national policies in terms of back-end fuel cycle options.

The Global Pattern

As outlined above, far from being only a technical challenge, the management of waste and spent fuel is driven by non-technical issues, making the whole process more complex. Globally speaking, nuclear power is well accepted by people who clearly perceive the benefits brought by this source of energy, especially when it comes to international issues like global warming. People recognise that nuclear power has real advantages in terms of environmental impacts compared to other sources of energy. However, the management of waste is at the core of public's fears regarding nuclear energy.

Polls[3] indicate that most people are rather reluctant to accept the construction of a waste repository in their vicinity. This seems to be the case for LLW disposal and, with a greater emphasis on the perception of hazards, for HLW disposal. Obviously, the most successful nuclear programmes will be the ones offering the best solutions to the nuclear waste quandary. In that regard, minimisation of waste volume and toxicity is a fundamental prerequisite which should be applied whenever possible.

Over the past few years, the international industrial community has begun to promote a "greener" agenda, meaning that concepts such as "sustainable development" and "the rights of future generations" are now part of the thinking of world business leaders. Applied to nuclear power, these notions call for putting the accent on the best way to address today's needs without endangering the world in which our great-grandchildren will live.

What are the implications for waste and spent fuel management? To put it bluntly, nuclear power will continue to be a widely approved energy source if, and only if, waste volume is the lowest possible and waste toxicity is reduced so as to lessen the impact on future generations.

As previously noted, nuclear countries have developed a two-fold response for waste and spent fuel management. The first, direct disposal, implies that spent fuel – containing plutonium and fission products, making it a really hazardous product – will be buried in a dedicated underground facility. The second one, recycling, makes use of recoverable products – including plutonium – while optimising the conditioning of the ultimate residue.

The Quest for a Comprehensive Solution

When unloaded from the reactor core, the fuel (which initially comprised 100% uranium), contains 96% uranium, 1% plutonium and 3% fission products and other actinides.

Recycling Fissile Materials

Plutonium and uranium are reusable materials. The recycling strategy allows these to be recovered with a high degree of efficiency (99.88% of the fissile materials contained in spent fuel are recovered in modern reprocessing plants). In-depth studies have shown that efficient plutonium extraction lessens the radiotoxicity of the final waste by a factor of 20 to 30, thus easing its underground disposal.

Plutonium and uranium are then available for reuse in nuclear fuel, through fabrication of new fuel for power reactors. Plutonium recycling in MOX fuel is a routine activity in Europe. Japan has decided to initiate its own plutonium-based fuel loading programme, while other Asian countries contemplate its use as a part of their back-end strategies. To date, 29 reactors are loaded with MOX fuel in Europe (15 in France, nine in

Germany, three in Switzerland and two in Belgium), and this figure should increase in the years to come as the French government recently gave the go-ahead to the further use of MOX fuel in 900 MWe-type reactors.

Using plutonium in nuclear reactors is an advantage in terms of energy output (1 gram of plutonium produces the same amount of electricity as the combustion of 1 to 2 tonnes of oil), of raw materials conservation (plutonium recycling means that less uranium will be consumed), and of non-proliferation (both reprocessing / recycling facilities and nuclear power plants are under the control of stringent international and national physical protection and safeguards programmes).

In addition, the utilisation of MOX fuel leads to a reduction of plutonium stockpiles. Whereas a reactor using enriched uranium produces 250 kg of plutonium per year, a 30% MOX fuel loaded reactor produces none, and a 100% MOX reactor (with a full MOX fuel core), burns approximately 60 kg of Pu per TWh generated. Thus, stabilising plutonium production is only the beginning. In the future, with the development of 50% or 100% MOX fuelled reactors, the fuel cycle system could offer the decisive advantage of burning more plutonium than it produces.

Conversely, leaving the plutonium intact in spent fuel will undoubtedly lead to the creation of so-called "plutonium mines", meaning that for hundreds of years a dangerous material could be exposed to the biosphere, either by accident or through a voluntary intrusion. One should not forget that nuclear energy involves dealing with some of the longest-active materials which can be found. This requires extra precautions, as the future of our societies cannot be predicted. We must therefore take all preventive measures, ensuring that the nuclear materials disposed of underground are the least hazardous to future generations. It is a moral responsibility for those who currently take advantage of nuclear energy.

As far as uranium is concerned, its recycling has advantages because reprocessed uranium (representing about 96% of recycled material) can be used in all major types of nuclear power reactor currently in operation. To date, several reactors have been loaded with fuel made out of re-enriched reprocessed uranium in France, Belgium, Japan and Germany. The present low levels of natural uranium prices do not render the recycling of reprocessed uranium route a cost-effective one. Nevertheless, this recycling pathway should not be evaluated solely on the basis of minimising short term fuel cost. A reasoned decision needs to be made within a long term framework, taking into account strategic and environmental considerations in conserving natural uranium resources and reducing ultimate waste quantities.

Reducing the Volume of Waste

As noted above, spent fuel contains only 3% fission products, which are viewed as the final waste product. A real minimisation of waste quantities is therefore achieved through the spent fuel recycling operation, thanks to the wide range of technologies developed by the industrial community.

The rationale for this waste management policy lies in conditioning each type of waste in accordance with its characteristics. This pertains to two categories of radioactive waste, LLW / ILW (these wastes are mostly technological wastes, i.e. wastes generated during industrial operations), and HLW (made of non-reusable parts of the nuclear fuel, i.e. fission products, actinides, hulls and end-fittings).

LLW and ILW are treated and conditioned via normal industrial methods, such as incineration, compaction or cementation. Recycling allows the conditioning to precisely match the characteristics of the waste, including the activity contained. Today, the volume of conditioned LLW generated during the recycling operation is about 1 m^3 per tonne of spent fuel.

Treating and conditioning HLW follows a different pattern. Such waste contains fission products and actinides. Briefly, fission products are highly radioactive, but mostly for a relatively short period, while actinides remain radioactive for several thousand years.

It is necessary to dispose of these wastes safely, and to ensure they will remain innocuous for several thousand years. During recycling, the separated HLW arises in the form of an aqueous solution. In this form, it can be stored safely in stainless steel tanks. However, it is easier to carry out the interim storage in a solid form. In any case, it is necessary to solidify the waste for final disposal. The quest for a suitable matrix in which to solidify HLW gave rise to the choice of glass, which has become the main option worldwide.

The development of this process of HLW vitrification in glass led to the specification of a standardised product which has been approved for HLW conditioning by safety authorities in several countries throughout the world. Today, vitrification of fission products contained in one tonne of spent fuel represents 0.1 m^3 of glass.

The recycling strategy also permits the consolidation of hulls and end-fittings into standardised packaging through a specific compaction process. This process takes advantage of the latest technological achievements and leads to an overall volume of conditioned HLW of 0.5 m^3 per tonne of spent fuel. In other words, HLW conditioning is stable, safe and internationally agreed, while direct disposal of spent fuel requires the development of an appropriate packaging for a product (spent fuel) which was not originally designed for disposal.

The standardisation issue has to be viewed as the cornerstone of the waste management concept of the recycling option. It means that HLW, regardless of its form, its activity and its final destination, will be contained in the same type of package. This is the "Universal Canister Strategy", already implemented by the French reprocessing industry.

Standardised HLW is an industrial product specifically designed to be stored for decades and finally disposed of in underground repository sites. This optimisation of HLW gives countries relying on recycling the ability to rationalise their disposal and waste repository policies. For instance, it will only be necessary to construct a single repository to receive all forms of HLW, whether it is canisters of vitrified glass or of compacted hulls and end-fittings. The use of a standardised industrial product will also lead to the simplification of repository design, with same-sized boreholes and galleries.

The recycling strategy thus introduces a new dimension to the waste and spent fuel management debate, via the use of industrial procedures giving birth to standardised waste forms and making the reuse of valuable materials a reality. But timescale and flexibility considerations are also inherently tied to the recycling strategy.

Timescale and Flexibility

Today, most nuclear countries are assessing their final disposal strategies. Some are trying to locate the most suitable site, while others have undertaken huge research and development programmes aimed at confirming (or voiding) the validity of the choices they have already made. In any case, current back-end strategies, direct disposal or recycling, make it possible to wait for some additional years before the opening of a repository.

In the case of direct disposal, current surface-based interim storage techniques (dry storage in casks or wet storage in pools) allows the spent fuel owner to wait for some years before finding a location for final disposal. Still, the storage period will have to be far longer in this case than in the recycling strategy, pending the construction of an underground final disposal site. Some spent fuel has now been stored for over 30 years, and a period of 50 years could easily be reached before final disposal.

However, in the recycling strategy the timescale issue takes on a different meaning. Between 10 and 15 years are necessary to close the fuel cycle, between the unloading of the spent UO_2 fuel to the delivery of fresh MOX fuel, and the interim storage of final waste and spent MOX fuel. It has to be noted that the recycling of plutonium in MOX fuel can technically reach two or three cycles, while future reactors able to perform multi-recycling tasks are envisioned. As noted, the concept of global management of nuclear materials pertains to MOX fuel as well.

The main difference from the direct disposal option is that within this time lapse the best possible use is made of recoverable materials, while greatly reducing the volume and toxicity of waste, and conditioning it in a form directly suitable for disposal. Furthermore, while the direct disposal option is a static process, recycling brings a useful degree of flexibility through the specific conditioning of different materials. Nuclear plants can continue to operate without fear of being overwhelmed by the problem of spent fuel storage, and wastes are safely treated and conditioned, thus reducing the feeling of urgency associated with the need to find a final disposal site.

Time is an asset when assessing the future of nuclear programmes. Technical developments will continue. For instance, Russia and Japan have recently decided to pool part of their research and development programmes in the fast breeder reactor area. This route seems very promising for the incineration of long lived radioactive elements. Obviously, it will require some time before this can be achieved on an industrial scale.

For the present, while enjoying the benefits of nuclear energy we must prepare for the future to avoid leaving a legacy for coming generations to deal with. The recycling option helps make the concept of "trans-generational equity" a palpable reality.

Assessing the Future

As we enter a new millennium, several leading nuclear countries have begun a global assessment of their nuclear policies, especially with regard to their nuclear waste disposal policy. Answering these difficult questions will take time, and will require firmness from government decision-makers and political representatives. Of course, each country, given its past nuclear experience and the status of its nuclear programme, will make the right decision regarding its own waste and spent fuel challenge.

It is worth underlining that managing waste and spent fuel will require each country to develop a national policy, whatever future developments might be. The very nature of nuclear energy requires national decisions to fulfil national needs. Sharing the burden of waste between several countries, through regional repositories, cannot be envisioned without a strong and individual commitment from countries to national solutions.

France benefits from the recycling strategy. All of its spent fuel is to be reprocessed, plutonium is recycled through MOX fuel, and some reprocessed uranium is also recycled. Wastes are conditioned and stored in dedicated facilities, while studies are underway regarding the underground disposal of HLW. The emphasis is no longer put on global questions such as the quantity of plutonium to be definitely buried, but on public acceptance considerations. The back-end solution exists.

Implementing the French recycling industrial strategy has been made possible because this solution has always been viewed by policy-makers as being driven by national interest. The recent creation of a parliamentary commission on the closure of the Superphénix fast breeder reactor backs this assertion.

Next, a consistent network of research and development bodies, governmental agencies and industrial companies ensures that each and every actor involved in the nuclear fuel cycle is responsible to the others. French nuclear companies and organisations are not isolated. Moreover, one of the reasons behind the successful French nuclear programme is that nuclear waste is the responsibility of the organisation which generates it.

Waste processing, conditioning and transport are the responsibility of the industrial actors, while waste disposal is the responsibility of an autonomous governmental agency. This clear distinction ensures that waste management is simplified, unlike in some other countries where governmental institutions are entirely in charge of managing spent fuel and nuclear waste.

Energy supplies are one of the twenty-first century's most immediate challenges. Due to a fast rate of population growth – the world's population will rise from 5 billion in 1990 to about 7 billion in 2010 – the international community could face a serious shortage of energy resources to meet the demand for electricity. Nuclear energy will play a role in the world energy mix. The duty of the nuclear community is to avoid nuclear programmes being stymied by the waste and spent fuel management issue. The global acceptance of nuclear energy is at stake.

Answers to the waste and spent fuel management issue do exist. The recycling strategy allows valuable nuclear materials to be safely handled and put to good use. It also reduces the volume of final wastes to be stored, and opens the door to an in-depth review of all possible options for the future disposal of those wastes. On the other hand, the "no-choice" option breeds an uneasy feeling of being unable to grapple with the waste and spent fuel issue, which incidentally generates a global negative reaction towards nuclear energy as a whole.

References

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