SPENT-FUEL REPROCESSING: MORE VALUE FOR MONEY SPENT IN A GEOLOGICAL REPOSITORY?

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ABSTRACT

Today, each utility or country operating nuclear power plants can select between two long-term spent fuel management policies:

- either, spent fuel is considered as waste to dispose of through direct disposal,
- or, spent fuel is considered a resource of valuable material through reprocessing-recycling.

Reading and listening to what is said in the nuclear community, we understand that most people consider that the choice of policy is, actually, a choice among two technical paths to handle spent fuel: direct disposal versus reprocessing.

This very simple situation has been recently challenged by analysis coming from countries where both policies are on survey. For example, ONDRAF of Belgium published an interesting study showing that, economically speaking for final disposal, it is worth treating spent fuel rather than dispose of it as a whole, even if there is no possibility to recycle the valuable part of it.

So, the question is raised: is there such a one-to-one link between long term spent fuel management political option and industrial option?

The purpose of the presentation is to discuss the potential advantages and drawbacks of spent fuel treatment as an implementation of the policy that considers spent fuel as waste to dispose of. Based on technical considerations and industrial experience, we will study qualitatively, and quantitatively when possible, the different answers proposed by treatment to the main concerns of spent-fuel-as-a-whole geological disposal.

INTRODUCTION

Today, nuclear energy provides 17 % of the world's electricity supply. Nuclear electricity is produced using over 400 reactors, some 350 of them being pressurized or boiling water reactors. They are in operation in approximately 20 countries. The availability factors of nuclear reactors have considerably improved in the past 20 years (especially in the US where the average availability factor is close to 90 %), representing an increase of energy output and consequently giving nuclear power a better competitive edge. Moreover, it is expected that the number of nuclear reactors is going to increase worldwide in the next decades (need for added capacity to supply sufficient energy - the engine of the economy) thus the need for geological repositories too.

Spent fuel management is a key issue for the sustainability of nuclear power. Spent fuel management including transportation, storage and final disposal is one of the most sensitive issues for the future of nuclear energy from both technological and economical aspects, not to mention the public acceptance aspects.

Today and in the next few decades, the majority of spent nuclear fuel comes from LWRs.

Two long-term spent fuel management policies are possible :

- either, spent fuel is considered waste to be disposed of,
- or, spent fuel is considered a resource of valuable material.

In both cases, a geological repository is necessary to dispose of the waste, which can be either spent fuel or ultimate waste from reprocessing.

The nuclear fuel cycle needs safety, life cycle cost reduction, resources optimization, environmental impact minimization, proliferation-resistance and technological maturity.
This paper discusses the potential advantages and drawbacks of spent fuel treatment as an implementation of the policy that considers spent fuel waste to be disposed of.

REPROCESSING TECHNOLOGY

When a spent fuel assembly is unloaded from the reactor, it still contains valuable components. The "ashes of combustion" consisting of fission products represent only 4 % of the spent fuel, while Uranium and Plutonium content are respectively 95 % and 1 %.

For many years, industries of the nuclear fuel cycle have been developing improvements in waste management in order to decrease waste volume and toxicity. In this way, many countries, (France, GB, Japan,…) have implemented reprocessing technologies which provide considerable benefits.

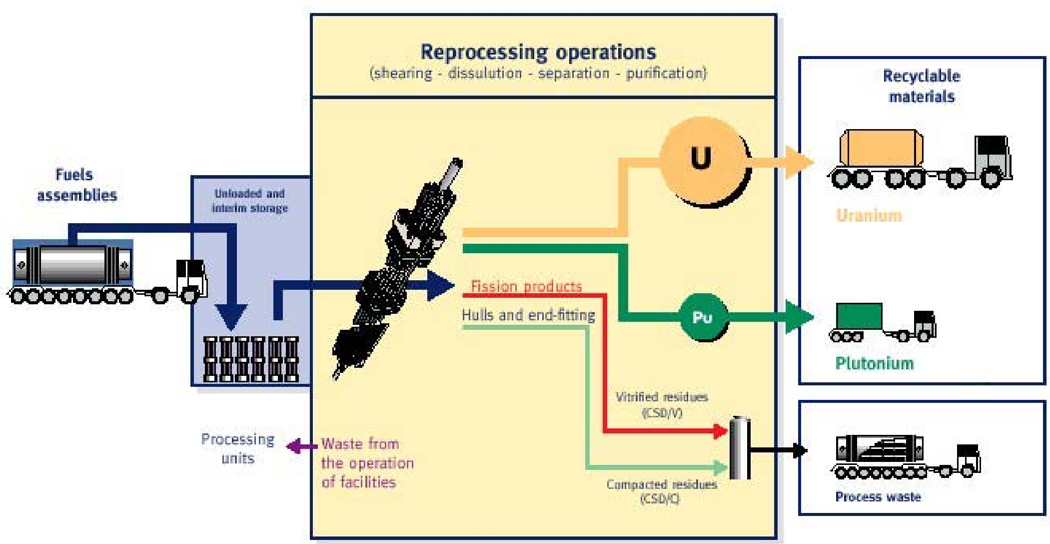

Fig. 1. What is treatment about

Based on the COGEMA Group know-how, this paper describes these technologies and explains how they can help solving waste management issues worldwide.

The main stages of the process involve dissolution in hot nitric acid followed by selective extraction of uranium and plutonium. Valuable materials (U, Pu) are separated from fission products and other actinides. The main industrial equipment used, such as the zirconium rotative dissolver, are compatible with nitric acid media. In addition, solvent extraction technologies (mixer-settlers, pulsed columns, centrifugal extractors) have been further refined to achieve a plutonium recovery rate of about 99,9 %.

Valuable materials

Uranium is the main ingredient in spent nuclear fuel (95 %). Uranium recovered by treatment can be re-enriched and recycled into fresh fuel. If it is not immediately re-used, it can be easily put in interim storage, such as in a strategic stockpile, without raising any proliferation risk. But if, after all, its re-use is not contemplated, reprocessed uranium is considered Low Level Waste (LLW) in most countries not needing to be disposed of in a deep geological repository.

Plutonium represents 1% of the spent fuel. According to policy or energy needs, separated plutonium can be conditioned, stored for future use, or re-used in MOX fuel assemblies. Alternatively, if one chooses to consider plutonium a waste, it can be immobilized in an adequate matrix (glass / ceramic) or conditioned according to the can in canister concept. The volume of waste to be disposed of increases at most by 25 % if all Pu is so disposed of.

Ultimate waste or residues

Ultimate waste is sorted, treated and conditioned as follows :

- High Level Waste (HLW) containing fission products which account for more than 99% of the spent fuel beta-gamma activity is conditioned as residues in borosilicate glass. This glass (vitrified waste) is poured into a Universal Canister, the UC-V. The vitrification process and UC-V technology are in use since many years as an industrially proven activity at COGEMA Marcoule and La Hague plants.
  Today, vitrification of the fission products contained in one metric ton of spent fuel amounts to 0,1 m^3 of glass, or about 0,7 UC-V. Despite these very good results, COGEMA pursues its R&D on vitrification, such as the promising cold crucible technology that would allow increasing fission products incorporation rates in the glass.

- Intermediate Level Waste (ILW) containing structural parts of fuel (hulls and end-fittings) as well as technological waste from reprocessing operation are conditioned as residues in Universal Canister for compacted waste : the UC-C. This new technology has been in operation since the beginning of 2002 and is today a fully implemented industrial reality. The goal is to produce about 1 UC-C per metric ton of reprocessed spent fuel.
  The compaction process allows a volume reduction factor of 4, compared to the previous process of cementation implemented at La Hague.

The volume of one UC is 0.18 m^3.
The quality of the produced residues fulfils technical specifications that guarantee the characteristics of the residue. Residues are packaged according to specifications agreed by the

safety authorities of our customers, i.e. Australia, Belgium, France, Germany, Japan, Netherlands and Switzerland.

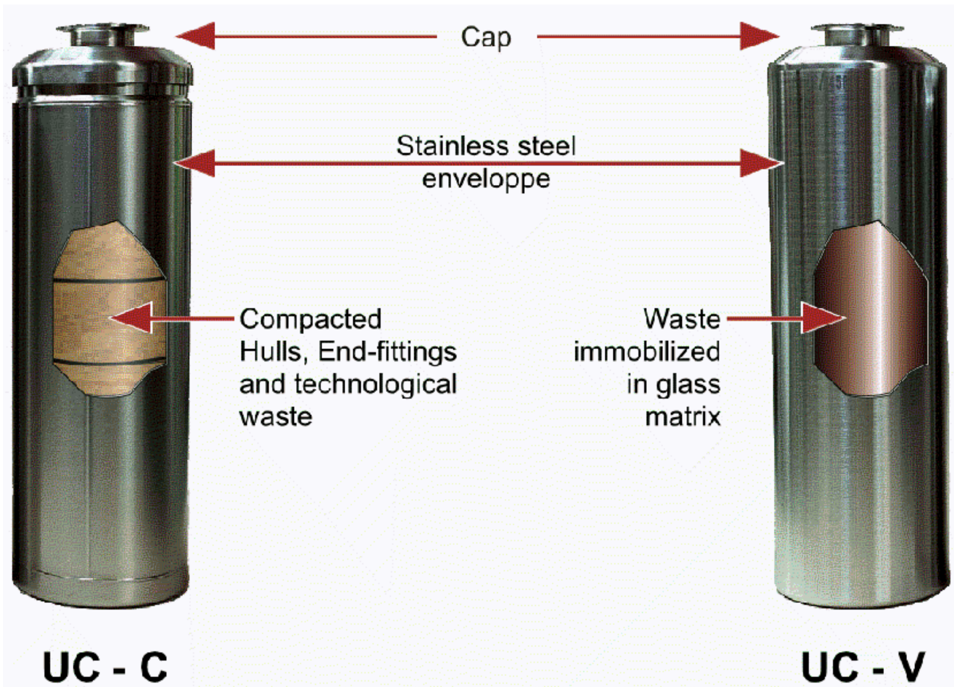

Fig. 2. Universal Canisters

COGEMA's waste management strategy lies in the use of the same canisters geometry for vitrified waste (UC-V) and for compacted waste (UC-C). This standardisation of ultimate waste packages allows simplification of all the further stages (handling, intermediate storage, transport and disposal in a geological repository).

The volume of ultimate waste to be disposed of in any geological repository is drastically reduced by treatment-conditioning. Indeed, the total volume of those residues is less than 0.5 m^3/metric ton heavy metal of initial uranium (mtHM or mtU). This is to be compared with direct disposal of the spent fuel, when the volume to be stored is more than 2 m^3/mtHM.

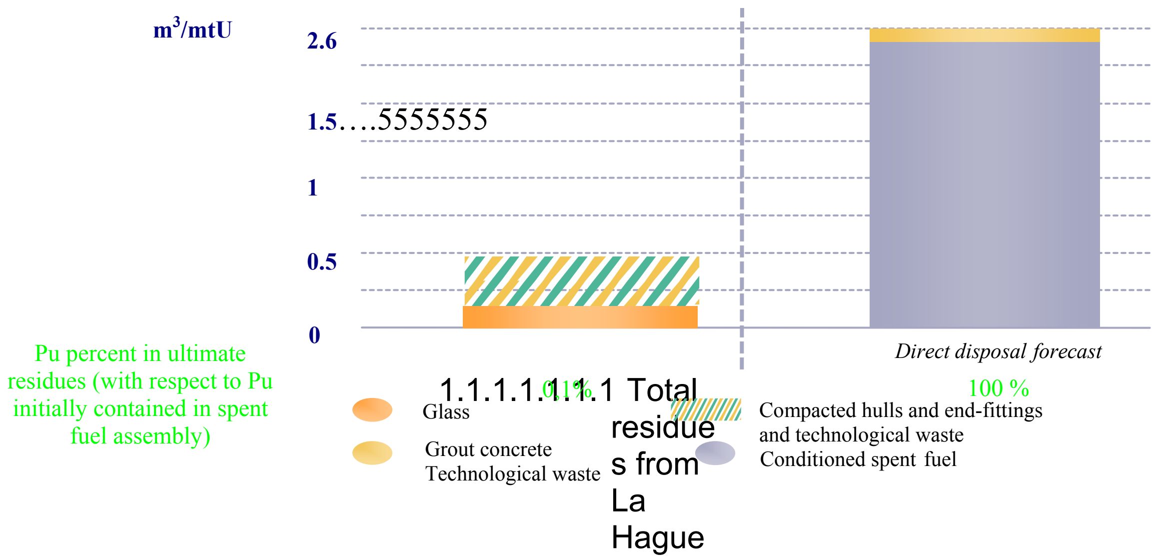

Fig. 3. Waste volume comparison

Direct Disposal vs. Treatment

Spent fuel treatment is a powerful means for managing two streams of highly active waste to be disposed of in geological repositories:

- Fission products and minor actinides (HLW)
- Alpha contaminated end-fittings and hulls (ILW)

So as to optimize final repository design and hence decrease as much as possible repository construction and operating costs, it is necessary that waste be cooled for several decades before being emplaced in the repository in order not to overheat the geological medium and to make it more practical to handle. Indeed, after treatment and conditioning, vitrified fission products and plutonium from a single assembly have the same thermal power output as the whole assembly itself, although in a smaller volume. Therefore, in case of a repository in which the storage capacity is limited by the permitted thermal loading per unit of volume, the quantity of vitrified waste that could be placed in the repository could not exceed the equivalent quantity of spent fuel assemblies if the glass is not cooled for an appropriate period. Once cooled, the equivalent of much more spent fuel in vitrified form can be stored in a fixed volume than whole assemblies.

In addition, by blending UC-V and UC-C, it might be possible to optimize the size of the repository by adjusting the heat load ("axial" dilution). The process consists in alternating UC-V and UC-C in order to decrease linear heat power, which prevents the waste package and the geological barrier from exceeding the maximum design temperature allowed.

Interim storage of waste under the Universal Canister form, even for a very long period, is advantageous since it is already in a form well suited for final disposal, and thus particularly robust. On the contrary, spent fuel is not designed for long term storage and would require more resources to meet safety requirements during a similar cooling period.

Interim storage facilities can be designed for storing:

- either both UC-V and UC-C together, benefitting from the advantages of geometrical standardization, for up to a century or more.
  The facilities can be modular. Each pit comprises rows of wells containing the canisters. Cooling of the containers is achieved using natural air circulation in a jacket enclosing each well. Thus, cooling air is not in contact with the containers.

- or UC-V in a facility as above and UC-C in storage cells.
  Cooling of the storage cells is ensured by forced convection of air in order mainly to control hygrometry. The loading capacity of such a storage facility is then very high: about 13 UC-C/$m^2$of building (storage area), or about 13 tHM/m^2.

Table I. Interim storage density of waste

STORAGE IN WELLS **Vitrified waste**	**COGEMA La Hague**	**≈ 10 t to 30 t eq HM/ m^2**
STORAGE IN WELLS **Compacted waste**	**COGEMA La Hague**	**≈ 13 t HM/ m^2**
STORAGE IN CASKS **Spent fuel**	**GORLEBEN TYPE**	**≈ 4,7 t HM/ m^2**

The result is that conditioned HLW corresponding to one metric ton of spent fuel (about 2/3 of a UC-V and less than one UC-C) can be safely stored for a very long period of time using a surface of about only 0.1 m^2/tHM.

Such facilities are in operation at La Hague.

Economics

Previous studies have shown that there is no much difference between the cost of direct disposal and reprocessing.[1]

Moreover, the cost of treatment services has constantly and significantly decreased over the last decade.

Recent studies have even shown that a deep geological repository would be close to 3 times more expensive (Safir 2 study in the case of Belgium [2]) for spent fuel direct disposal than for disposal of the waste (Universal Canister) from reprocessing. Obviously, the cost of construction and operation of a reprocessing plant has also to be taken into account.

In case of an analysis of a realistic scenario, we have to consider that the time schedule of the two options cannot be the same because of the thermal constraints previously described.

Instead of a first geological repository and a second one (necessary to dispose of all spent fuels) a few decades later, the Reprocessing option entails the investment of a reprocessing plant but enables to postpone for 30 to 50 years the commissioning of the first repository (during cooling time of UC) and for more than 100 years for the second repository. Economic balance may well tip towards the Reprocessing option, but this analysis has to be performed with real data of an existing project.

CONCLUSION

We have shown in that paper that it would be possible to overcome the apparent one-to-one link between long term spent fuel management political option and industrial option.

Spent fuel treatment could benefit a spent fuel management programme, in a sustainable development strategy, by reducing ultimate waste volumes, assuring a safe and secure intermediate storage of high level waste before it is eventually disposed of in a geological repository and offering a choice of either recycling fissile materials or immobilizing also plutonium, if considered waste.

Moreover, such a technical option is probably economically attractive, especially thanks to the implementation of proven reprocessing technologies and by enabling one to dispose of more spent fuel in a given geological repository. Complementary studies have to be performed to confirm on specific sites that spent fuel treatment create more value for money spent in geological repository.

REFERENCES

[1] The Economics of the Nuclear Fuel Cycle – OECD/NEA 1994

[2] Technical overview of the SAFIR 2 report, Safety Assessment and Feasibility Interim Report 2 (NIROND 2001-05 E)