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Possible Used Fuel Management Options For A Single Reactor Utility

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ABSTRACT

Used nuclear fuel generated by the operation of Nuclear Power Plants (NPP) needs to be managed in a safe, responsible and effective way. Whereas utilities managing several NPP can implement large scale used fuel management operations, a single reactor utility will chose solutions adapted for relatively low amount of used fuel.

There are currently two different approaches for managing used fuel:

- Open fuel cycle, or "once-through" strategy, where used fuel is considered to be waste and disposed of after wet or dry interim storage following in-reactor use;
- Closed fuel cycle, or "recycling" strategy, where used fuel is considered as valuable material as it mainly contains reusable uranium and plutonium and thus recycled; such strategy can be implemented directly after in-reactor use without interim storage step and can also be put in place after interim storage; by treating used fuel, 96% of the nuclear material is recovered and recycled as Mixed OXide (MOX) fuel and Enriched Reprocessed Uranium (ERU) fuel; the remaining 4% of non-recyclable material, as well as cladding and structural elements of fuel assemblies, are packaged for final disposal.

In addition, long term interim storage of used fuel has been retained by some states until decision is made for one or the other of the two available options, keeping in mind that interim storage, even long term, is a waiting solution and not a sustainable one.

For all options, disposal is the final radioactive waste management step: either direct disposal of used fuel or disposal of final residual waste remaining after used fuel treatment.

The purpose of the paper is to present the possible used fuel management options for a single reactor utility, clarifying advantages and drawbacks of each of them according to following criteria: safety, security, sustainable development, environment protection, non-proliferation, public acceptance, economy.

Keywords: used fuel, sustainable, radioactive waste, open fuel cycle, closed fuel cycle

1 INTRODUCTION

With sustainable development, environment protection, and public acceptance in mind, single reactor utilities (and states) are looking into their options for used nuclear fuel (UNF) management. UNF needs to be managed in a safe, responsible and effective way.

There are two options for UNF management: open fuel cycle with direct disposal and closed fuel cycle with recycling of UNF (see Figure 1).

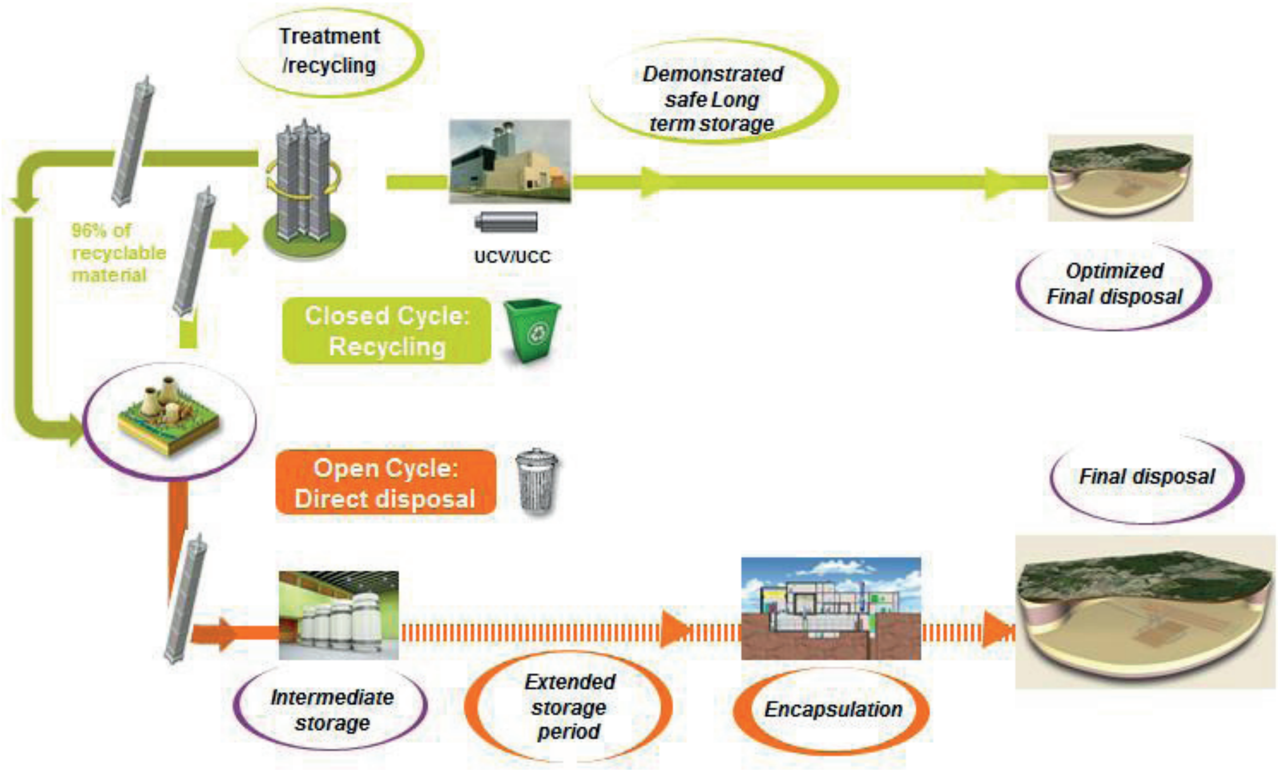

Figure 1: Two options for UNF management, direct disposal and recycling

These options can be implemented either in the state itself or in the framework of an international cooperation program: for example, ERDO working group in which a number of European counties/utilities currently take part, is aiming at investigating the feasibility of implementing shared solutions for safe and very long-term management of long-lived nuclear waste.

In addition, long term interim storage of UNF has been retained by some states until decision is made for one or the other of the two available options, keeping in mind that interim storage, even long term, is a waiting position and not a sustainable solution.

For all options, disposal is the final radioactive waste management step: either direct disposal of UNF or disposal of final residual waste remaining after used fuel treatment. It is widely accepted in the technical community that the only currently feasible method to ensure very long-term safety for High Level Waste (HLW) or UNF is isolation in deep, stable geological formations, usually several hundred meters or more below the surface

The paper presents a panorama of UNF management available options for utilities operating a single reactor or a small fleet of reactors, clarifying advantages and drawbacks of each of these options according to following criteria: safety, security, sustainable development, environment protection, non-proliferation, public acceptance, economy.

The following factors may especially influence the decisions to make:

- Remaining reactor lifetime, lifetime extensions
- Need for extended interim storage of UNF before availability of a definitive solution
- Uncertainty concerning geological disposal availability (incl. schedule).

2 OPEN FUEL CYCLE: ADVANTAGES AND DRAWBACKS

In case of open fuel cycle, or “once-through” strategy, used fuel is considered as waste and disposed of after several decades of extended wet or dry interim storage (see Figure 2) which have been following in-reactor use. There are two main reasons for this need to extend the initially designed storage capacity on reactor site before evacuation of UNF to the final repository can be implemented:

- Developing a final repository is a very long process
- 40 to 60 years of storage are mandatory for the UNF to be cooled enough so that there is no need to include forced ventilation system in the disposal.

Figure 2: Examples of UNF interim storage: centralized pool and dry storage casks

After storage and before disposal, the UNF needs to be encapsulated in a corrosion resistant and mechanically stable container, which will provide isolation for thousands of years.

Most programmes under development worldwide for direct disposal of UNF consist in deep geological disposal either in clay or granite. Tuff was the host rock for Yucca Mountain project in the US, and salt is still considered as a possible option in the US as well as in Germany and Spain.

The most advanced states in the process of setting a final repository for UNF are Finland and Sweden which are considered as benchmark for other states.

As open fuel cycle strategy states, Finland and Sweden have been developing the KBS-3 approach: UNF first is encapsulated in copper, and the copper canisters then are placed in granite basement rock at a depth of about 500 meters and surrounded by bentonite clay.

In addition, final repositories for UNF require implementation of safeguards in order to comply with non-proliferation objectives aiming at detecting any diversion of declared nuclear material or any undeclared nuclear material activity. The IAEA figure 3 below illustrates control points that could be implemented in the framework of a deep geological repository including used nuclear fuel.

It is to be noted that this figure does not show the virtual containment controls that are to be implemented according to IAEA once the repository will be closed.

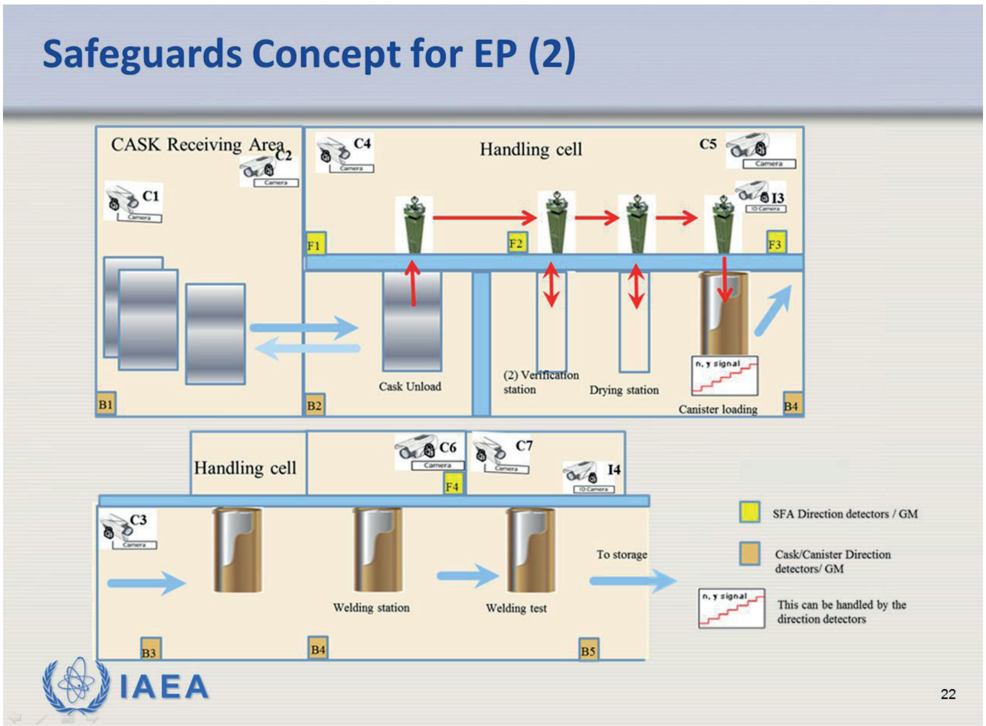

Figure 3: Safeguards control points in UNF deep geological repository concept [1]

Compared with a closed fuel cycle, a direct disposal approach presents several drawbacks as it leaves to future generations:

- Surveillance of very long-lived high level radioactive waste (need for one million years for UNF to reach ore radioactivity level) and proliferating material (security of used fuel inventories becoming a challenge taking into account terrorist attacks context), during extremely long periods of time
- Management of large majority of the safety and economical risks.

On the other hand, the open fuel cycle strategy has several advantages:

- It does not require separation of plutonium which is, in some societies, a benefit regarding public acceptance
- The high expenses are significantly postponed as majority of the back-end management funding is required for the encapsulation, the geological repository and the long-time surveillance.

A utility/state operating a single reactor or a small fleet of reactors can chose the open fuel cycle strategy with the objective of developing with others an international disposal. During such development, the utility would need to implement interim storage of UNF. Depending on requirement for flexibility, modularity, security, short-term cost effectiveness, the utility will chose among the various available solutions: dry storage casks, vault dry storage, wet storage.

3 CLOSED FUEL CYCLE: ADVANTAGES AND DRAWBACKS

In case of closed fuel cycle, or “recycling” strategy, used fuel is considered as valuable material as it mainly contains reusable uranium and plutonium and is thus recycled. Such strategy can be implemented directly after in-reactor use without interim storage step and can also be put in place after interim storage. By treating used fuel (see figure 4), 96% of the nuclear material is recovered and recycled as Mixed OXide (MOX) fuel and Enriched Reprocessed Uranium (ERU) fuel; the remaining 4% of non-recyclable material, as well as cladding and structural elements of fuel assemblies, are packaged for final disposal.

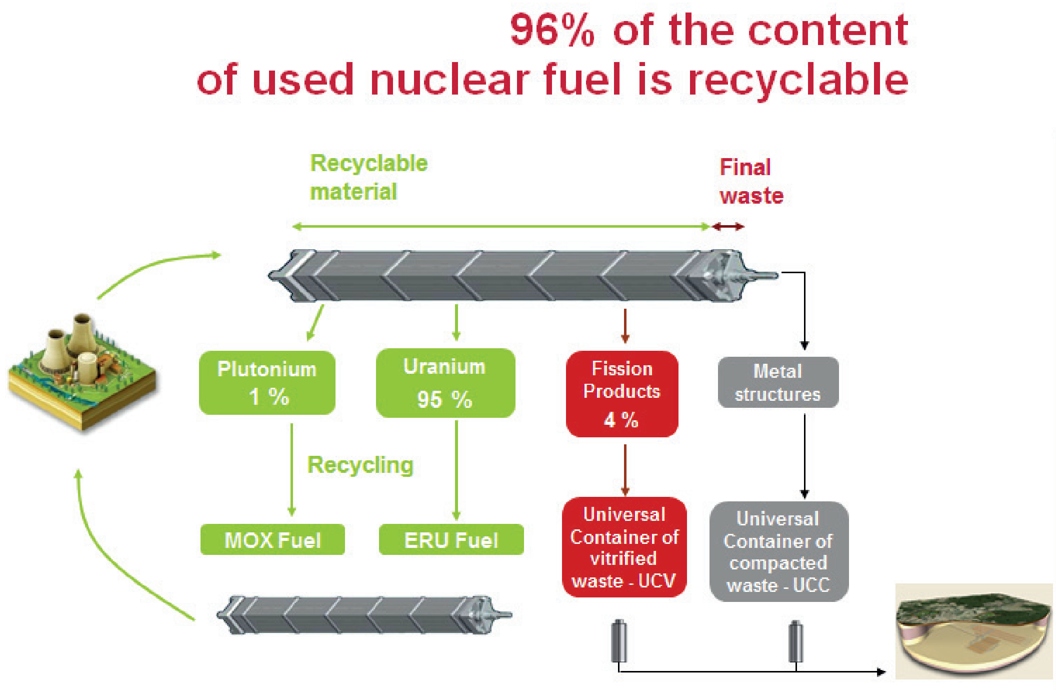

Figure 4: UNF recycling – 96% of the nuclear material is recovered

Several states have chosen the closed fuel cycle strategy including a state with a small fleet of reactors: France, Russia, China, India, Japan, the Netherlands.

After recycling of UNF, the residual waste is conditioned in very stable form and stored while waiting for final disposal either in vault storage or in dry storage casks facility.

The most advanced state in the process of setting a final repository for universal canisters is France, considered as benchmark for other states: the project consists in deep geological disposal in clay.

UNF recycling brings huge benefits on final repository as it:

- Leads to a drastic reduction of the volume of conditioned/packaged HLW and long-lived intermediate level radioactive waste (LL-ILW) for disposal, thanks to the removal of uranium and plutonium
- Decreases the long-term radiotoxicity as well as the short-term heat load of HLW to be disposed of
- Eases final repository design as safeguards are not required thanks to uranium and plutonium removal from final waste; this advantage coupled with the reduction in waste volume, long-term radiotoxicity and short-term heat load of HLW lead to a strong optimisation of the final repository
- Gives additional time for implementing the final disposal repository taking into account the demonstrated stability of final waste (stored pending disposal) and ease of above ground storage
- Eases public acceptance process in the framework of final repository implementation
- Reduces the risks associated with the uncertainty surrounding final disposal costs.

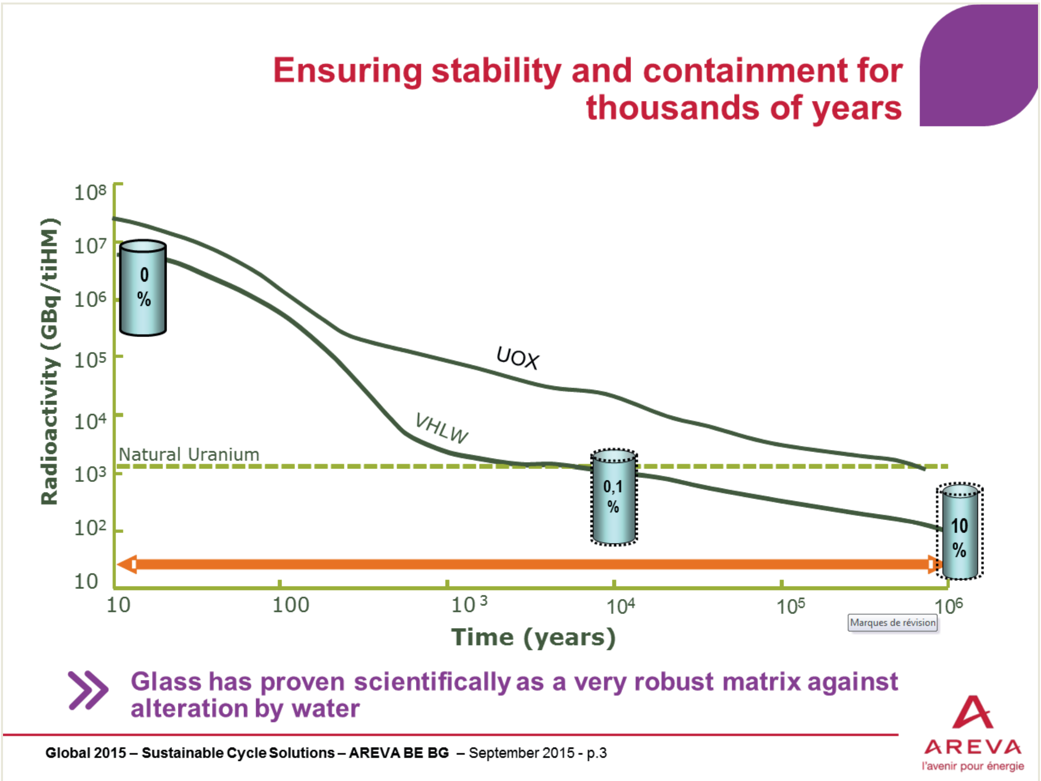

Figure 5: UCV radioactivity decrease and glass matrix robustness [2]

Recycling approach presents two main difficulties:

- Public acceptance may not be in favour of the recycling activity, with a misled but usual perception that plutonium is "produced" in the treatment facility, rather than retrieved and reused in recycled fuels (plutonium being in fact produced through irradiation in reactors)
- Strong financing must be implemented upfront: an important share of the back-end management funding is required for recycling the fuel, while funds dedicated to further storage and disposal are more limited as volumes and risks significantly decrease vs open cycle options.

On the other hand, the advantages of closed fuel cycle strategy are numerous:

- It is highly sustainable as it removes for future generations the burden related to management of very long-lived high level radioactive waste (meaning the long-lived HLW to manage reaches uranium ore activity level in 2,000-3,000 years as compared to UNF activity which needs about 10^6 years for getting to uranium ore activity level, see figure 5), proliferating material, and economical risks
- It facilitates the public acceptance about final repository implementation and strongly optimizes its design thanks to
  - no requirement for safeguards
  - drastic reduction in waste volume, long-term radiotoxicity and short-term heat load of HLW
  - no conditioning or repacking facility needed.

A utility/state operating a single reactor or a small fleet of reactors can chose the closed fuel cycle strategy by implementing recycling with a recycling services provider like AREVA in France.

Uranium and plutonium recovered from UNF recycling can then be reused either in the utility own reactor(s) or in third party reactor(s), depending on utility reactor's lifetime.

One to two decade(s) after recycling, the utility will receive the final waste remaining after UNF treatment, conditioned into universal canisters and can store them in vault storage or dry storage casks, both with simplified design compared to UNF storage.

As for the final step of radioactive waste management, the final disposal, the utility/state may develop with others an international disposal, bringing to it the benefits of having recycled UNF.

From a global point of view, it will be technically simpler and economically more effective to implement an international disposal for various types of universal waste canisters than for UNF with various origins.

4 CONCLUSION

There are two options for UNF management, each of them presenting several advantages and drawbacks: open fuel cycle with direct disposal and closed fuel cycle with recycling of UNF.

Direct disposal presents several drawbacks as it leaves to future generations a burden related to:

- Surveillance of very long-lived high level radioactive waste and proliferating material
- Management of large majority of the safety and economical risks.

On the other hand, this strategy has several advantages:

- It does not require separation of plutonium which is a benefit regarding public acceptance
- The high expenses are significantly postponed as majority of the back-end management funding is required for the encapsulation, the geological repository and the long-time surveillance.

UNF recycling presents two main difficulties:

- Public acceptance may not be in favour of the recycling activity
- Strong financing must be implemented upfront as large part of the back-end management funding is required for recycling the fuel.

On the other hand, the advantages of closed fuel cycle strategy are numerous:

- It is highly sustainable as it removes now the burden related to management of very long-lived high level radioactive waste, proliferating material, and economical risks
- It facilitates the public acceptance about final repository implementation and strongly optimizes its design.

A utility or state operating a single reactor or a small fleet of reactors will chose the UNF management strategy based on deep assessment of international regulation, own state regulation specificities, economics, certainties, financial and technical risks, energetic independence, sustainability. For this, the utility can benchmark the strategies chosen by others and also use the services providers industrial experience.

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