# NUCLEAR SPENT FUEL STORAGE: CONCEPTS AND SAFETY ISSUES

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**Abstract**

The IRSN (Institut de radioprotection et de sûreté nucléaire), the French technical support organization, was asked by the parliamentary inquiry Committee on the safety and security of nuclear installations to provide a report on the concepts and safety issues regarding storage of spent fuel from nuclear power reactors. Based on its expertise in France and on its knowledge acquired during services performed abroad, IRSN examined the concepts of wet and dry spent fuel storage existing worldwide and in France, as well as the associated safety issues. In conclusion, IRSN emphasizes that the choice of a type of spent fuel storage must be assessed with regard to the following considerations. The two types of spent fuel storage, wet or dry, do not completely serve the same needs, as wet storage is essential for spent fuel with high residual heat and dry storage is well suited to highly cooled fuels. In any case, these two types of storage are complementary, but the choice of one or the other largely depends on national choices in terms of spent fuel management (reprocessing or not).

The type of spent fuel (UOX, MOX…) affects the choice of the type of storage, at least for a certain period of time. Thus, spent MOX fuels have a higher residual heat and this decreases less rapidly. Their cooling time before being placed in dry storage is thus much longer than for spent UOX fuels. From the safety point of view, whatever the type of storage, the key parameter is the residual heat of the spent fuel to be stored. In this respect, wet storage, which is generally used for spent fuel with higher residual heat, requires more extensive safety provisions than dry storage where safety relies on passive systems. IRSN also considers that a particularly important point for the safety of spent fuel management operations is the control of zirconium fuel cladding ageing, which depends on the storage temperature. On this point, wet storage offers guarantees whereas, in dry storage, the ability to directly and easily examine fuel cladding is reduced.

## 1. BACKGROUND

In December 2017, the French National Assembly created a Committee of inquiry into the Safety and Security of Nuclear Facilities. The creation of the Committee was decided after several intrusions of non-governmental organizations into the premises of nuclear power plants, the last targeting spent fuel storage pool security.

During the spring of 2018, the Committee, composed of about 30 parliamentarians, alternated hearings in the Assembly offices and visits of nuclear sites. The Committee's initial work had revealed that spent fuel management presents particular issues. The operation of nuclear power reactors leads to the generation of spent fuel, which then has to be stored for a period of time dictated by national choices regarding the management of radioactive materials and waste (reprocessing/recycling, long-term storage, etc.). In this context, the Committee learned of EDF's plan to build a centralized spent fuel pool facility, designed to store spent fuel for a period of around one hundred years. It also found that storage in a pool is not the only option and that an increasing share of spent fuel in many countries is put into 'dry' storage using large containers (or 'casks').

Therefore, on 26 March 2018, the Chair of this Parliamentary Committee of Inquiry wrote to the French Institute for Radiological Protection and Nuclear Safety (IRSN – Institut de radioprotection et de sûreté nucléaire), the French technical support organization, to seek its technical opinion on the nuclear safety issues associated with a strategy for managing irradiated nuclear fuel (also known as spent fuel) based on the storage of that fuel only in a pool (or underwater so called wet storage) or also in dry storage facilities.

Based on its expertise in France and on its knowledge acquired during services performed abroad, IRSN examined the concepts of spent fuel storage existing worldwide and in France, as well as the associated safety issues, taking into account the characteristics of different types of fuel and the various types of storage (wet or dry, on-site or centralized).

The objective of this presentation is to introduce the main findings of the report submitted by IRSN to the Committee in June 2018. The IRSN report is published in English on IRSN Website [1].

## 2. INTRODUCTION TO STORAGE

It should be first reminded that storage is a facility dedicated to the temporary holding of radioactive material or waste. This supposes that the retrieval and the transport of the material or waste could be done after the period of storage. Therefore sufficient provisions should be taken regarding traceability and transport means. Whatever the storage concept is, four fundamental safety functions have to be ensured, both for normal conditions and accidental situations: protection against radiation exposure, sub-criticality of fissile material, confinement of radioactive material and cooling of radioactive material.

## 3. FUTURE OF SPENT FUEL ASSEMBLIES

Spent fuel from nuclear power plants requires interim storage after being unloaded from the reactor. Its initial residual heat is too high. So decay of the radioactivity that it contains, which gradually reduces this heat, is necessary to enable it to be transported and managed using the chosen method. In all cases, it is stored initially in the reactor spent fuel pool. Then, depending on the chosen management option (reprocessing or disposal), two practices are used throughout the world.

If the spent fuel is to be reprocessed (as it is in France, Japan and Russia), the reprocessing plants have pools to store it before reprocessing (generally during five to ten years after it is unloaded from the reactor). The use of this type of storage is essentially linked to the processes of these plants, the pools in which the fuel is placed being directly connected to the reprocessing workshops. In addition, the capacity of these pools is generally very large to provide a buffer between activity at the reactors and activity at the plant and to allow additional cooling. Once they are separated, uranium and plutonium are sent for recycling into fuel assemblies made from plutonium (MOX) or from enriched reprocessed uranium (ERU). The storage methods for spent MOX and ERU fuels then depend on the planned future of these fuels in the countries concerned.

If spent fuel is not reprocessed (as in most places in the world), the unloaded fuel is generally placed in dry storage facilities once it has cooled sufficiently in a pool. Current storage concepts are based on the average residual heat of fuel assemblies being around 2 kW. To a certain extent, it should be possible to adapt these concepts.

As illustrated on Fig. 1, the residual heat per unit of the fuel assemblies to be stored is a decisive factor in determining the type of storage to be used.

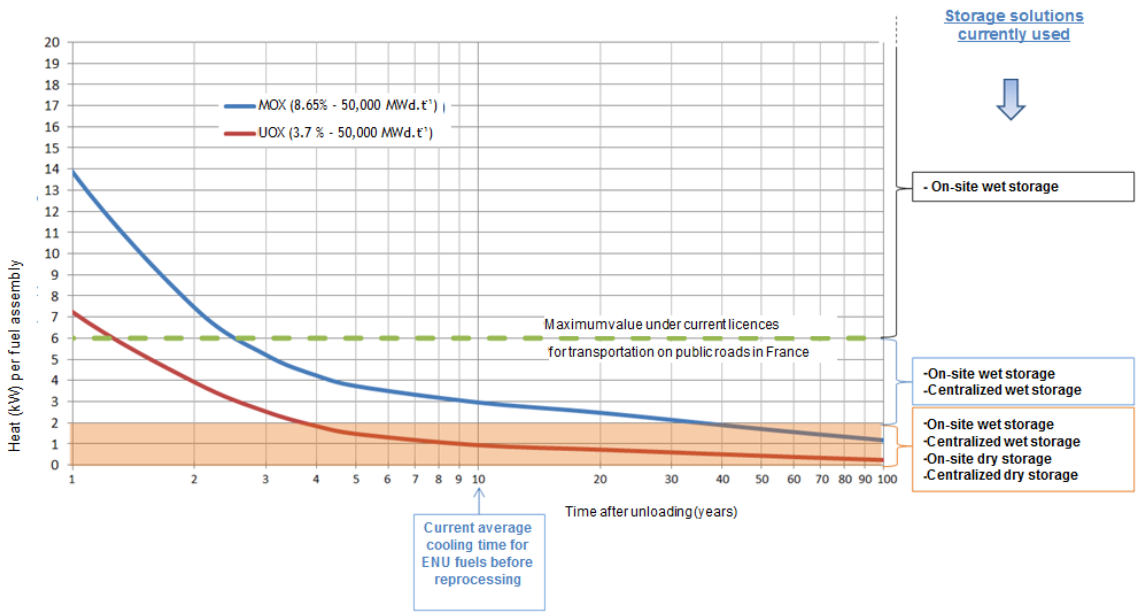


*FIG. 1. Suitability of storage solutions based on the residual heat of the spent fuel.*

So, storage in a pool is essential for spent fuel that has been recently unloaded and dry storage is suitable for fuel that has cooled significantly.

In any case, the two types of storage are complementary, but the decision to use one or the other after an initial cooling phase, of necessity in a pool, depends to a large extent on national choices regarding spent fuel management.

## 4. SPENT FUEL MANAGEMENT IN FRANCE

In France, the decision to store spent fuel in a pool is linked primarily to the choice to reprocess spent fuel for recycling plutonium (24 of the 900 MW reactors are currently licensed to use MOX fuel) and uranium (four 900 MW reactors are currently licensed to use ERU fuels).

After being unloaded from the reactor, ENU spent fuels are:

— Stored in a reactor pool until their characteristics are compatible with transportation to the Orano Cycle site at La Hague, particularly when their residual heat is around 6 kw per fuel assembly with current casks and under current transport licences;
— Stored in pools on the Orano Cycle site at La Hague until they are reprocessed, which happens approximately 10 years after the end of their irradiation in a reactor.

Spent ERU and MOX fuels are managed in a similar way, but their reprocessing is differed. Pending a decision about their future, EDF plans to create a centralized storage pool to store spent MOX and ERU fuels.

Spent ERU fuels have similar characteristics to spent ENU fuels. The ENU fuels currently used by EDF could, with the current concepts, be stored in dry conditions after cooling for around five years. However, because of the amount of time remaining before they are reprocessed, there seems to be little point in using this type of storage. If a spent fuel reprocessing plant were to be unavailable for a long period (eventually causing saturation of the existing storage capacity), using this type of storage could be one solution.

Fresh MOX fuels loaded into a reactor have a high plutonium content to give them an equivalent burnup to that of the ENU fuels used with them in the reactor. Due to this plutonium content and its isotopic composition, spent MOX fuels have a higher residual heat. Because of their higher transuranium element content, their residual heat is also slower to decay. The cooling time before they can be placed in dry storage is

therefore substantially longer than for spent ENU fuel, i.e. it takes several decades to reach a residual heat per fuel assembly of 2 kW. The use of dry storage could therefore be envisaged only beyond this period of time.

## 5. ASSETS AND LIMITING FACTORS OF WET STORAGE

It is obvious that wet storage implies the use of pool to store the spent fuel underwater. Taking a closer look at the existing concepts of pools, it could be mentioned that such storage could be located:

- Above-ground as it is the case in nuclear power plants to facilitate loading/unloading of fuel;
- Semi-underground: in that case, the water level is close to the ground level;
- Underground such as in the central interim storage facility for spent nuclear fuel (named clab) in Sweden.
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Two types of storage modes of spent fuel assemblies could be observed either in racks or in baskets. Wet storage is particularly suitable for fuels with a high residual heat, which can therefore not remain in air without deterioration of their cladding. Water is an effective coolant and active cooling systems that use it can keep fuel cladding at low temperatures. In addition, a pool has considerable thermal inertia, making it easier to deploy emergency systems if the cooling systems are lost.

The main safety requirements for wet storage are to maintain a sufficient water inventory in the pool and to have cooling systems available in all plausible circumstances. Because of the high residual heat of the spent fuels contained in the pool, a prolonged loss of cooling without water makeup could have very significant consequences for the environment, with it becoming impossible to go near the pool because of the high dose rate induced by the fuel in the absence of any attenuation of the radiation by water.

Consequently, a spent fuel pool, particularly if it receives spent fuel that has hardly cooled, must be of a particularly robust design - with sufficient margins to cope with any risks that can be envisaged - and its operation must allow appropriate monitoring of both the installation itself and the fuel it contains.

Experience feedback from the Fukushima accident lead safety approaches for controlling these risks to be reinforced, aiming to maintain a sufficient water inventory in extreme situations of natural origin.

Current industrial techniques enable pools to be built that control the risks of fuel uncovering, with the buildings housing the pool providing protection against external hazards (particularly the aircraft shell).

It generally takes about a decade to build a facility of this kind, based on current experience feedback from nuclear facilities built in France.

## 6. ASSETS AND LIMITING FACTORS OF DRY STORAGE

There is a wide variety of dry storage types existing worldwide. As for the wet storage facilities, dry storage could be above-ground, semi-underground or underground. These various types could be summarized into three main categories:

- Storage in wells in concrete structures with a plug;
- Storage in casks comparable to transport packages but used for dual purpose (transport and storage);
- Storage in silos which could be either horizontal or vertical; for this concept spent fuel is placed into a canister that is introduced in a concrete structure.

Dry storage is reserved for fuel that has cooled sufficiently (to around 2 kW on average per fuel assembly with current concepts). Consequently, it has the advantage of generally using passive cooling systems, which limits operating constraints, and it lends itself particularly well to modular construction, adapting to needs or even enabling old modules to be replaced over time.

The safety requirements are the maintenance of passive cooling and the quality of the containment barriers between the radioactive materials and the environment.

This type of storage has the advantage of a simpler, more robust design and less operational intervention. Depending on the design, direct monitoring of the condition of the fuel cladding (the first containment barrier), which is subject to the most demanding thermal conditions, is generally not possible.

In any case, if an accident happens, the smaller number of fuel assemblies and their lower residual heat will mean fewer consequences for the environment.

It generally takes around five years to build this type of facility, depending on its modularity and whether or not existing cask concepts and support installations are used.

## 7. STORAGE FACILITY LIFETIME

Moreover, regardless of the type of storage, significantly longer storage periods than the usual periods (of a few decades) will require the definition of appropriate requirements (particularly in terms of structure design and of safety margins).

## 8. CONTROLLING THE AGEING OF ZIRCONIUM FUEL CLADDING

For IRSN, one particularly important point for the safety of spent fuel management is controlling the ageing of zirconium fuel cladding, which depends on storage temperature. This cladding is the first containment barrier for the radioactive materials. In addition, its mechanical strength is important for the operations to take place after storage (transport, reprocessing or disposal).

Wet storage offers guarantees in this respect, given the low temperatures and the potential for direct examination of cladding. Countermeasures (canisters for defective fuel) can also be taken if ageing phenomena are detected. There is a significant experience feedback available in France and throughout the world on the behaviour of cladding underwater, at least for periods of a few decades.

With dry storage, it is more difficult to examine fuel cladding directly. Any inspections made are at best indirect (no release of gases into the cask cavity, etc.), or impossible (fuel canisters sealed by welding constituting the second and final confinement barrier); they do not enable the detection of ageing mechanisms.

Any guarantees that the ageing of cladding is controlled are based primarily on studies, which have notably defined the maximum acceptable temperature for cladding in storage. No examinations of fuel carried out to date, as far as IRSN is aware, have challenged the findings of these studies. However, many studies are ongoing. Moreover, there is limited information available for fuels with a high burnup (more than 45 GWd/t), for MOX fuel (especially with a high initial plutonium content) and generally for long storage periods (more than 40 years).

## 9. CONCLUSION

To conclude, IRSN considers that decisions about the type of storage to be used for spent fuel must be assessed in the light of the following considerations.

The two types of spent fuel storage that could be envisaged (wet or dry) do not serve exactly the same needs, since wet storage is absolutely necessary for fuel that has hardly cooled and dry storage is suitable for fuel that has cooled substantially.

The type of spent fuel (ENU, MOX or ERU) affects any decision about which type of storage to use, at least for a certain period of time, because MOX fuels have a higher residual heat for longer.

From a safety point of view, regardless of the type of storage, the decisive parameter is the residual heat of the fuel to be stored. Wet storage, which generally contains hotter fuel, requires more substantial safety measures than dry storage, for which more passive measures can be implemented. In dry storage, cladding (the first containment barrier) is subject to greater thermal stress and is more difficult to inspect.

## REFERENCES

[1] IRSN Report No 2019-00181, Storage of nuclear spent fuel: concepts and safety issues, IRSN, June 2018 (French issue), http://www.irsn.fr/spent-nuclear-fuel-storage.