Safe Advantage on Dry Interim Spent Nuclear Fuel Storage

L.S. Romanato
Centro Tecnológico da Marinha em S.Paulo (Brazilian Navy Technological Center)
2468 Professor Lineu Prestes Ave, São Paulo, 05508-000, Brazil

ABSTRACT

This paper aims to present the advantages of dry cask storage in comparison with the wet storage (cooling water pools) for SNF. When the nuclear fuel is removed from the core reactor, it is moved to a storage unit and it wait for a final destination. Generally, the spent nuclear fuel (SNF) remains inside water pools within the reactors facility for the radioactive activity decay. After some period of time in pools, SNF can be sent to a definitive deposition in a geological repository and handled as radioactive waste or to reprocessing facilities, or still, wait for a future solution. Meanwhile, SNF remains stored for a period of time in dry or wet facilities, depending on the method adopted by the nuclear power plant or other plans of the country. Interim storage, up to 20 years ago, was exclusively wet and if the nuclear facility had to be decommissioned another storage solution had to be found. At the present time, after a preliminary cooling of the SNF elements inside the water pool, the elements can be stored in dry facilities. This kind of storage does not need complex radiation monitoring and it is safer then wet one. Casks, either concrete or metallic, are safer, especially on occurrence of earthquakes, like that occurred at Kashiwazaki-Kariwa nuclear power plant, in Japan on July 16, 2007.

INTRODUCTION

Safety and security of spent nuclear fuel (SNF) interim storage facilities are very important. These locations have a great concentration of fission products, actinides and activation products. For SNF wet storage, the water pool level has to be constantly monitored avoiding possible fuel element exposition to atmosphere and the occurrence of the element cladding melting, releasing fission material. If the stored fuel were exposed to air, the zirconium cladding would react exothermically, catching fire at about 1,000ºC. NRC (Nuclear Regulatory Commission) concedes that such a fire cannot be extinguished; it could rage for days. By the way, spent fuel pools hold five to 10 times more long-lived radioactivity than a reactor core. Particularly there are large amounts of Cesium 137 (Cs-137) in fuel pools. With a half-life of 30 years, Cs-137 gives off highly penetrating radiation and it is absorbed in the food chain as if it were potassium. According to NRC, as much as 100 percent of a pool’s Cs-137 would be released into the atmosphere in a fire resulting in massive off-site radiation exposures. A single SNF pool holds more Cs-137 than was deposited by all atmospheric nuclear weapons tests in the Northern Hemisphere combined [1].

We must consider other factors on analyzing the safety of a facility, like:

(a) Seismic factors: an earthquake measuring 8.0 on the Richter scale could cause cracks in the SNF storage pool walls. Water could leak through the cracks exposing the stored SNF to atmosphere;

(b) Electrical blackout (with failure of the SNF pool cooling system);

(c) Fall of heavy object in the pool that could damage the walls and bottom of the pool otr the spent fuel;

(d) Unauthorized invasion with aggressive intent; or

(e) Airplane crash.

A safety plan is important and concern, either for an interim wet storage facility or for an interim dry storage facility. For wet storage, the most important care concerns primarily with the pool and for the dry storage importance must be given to the storage casks, by the way, physical and radiological criterions of safety must be warned.

Safety and security of SNF is commented nowadays by environmentalists who reported nuclear power as a technology of mitigation on Greenhouse emission [2].

INTERIM STORAGE

Spent nuclear fuel can be safely shielded with water, steel or concrete. Usually there are two types of spent fuel storage: wet storage, in which water is responsible for the cooling and dry storage, in which the spent fuel is kept cool by air circulation.

Wet Storage

The spent nuclear fuel assemblies removed from reactor core (about 1/3 of reactor fuel is spent and substituted every 12 to 18 months) [3] is intensively radioactive and usually called “hot”. To allow the SNF decay it should be maintained for a period of time, in water pools, inside the building of commercial nuclear power plant site. These pools are designed with reinforced concrete walls and steel liners. Water is an efficient shield and allows good cooling, but must be constantly purified. In the storage pool, the radiation decay and the heat emitted from the SNF assemblies decrease with time. One ton of SNF from 600 MWe PWR (Pressurized Water Reactor) generates about 2,000 kW heat when recently removed from the reactor. This heat decreases to 10 kW after one year and to 1kW after ten 10 years in water pools storage [4]. Generally the water pool has a limited size and only it is important at the initial stage of SNF storage.

Dry Storage

Dry storage has been successfully adopted worldwide and differs from wet storage totally. Before being transferred to dry storage, SNF must remain for some years in water pools for initial decay of activity and heat. In dry storage the spent fuel is placed inside airtight stainless steel canisters. Fuel oxidation in these canisters is avoided by the use of an inert gas or a slightly reactive gas. Canisters are made of metal and/or concrete and are radiation barriers. Heat cooling is achieved by circulation around the outside of the metal canister by passive convection of environmental air vents on the side of the container.

The management of dry storage is less expensive and it provides many security and safety characteristics. Periodic maintenance and a constant monitoring increase the system reliability for longer periods. Rigorous safety requirements allow a dry storage to withstand incidents, airplanes crash and weather conditions as floods or earthquakes. Radiation shielding is made by thick concrete, cast iron, steel, lead walls or a combination of them.

There are many types of dry storage facilities as follows:

Vault storage

In this type of storage, SNF is stored in reinforced concrete buildings in which the exterior structures are the radiological barriers. The inner area has also metallic lined cavities on the floor that are ready to receive the SNF elements (Fig. 1). The pipes are externally cooled by insufflated air or sometimes by natural air circulation. The heat transfer between the pipes and the environment allows SNF cooling by convection.

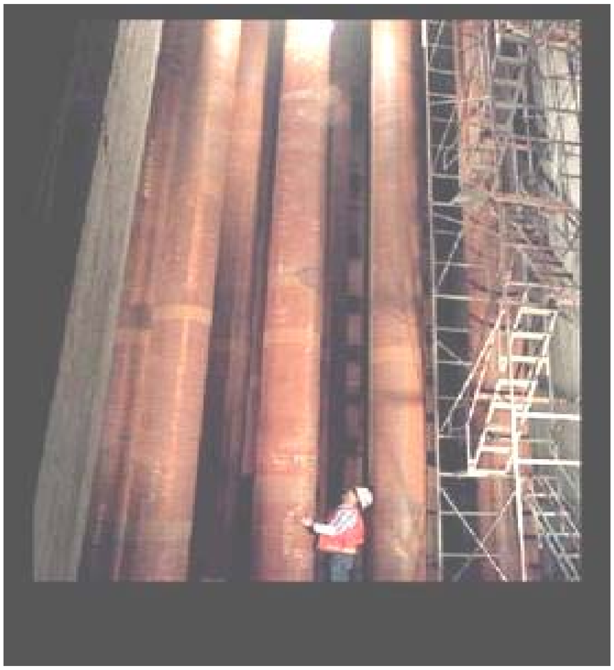

Fig. 1. Metallic pipes view in a vault facility storage type for SNF. (www.qmetrics.com)

Silos storage

In silos storage system, SNF is inserted inside concrete cylinders lined with metallic canisters. These steel canisters provide a leak-tight containment of the SNF. These silos stay above the floor surface (Fig. 2). The storage position can be vertical or horizontal. Concrete is the structural material and radiation shielding (like the building in vault storage). Heat is removed from the concrete cylinders by air convection through special ducts. Fuel transfer from reactor to this kind of silos is made through a special cask designed for this purpose.

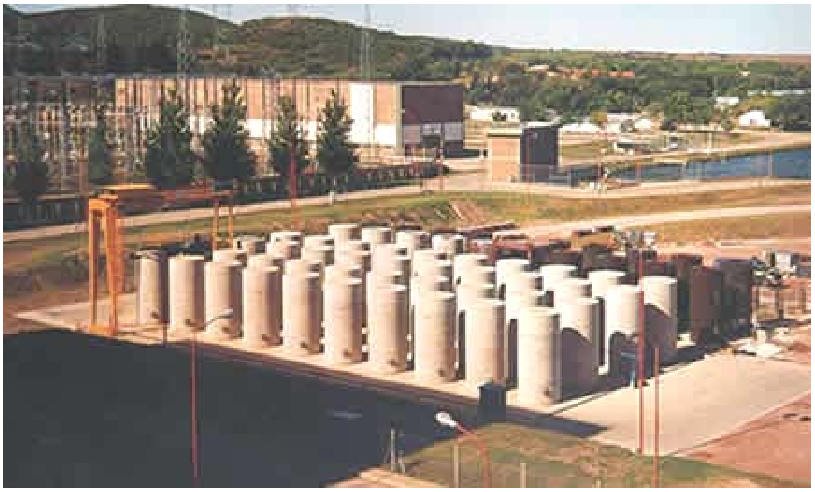

Fig. 2. Argentine storage of SNF placed inside concrete silos (www.invap.net)

Cask storage

Usually casks have a thick wall cylinders (about 65 cm thickness) made from metal, concrete or a combination of both. Metallic casks (Fig. 3) generally are made of cast steel with one or two lids which are bolted or welded in the cask body. The steel cask provides a leak-tight containment of the spent fuel and provides shielding against gamma radiation. The surface inside cask is lined with a special resin (in general polyethylene) that is the neutron absorber. There are winglets on the external surface for better heat transfer to the environment. The external surface of the cask has trunnions which allow the cask to be lifted and displaced. Shock absorbers of the cask installed at the bottom and the cover assure transport stability.

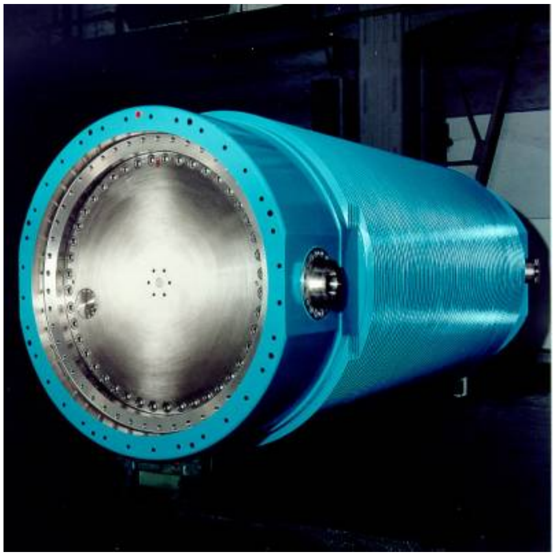

Fig. 3. German metallic SNF cask (www.gns.de)

Concrete casks (Fig. 4) have the same inner disposition than the metallic cask. SNF are distributed in inner baskets inserted into metallic containers and then into the concrete cask. Concrete shields neutrons and gamma radiation. Cooling is performed through ducts located inside the concrete cask that transfers the outside containers heat to the external environment. Generally concrete casks are heavier than the metallic ones because the concrete walls are thicker than the metallic walls, but concrete casks are less expensive than the metallic ones.

Fig. 4. Concrete casks at Palisades site, U.S.A. (www.bngfuelsolutions.com)

Advantages and Disadvantages of SNF Storage Systems

Wet storage facilities have a worldwide high acceptance degree because the storage methods are standardized and well characterized. During the last 10-20 years, it was evidenced that the corrosion of fuel elements, in wet storage, has been reduced [5], but as the fuel is submerged in water at temperatures about 40ºC, corrosion tends to increase because oxidation is favorable at this temperature, so this process should be well controlled. Other problems can occur during the handling, like damages due some kind of failure of SNF or through external events. More disadvantages of wet storage system are: redundancies for the electrical systems, cooling systems and the maintenance of water level in the purposed limits to avoid the increase of cladding temperature when SNF is submerged. The limited size of the pools avoids storing more SNF elements, if necessary.
The occurrence of earthquakes, like that occurred at Kashiwazaki Kariwa nuclear power plant, in Japan on July 16, 2007, show us another problem with wet storage facilities. Tremors of magnitude 6.8 on Richter scale caused 1.2 cubic meters of water to spill from the spent nuclear fuel cooling pool of unit 6 [6]. The radioactivity released was extremely small [7] but it could be worse.

All dry storages systems must have a passive cooling and it is an advantage. SNF can be removed from the reactor, dried, inserted into the cask and transported to the storage place (SNF can be inserted into casks inside the pools or in hot cells specially designed). The same casks can be used for transport and storage. We can say that the casks have a great mobility. If in the future the stored cask needs to be sent to another facility or to the reprocessing plant or even to a definitive repository, it can be easily transported without SNF elements transference As the casks are not fixed on the concrete pad, it is more difficult to crack or fail in an earthquake.
Another advantage is that dry facilities can be increased and store more SNF casks.

In Table I is shown some advantages and disadvantages according the storage type. [8]

Table I. Advantages and Disadvantages on SNF Storage Facilities.

Type	Advantages	Disadvantages
Wet Storage		
Pool	1. SNF inspection 2. SNF changing	1. Purity, cooling and H_2O level control 2. Corrosion 3. Restricted size of storage
Centralized pools	1. SNF cylinders mobility	1. Purity, cooling and H_2O level control 2. SNF transportation 3. Restricted size of storage
Dry Storage		
Vaults	1. No SNF corrosion	1. Lack of SNF inspection 2. Restricted size of storage
Silos	1. No SNF corrosion 2. Passive cooling 3.Variable size of storage	1. Lack of SNF inspection
Metallic casks	1. No SNF corrosion 2. Passive cooling 3. Variable size of storage 4. Transport cask is the same as storage 5. Casks mobility	1. Lack of SNF inspection
Concrete casks	1. No SNF corrosion 2. Passive cooling 3. Variable size of storage 4. Transport cask is the same as storage 5. Casks mobility 6. Lower cost than metallic	1. Lack of SNF inspection

Terrorism in nuclear fuel storage facilities

The terrorist attacks in Unites States on September 11, 2001 have multiply the activities in the area of physical protection of different types of nuclear plants in many countries. This problem should be taken into account in the construction of the spent fuel storage sites.

All kinds of nuclear fuel storages must be facilities with a minimum potential to terrorist attacks. A "robust" construction is necessary and this means that a facility for storage of spent fuel must be designed to be resistant to these attacks. After different terrorist attacks around the world, the new construction strategy should be implemented as a major element of a defense-in-depth for worldwide nuclear facilities.
Studies show that a passenger airplane at 800 km/h crashing against a SNF concrete cask will not damage this structure. [9]

To establish the ability of various dry-storage design approaches to put up various design-basis risks, full-scale experiments are needed. Performance specifications for dry storage must be developed with stakeholder input. Reinforcements must be seen as an important component of country security.

CONCLUSIONS

After all these considerations it can be concluded that dry interim storage for spent nuclear fuel is more advantageous for long time and it is safer than wet storage. Casks are mobile and can be used both for transport and storage; however, wet storage continues to be very helpful after SNF withdrawal from the core reactor before any other SNF interim storage.

REFERENCES

1. R. ALVAREZ, "¿Y el Combustible Agotado?" Bulletin of the Atomic Scientists. v.58, n.1, p.45-47. ene./feb. (2002).
2. Intergovernmental Panel on Climate Change. 4th Assessment Report approved at the 9th Session of Working Group III of IPCC. Bangkok, Thailand. 30 Apr to 4 May 2007. http://www.ipcc.org.ch
3. "Spent fuel pools", http://www.nrc.gov/waste/spent-fuel-storage/pools.html (2007).
4. P. MOUNFIELD, *World Nuclear Power*. Routledge, London, England (1991).
5. Nuclear Energy Agency. *The Safety of the Nuclear Fuel Cycle*. Paris. 1993.
6. http://www.world-nuclear-news.org/regulationSafety/Kashiwazaki_Kariwa_nuclear_units_shutdown_on_earthquake_160707.shtml (2007)
7. Engineering Safety Review Services - Preliminary Findings and Lessons Learned from 16 July 2007 Earthquake at Kashiwazaki-Kariwa NPP – Mission Report Vol I, 6 - 10 Aug 2007, IAEA, Vienna
8. L. S. ROMANATO, "Spent Nuclear Fuel Storage". Master degree Dissertation. IPEN. Brazil. (2005)
9. C. PENNINGTON and M. MCGOUGH. "Madness and Spent Fuel Cask Safety". Radwaste Solutions, pp. 25 - 30. May/Jun 2002.