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ADVANTAGES OF DRY HARDENED CASK STORAGE OVER WET STORAGE FOR SPENT NUCLEAR FUEL

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ABSTRACT

Pools are generally used to store and maintain spent nuclear fuel assemblies for cooling, after removed from reactors. After three to five years stored in the pools, spent fuel can be reprocessed or sent to a final disposition in a geological repository and handled as radioactive waste or sent to another site waiting for future solution. Spent fuel can be stored in dry or wet installations, depending on the method adopted by the nuclear plant. If this storage were exclusively wet, at the installation decommissioning in the future, another solution for storage will need to be found. Today, after a preliminary cooling, the spent fuel assemblies can be removed from the pool and sent to dry hardened storage installations. This kind of storage does not need complex radiation monitoring and it is safer than wet storage. Brazil has two nuclear reactors in operation, a third reactor is under construction and they use wet spent fuel storage . Dry hardened casks use metal or both metal and concrete for radiation shielding and they are safe, especially during an earthquake. An earthquake struck Japan on March 11, 2011 damaging Fukushima Daiichi nuclear power plant. The occurrence of earthquakes in Brazil is very small but dry casks can resist to other events, including terrorist acts, better than pools. This paper shows the advantages of dry hardened cask storage in comparison with the wet storage (water pools) for spent nuclear fuel.

1. INTRODUCTION

A nuclear power reactor uses nuclear fuel to produce eletricity. A reactor with 1GWe generates about 20,000 to 30,000 kg of spent nuclear fuel (SNF) per year [1]. The management of this fuel is very important and there are discussions regarding the proposed alternatives related to proliferation risks and hazards for environment.

When irradiated or spent nuclear fuel is removed from reactor, it is still thermally hot, highly radioactive, and potentially harmful. It needs to be cooled and shielded safely and the initial storage involves specially designed water pools. The SNF assemblies are moved into the water pools existing at all reactor buildings from the reactor vessel along water canals. The SNF remains cooling in the pool and waits about three years for another interim storage that can be dry storage, or for a final disposition.

The Brazilian Nuclear Program does not contemplate a dry storage method for SNF from nuclear power plants. Today, SNF is stored inside water pools located at the nuclear reactor sites.

2. INTERIM STORAGE

There are two acceptable storage methods for SNF: wet storage, where water is used as the heat conductor and dry storage, where natural air circulation dissipates heat. Figure 1 shows the interim storage concept [2].

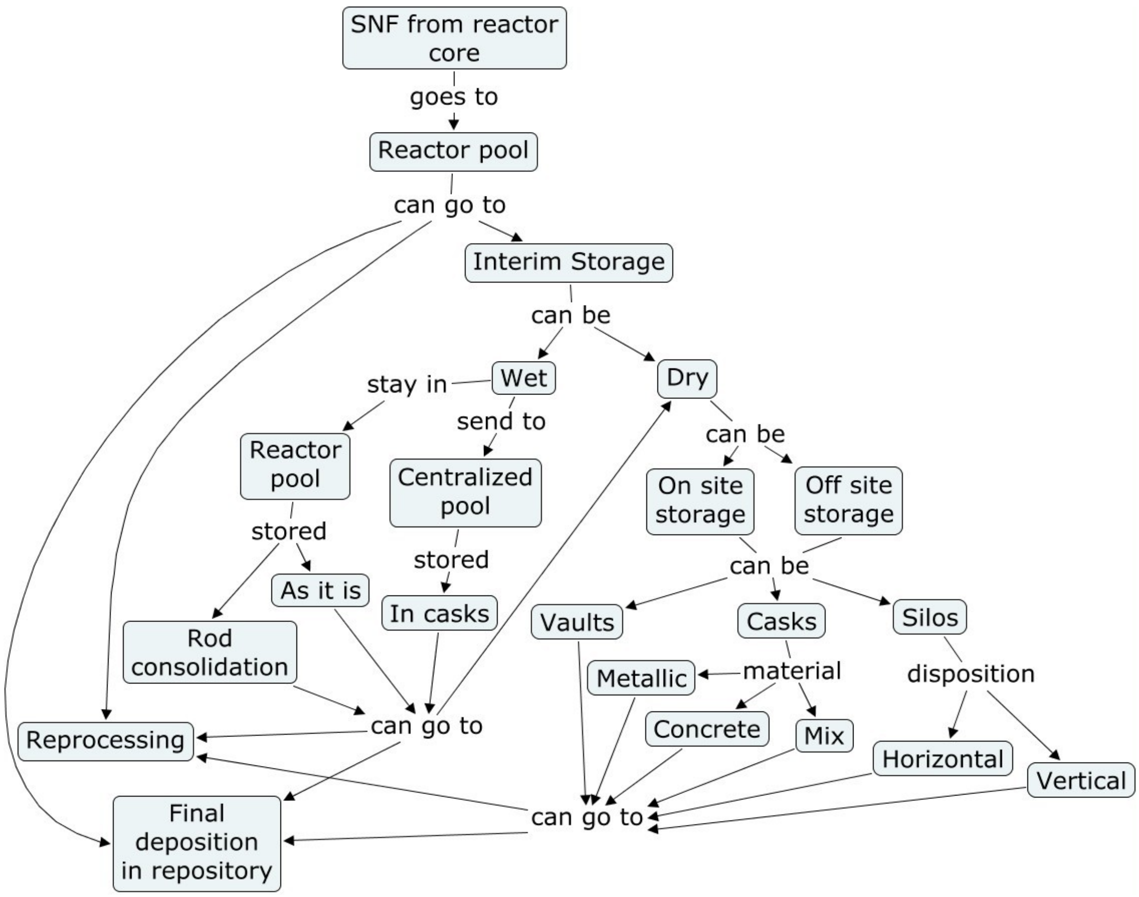

Figure 1. Interim storage concept

2.1. Wet Storage

About 1/3 of the reactor fuel is spent and substituted from the reactor core every 12 to 18 months [3], it is intensively radioactive or generally called "hot". Waiting the radioactive decay of some elements, SNF should be maintained for some time in water pools (Fig. 2). Water is an efficient shielding and allows good cooling. In the storage pool, radioactivity and heat decrease in time. One ton of SNF from 600 MWe PWR (*Pressurized Water Reactor*) or BWR (*Boiling 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 [4]. The activity of the SNF also decreases in time.

SNF continues to generate heat because of radioactive decay of the elements inside the fuel.

To remove the heat from the pool, electric pumps circulate water through external heat exchangers and a low temperature at the pool is maintained.

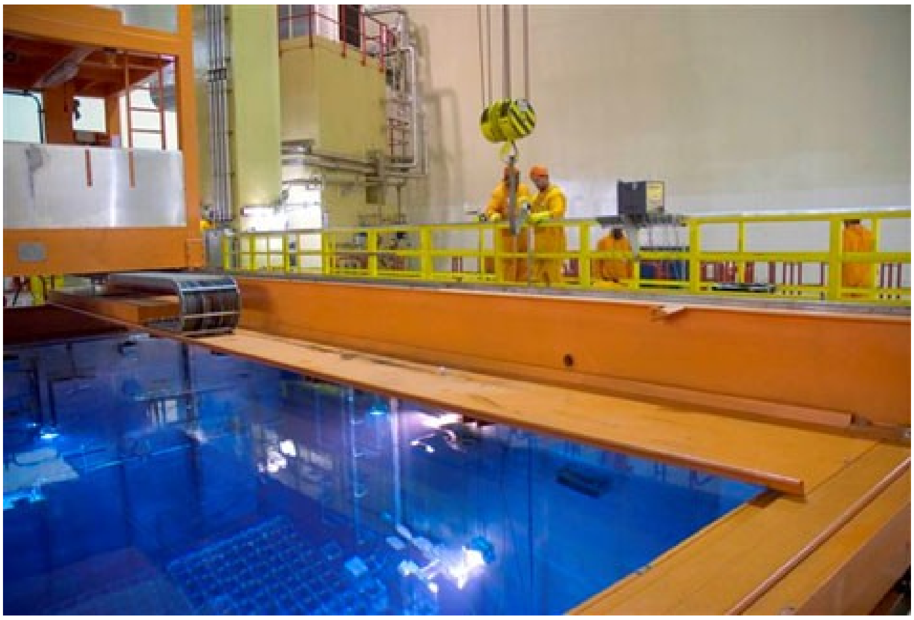

Figure 2. Spent fuel pool (www.eletronuclear.gov.br)

To increase the wet storage capacity, an option is the replacement of the pool rack by another which allows the SNF compaction. Reducing the distance between the fuel assemblies, the stored volume can be increased at a minimum of 30% [5], this option has been adopted in many countries [6]. Another possibility is the construction of additional pools or increase the actual pools volume. One practice, used in some countries, is the transference of SNF to a bigger installation, known as centralized pools, that can store SNF from many reactors and are used in small countries.

SNF rod consolidation is another option to store more assemblies submerged in water. SNF is disassembled, the rods are consolidated and placed into the pool, again. The storage capacity may double (compaction rate 2:1, i.e., two SNF assemblies in a same place) [7].

2.2. Dry storage

Dry storage has been successfully adopted worldwide and differs from wet storage by the use of an inert or a slightly reactive gas inside the cylinder where the SNF is stored, to avoid the fuel oxidation. These cylinders provides a leak-tight containment of the spent fuel. The cylinder is surrounded by additional metal or concrete which provide the radiation shielding, acting like water in the wet storage. Heat cooling is made by natural air convection. Before the transference for dry storage, SNF must remain for some years in pools for initial cooling and heat decay.

Dry storage can be done in vaults, silos and casks, all of them shielded.

2.2.1. Dry storage in vaults

A reinforced concrete building has cavities in the floor (vaults) which will have metallic cylinders that receive the SNF (Fig. 3).

Figure 3. Vault storage (www.cea.fr)

2.2.2. Dry storage in silos

The silos are horizontal or vertical concrete cylinders with metallic canisters inside them, the canisters contain SNF (Fig. 4). Heat is removed from SNF by natural air convection through special ducts.

Figure 4. SNF storage in concrete silos in U.S.A.(www.yuccamountain.org)

2.2.3. Dry storage in hardened casks

Usually casks are made from metal, concrete or a combination of both. Metallic casks use steel, cast iron, lead and cooper; concrete casks use diferent formulations of sand, gravel, cement, water and iron for reinforcing. They are placed in robust above-ground concrete or steel structures and are not fixed on the floor, by this reason the transport of the SNF from the reactor for storage or for another installation is easier than other types of dry storage.

2.2.3.1. Metallic casks

Metallic casks (Fig. 5) generally are made from cast steel with one or two lids that are bolted or welded at the cask body. The steel cask provides a leak-tight containment of the spent fuel and provides shielding against gamma radiation. Inside the cask, there is a special resin (e.g., polyethylene) that shields neutrons. There are cooling fins on the external surface of the cask for better heat transfer with the environment. The external surface of the cask has trunnions which allow the cask to be lifted and displaced. Shock absorbers installed at bottom and cover of the cask assure its integrity in case of transport accident.

Figure 5. Metallic cask installation (www.kernenergie.de)

2.2.3.2. Concrete casks

Concrete casks (Fig. 6) have the same inner disposition as metallic casks. SNF are distributed in metallic baskets inserted inside steel cylinders, that are surrounded by concrete. The concrete cask provides neutrons and gamma radiation shielding. Heat is transferred through ducts, located at the cask wall, connecting the steel cylinders with external environment. Generally, concrete casks are heavier than the metallic ones because their walls are thicker, although they are less expensive [8].

Like the metallic casks, they are placed in robust above-ground concrete or steel structures and they are not fixed on the floor.

Figure 6. Concrete cask installations (www.nacintl.com)

3. ACCIDENTS INVOLVING SPENT FUEL

A problem shown with wet storage installations was the occurrence of earthquakes. An earthquake occurred in Japan on July, 16, 2007 and struck Kashiwazaki Kariwa nuclear power plant. Tremors of magnitude 6.8, on Richter scale, caused the spill of 1.2 cubic meters of water from the SNF unit 6 cooling pool [9]. The radiation level released was extremely low [10] but it could be worse.

The massive earthquake on March, 11, 2011, of magnitude 9, on Richter scale, near the east coast of Honshu, Japan, damaged the power supply of Fukushima power plant and triggered the automatic shut-down of the three operating reactors, Units 1, 2, and 3 [11]. The control rods in those units were successfully inserted into the reactor cores, ending the fission chain reaction. The remaining reactors Units 4, 5, and 6 had previously been shut-down for routine maintenance purposes. Backup diesel generators, designed to start-up after a blackout, started to provide electricity to circulate coolant for the six reactors.

After the earthquake, a large tsunami washed over the reactor site, knocking out the backup generators. While some batteries remained operable, the entire site lost the ability to maintain proper reactor cooling and water circulation functions.

Spent nuclear fuel at the Fukushima Daiichi plant were stored in seven pools (one at each reactor, plus a shared pool) and in a dry cask storage facility (containing nine casks).[12] Sixty percent of the spent fuel on site was stored in the shared pool, in a building separated from the reactor buildings; 34 percent of the spent fuel was distributed between the six reactor fuel storage pools, and the remaining six percent was stored in nine dry storage casks. Figure 7 shows the maneuver crane of spent fuel at the unit four reactor, after the steam explosion that happened at the reactor building.

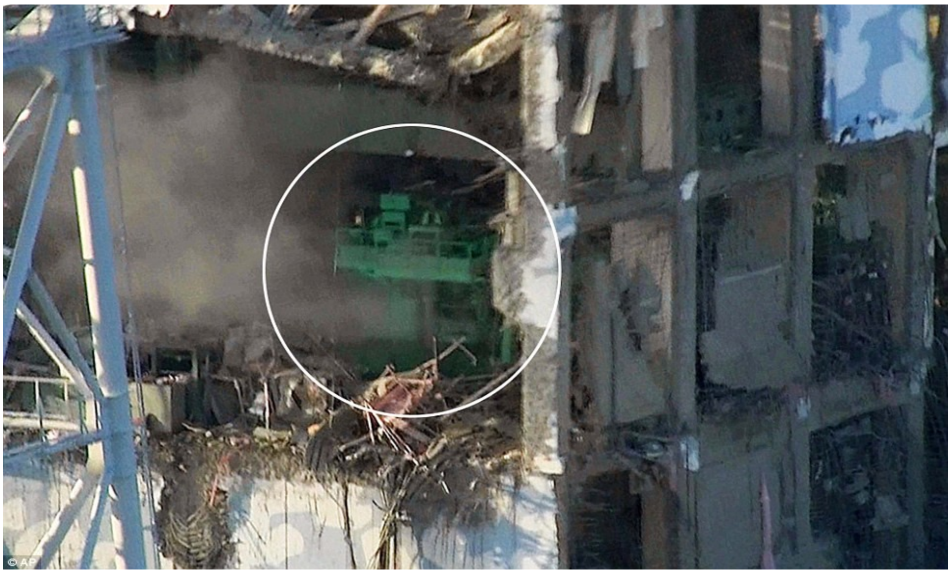

Figure 7. Fukushima's reactor unit four(www.dailymail.co.uk)

The spent fuel pools at the four reactor buildings had their cooling circulation restored. A support structure will be built under unit 4 pool until 2012. Afterwards Spent fuel will be removed to central storage on-site [13].

4. SPENT FUEL IN BRAZIL

Today, Brazil has six nuclear reactors, four of them are research reactors (TRIGA from CDTN – Nuclear Technology Development Center, MB-1 from CTMSP/IPEN – Navy Technological Center in São Paulo / Energetic and Nuclear Research Institute, ARGONAUTA from IEN – Nuclear Energy Institute and IEA-R1 from IPEN - Energetic and Nuclear Research Institute) and two are power reactors (PWR Angra 1 and Angra 2). Angra 3 is under construction.

SNF generated in IEA-R1 is stored inside the pool at the reactor building. There were two SNF transports in dry casks from IEA-R1 to USA, in 1999 and 2007 [14]. The other research reactors generate a small amount of SNF [15] and they are stored at the reactor sites. The SNF from Angra 1 is stored in a pool at a building outside the reactor and the SNF from Angra 2 is stored in a pool located at the reactor building.

A repository for long-term storage of spent fuel in Brazil is expected by 2026 [16].

5. ADVANTAGES

All dry storage methods must have a passive cooling system and they must provide shielding against the radiation emitted from the radionuclides. SNF can be removed from reactor pool, dried, inserted into a cask, filled with an inert gas, sealed and transported to the storage place. The same casks can be used for transport and storage. Storage may be at the same site of the reactor (on-site storage) or not (off-site storage). If the stored cask needs to be sent to another installation or to the reprocessing plant or even to a geological repository in the future as final disposition, it can be easily transported without SNF assemblies transference, so, casks have a great mobility. As the casks are not fixed on the concrete pad, it is more difficult to crack or fail in an earthquake.

Casks do not have water to leak to environment and do not need forced cooling, purification or control the water level and still, SNF stored in casks has less corrosion than in wet storage pools.

Casks have less SNF at risk in an accident than a spent fuel pool and leakages in a cask are easier to solve than breaches in a pool.

Table 1 shows some advantages of dry storage.

Table 1. Advantages of SNF Dry Storage

	Casks at dry storage	Wet storage
Mobility of SNF	Possible	No mobility
Cooling of SNF	Passive cooling	Forced cooling
Purification system	None	Necessary
Leakages	Easy to repair	Hard to repair
Inventory of SNF at accident	Only SNF in the cask	All SNF at the pool
Waste generation	None	Great amount of liquid waste

6. CONCLUSIONS

The best SNF storage method is a combination of wet storage with dry storage in casks. SNF would be stored in a pool for approximately three years then would be transferred to casks for dry storage, until the final disposition. This way allows the spent fuel pools to be smaller than they are today.

When SNF assemblies are stored in casks, they are protected from some external events, they are more resistant to earthquakes and the casks can be freely moved by transporting vehicles at the storage installation.

How dry storage does not have water control, it does not need the expensive cooling and purification systems as there are in pools.

The design of a Brazilian dry storage installation shall be capable to store all SNF generated at the reactors' site until the construction of a place for final disposition.

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