Safety and Environmental Protection during Interim Storage of Spent Nuclear Fuel

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1. Background

Interim storage is a system for temporary storage of spent nuclear fuel for a period from initial removal from the reactor until reprocessing or direct ultimate waste disposition. Spent fuel degradation causes as fuel/cladding interaction, oxidation and hydration, thermo-mechanical properties, and radiological source term during storing discussed in this paper.

This paper covers the neutronic characterization of VVER1200 average spent fuel assembly. SCALE/ORIGEN-ARP used for modelling and calculations that started from its first fresh loading in the core till its discharge from the reactor core and transferred to the wet storage for decay heat removal and cooling for about 10 years. The radiological source term, gamma ray and neutron emission rates at high burn-up in the decay period from 0.1 to 1E+06 years.

2. Safety of interim storage of spent nuclear fuel

The important thing in handling and storage is to protect personnel and environment from harmful effects of radiation. After SF cools down and intense initial radioactivity has decayed, a decision is taken to choose one of the following storing options for the spent fuel; wet pool storage, dry storage vaults, dry storage silos, and dry storage casks.

The storage technology addresses the following safety requirements:

- Fuel cladding integrity should be maintained;
- Fuel degradation should be prevented;
- Subcriticality of the spent fuel is maintained;
- Radiological shielding of the spent fuel should be provided
- Environmental protection should be assured
- Fuel retrievability should be available

3. Spent fuel degradation in wet storage

The main causes of spent fuel degradation in wet storage are

3.1. Water Chemistry

Underwater storage exposes SF and packaging to the potential for galvanic corrosion and the potential of corrosion from other materials within the pool, such as chlorine can occur.

Degradation of uncoated concrete basins can contribute to contamination of the basin water with chlorides and metal ions that can corrode metal cladding and structural materials. Water chemistry is typically controlled to mitigate fuel corrosion. Basin storage systems include stainless steel liners (with leak detection) and filter and deionization systems to maintain basin chemistry and to provide radioactivity removal from the water.

3.2. Water Chemistry-Related Degradation

3.2.1. Aluminium-based fuel

Aluminium is used as a canister material and as a structural material for holding canisters in a water basin. Corrosion modes can lead to cladding penetration within a year of exposure to aggressive water chemistries. Deposits of aluminium hydroxide films on zircaloy clad have been observed after extended water basin storage in aluminum canisters. Radiolysis of water causes storage container pressurization, weld embrittlement, and flammable gas generation. Such issues are controlled through proper water chemistry. Water chemistry specifications typically define pH, chloride concentration, conductivity, and basin water temperature. Water quality standards limit chlorides to less than 1 ppm and conductivity to less than 2 micro-siemens/cm. Consequently, if conductivity is carefully controlled, addition controls on the pH levels are not necessary.

3.2.2. Uranium Metal Spent Nuclear Fuel

As a cladding failure, a reaction between the exposed uranium metal and water forms uranium hydride that leads to SF rods swelling and subsequent additional cladding damage. Each cycle of fuel-water reaction produces contamination of water in the canister, or the storage pool. As a result, degraded uranium metal fuels are stored and transported in canisters after removal from the basin. Radiolysis of water within the SF-water corrosion products must also be addressed for long-term storage.

3.2.3. Uranium Dioxide Oxidation Control Measures

These measures are important during all phases of spent fuel management, including storage, transport, and implementation of final disposition. These measures are

- Establishing time limits for exposure of fuel pins to air based on thermal analysis,
- Using inert environments in leak tight containers to limit oxygen access.

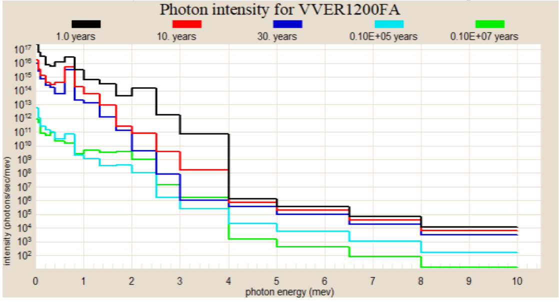
4. Case study: spent fuel storage of VVE-1200 type

4.1 Modelling and Simulation of the fuel assembly

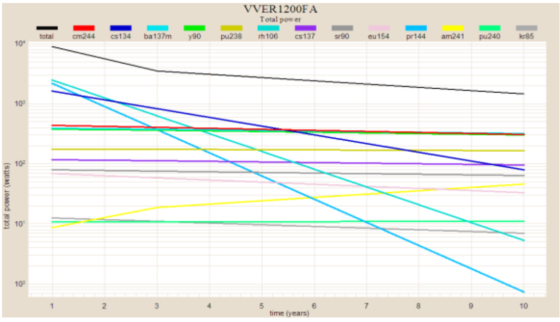
VVER-1200 Fuel assembly is hexagonal in design with one central tube, 312 fuel pin locations and 18 guide tubes for feeding water and control rods positions. Fuel assemblies comprise top nozzle, bottom nozzle, and bundle of fuel elements in a rigid welded framework.

4.2. Calculation of the source term

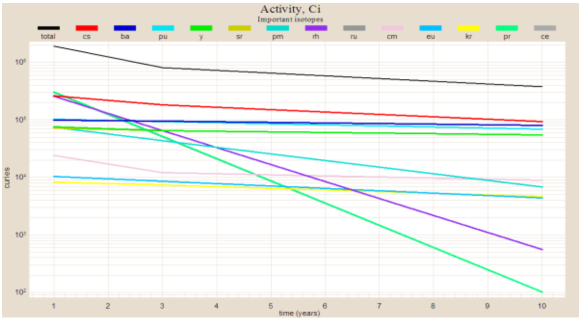
ORIGEN-ARP was used to irradiate an average VVER-1200- FA with enrichment of 4.9% for 896 days of power operation against different decay times till 1E+6 Yrs. The results include the photon intensity, decay power with the contribution of selected radioisotopes in the total power and the total activity with the contribution of selected radioisotopes.



Photon intensity vs photon energy at different cooling times



Total decay power with the contribution of selected isotopes vs decay time



Total activity with the contribution of selected isotopes vs decay time

The total characterization parameters for the average VVER-1200 fuel assembly were presented in the following Table,

Discharge BU	37.8GWd/MTU
Effective full power operational days (EFPD)	896 days
Cooling period	10 years
Mass of total Inventory	456 Kg
Total radioactivity	2.262E+05 Ci
Total decay heat	616.6 Watts
Total neutrons	7.609E+07 neutron / sec
Total Gamma intensity	6.08E+16photon / sec
Mass of U-235	7.863 Kg
Mass of U-238	440.3 Kg
Mass of Pu-239	3.48 Kg

5. Conclusions and Acknowledgements

- ➢ The neutronic characterization of an average spent fuel assembly of VVER-1200 power reactor was simulated and modelled using the codes MCNP 6.1 and SCALE/ORIGEN-ARP. The depletion process started from its first loading as clean and fresh fuel assembly till its average discharge burn-up. The characterization results of the radioactivity, the gamma radiation distribution, and the decay heat were calculated at discharge time and different cooling times. These results are necessary for the cask design. The IAEA safety standards provide a robust framework of fundamental principles, requirements, and guidance to ensure safety of spent nuclear fuel management and radiation protection management during spent fuel handling, transport and final storage or reprocessing.

International Conference on the Safety of Radioactive Waste Management, Decommissioning, Environmental Protection and Remediation: Ensuring Safety and Enabling Sustainability, CN-318
Vienna, Austria; 6-10 November 2023