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Criticality Analysis of New Fuel Storage System for LEU+ Fuel

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1. Introduction

With the introduction of Low Enriched Uranium Plus (LEU+) fuel in commercial reactors, a comprehensive criticality analysis is required due to the distinct criticality characteristics that LEU+ fuel presents compared to conventional Low Enriched Uranium (LEU) fuel.

LEU+ fuel, which has an enrichment level slightly above the traditional 5% threshold, offers improved economic benefits by extending the fuel cycle and reducing the frequency of refueling outages. The United States Nuclear Regulatory Commission (NRC) has recognized the potential of LEU+ fuel and has granted approvals for its use in Pressurized Water Reactors (PWRs). Notably, Framatome has received NRC approval for the deployment of LEU+ fuel in PWRs, and Westinghouse has submitted a topical report to the NRC, seeking similar approvals. These developments indicate a growing interest in the adoption of LEU+ fuel within the nuclear industry, both domestically and internationally.

Given these advancements, it is essential to perform a detailed criticality analysis for the storage of LEU+ fuel in new fuel storage racks. This study aims to conduct such an analysis, building upon the findings from previous studies on spent fuel pool storage and addressing the specific challenges associated with higher fuel enrichment levels.

2. Methodology

This study employs the Monte Carlo N-Particle (MCNP6) code [1] to perform a criticality analysis of the new fuel storage racks. The analysis focuses on evaluating the criticality behavior of various enrichment of LEU+ fuel within a representative model of a typical new fuel storage rack design. Three distinct configurations were analyzed:

1. Reference Model: The storage rack without neutron absorbers.
2. Two-Absorber Model: The storage rack with two neutron absorbers attached.
3. Four-Absorber Model: The storage rack with four neutron absorbers attached

2.1 Modeling

For criticality analysis, a 7×8 module of the new fuel storage rack was modeled. Specifically, one of the two modules in the storage system was modeled and reflective boundary condition was applied to represent the adjacent module. To ensure conservative results, the storage racks were assumed to be filled with pure water at maximum density (1 g/cm³). Additionally, most structural materials, excluding the fuel rods and guide tubes, were replaced with water to provide a conservative estimate of the system's criticality.

The input data for the fuel assemblies and the new fuel storage rack were derived from the reference document [2], which provides detailed specifications and design parameters. The neutron absorbers used in the two-absorber and four-absorber models were designed with the same specifications as those used in Region 1 of the spent fuel pool storage racks. This ensures consistency in the material properties and effectiveness of neutron absorption across different storage areas.

The study compares the criticality of a conventional UO_2 fuel assembly with that of a LEU+ fuel assembly, varying the enrichment levels between 5.0% and 8.0%.

Fig. 1 and 2 show the new fuel storage system and each storage rack model, respectively. The storage rack with two neutron absorbers model, where the absorbers were alternately placed in vertical and horizontal orientation to optimize neutron shielding.

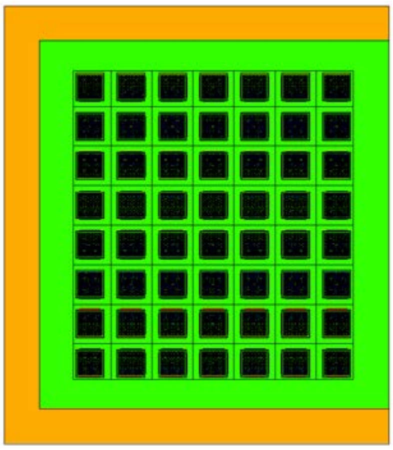

Fig. 1 Top view of new fuel storage system

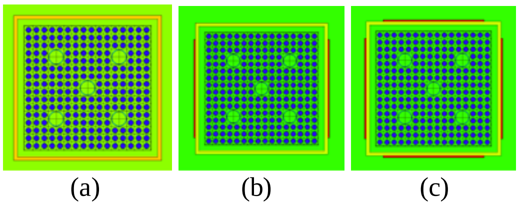

Fig. 2 Storage rack models
(a) Reference (b) 2-absorber (c) 4-absorber

2.2 Analytical approach

The k_{eff} for each fuel type was calculated using the MCNP6 code. Material compositions for the fuel and structural components were sourced from relevant technical references, and the ENDF/B-VII nuclear data library [4] was utilized for generating cross-section data. The simulations employed 10,000 neutrons over 1,200 generations to minimize statistical uncertainty, with the first 200 generations disregarded to eliminate bias from initial values, thereby ensuring accurate $_{keff}$ evaluations.

3. Results

The analysis of the three configurations yielded the following findings.

The storage rack without neutron absorbers can only accommodate fuel with an enrichment of up to 5.5%. The k_{eff} of 6% enriched fuel was 0.93701. However, when considering uncertainties, there is a possibility that the k_{eff} could exceed the criteria, making it unsuitable for storing higher-enriched fuel.

The two-absorber model is effective up to 6.5% enrichment fuel but is not suitable for 7% enrichment. The criticality of 7% enriched fuel yielded a k_{eff} value of 0.94576. When uncertainties are considered, the k_{eff} would exceed the criteria, indicating that this configuration is not adequate for storing fuel with an enrichment above 6.5%.

With four neutron absorbers attached, the storage rack can safely accommodate fuel with an enrichment of up to 8%. This configuration provides the greatest reduction in neutron flux, ensuring subcriticality even with higher-enriched fuel.

These results demonstrate that the criticality safety of new fuel storage racks can be significantly enhanced by the strategic placement of neutron absorbers, allowing for the safe storage of higher-enriched LEU+ fuel.

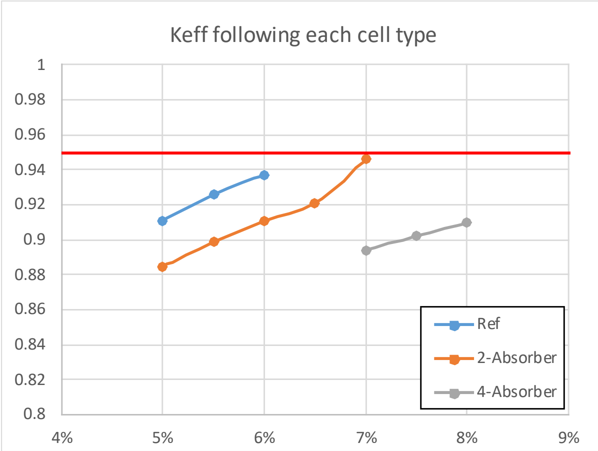

Fig. 3 k_{eff} with fuel enrichment for different models

4. Conclusion

This study conducted a criticality analysis to evaluate the feasibility of storing LEU+ fuel in new fuel storage racks. The results indicate that while the reference and two-absorber models have limitations when storing higher-enriched fuels, the four-absorber model provides a safer configuration for storing LEU+ fuel with enrichment up to 8%. Therefore, to store higher-enriched fuel, facility improvement is necessary.

Furthermore, it is recommended that future evaluations focus on optimizing the number and size of neutron absorbers to ensure subcriticality is maintained while accommodating varying fuel enrichment.

Acknowledgements

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