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Assessment of Burnable Poison Reactivity in the ATF Fuel Assembly

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1. Introduction

The safety of fuel system comprising cladding material and fuel became a relevant concern in the nuclear fuel industry after Fukushima Daiichi nuclear reactor accident, where an estimated 14 meter tsunami hit the site of the reactors damaging many of the generators, as well as battery backup systems challenging the fuel system performance under loss-of-coolant condition. As the result of the accident consequences, United States (U.S.) Congress launched a development program to pursuit advanced fuel technologies in order to enhance the safety of nuclear power reactors in U.S.. This research and development program started with a budget of about $60 million dollars, and the U.S. Department of Energy, specifically the Office of Nuclear Energy was appointed to coordinate efforts among research institutes, universities, and nuclear industry to develop Accident Tolerant Fuels (ATF) that would enhance the safety of light water reactors [1]. This work aims to perform an assessment of neutronic reactivity of different kinds of ATF fuel assemblies with presence of burnable poison pins (UO_2-Gd_2O_3) using a Monte Carlo simulation.

2. Accident Tolerant Fuel

Nowadays, the nuclear industry had been engaged in activities of research and development to obtain new fuel designs with enhanced accident tolerance, which present a better performance specially during loss-of-cooling conditions compared to the standard fuel system (uranium dioxide (UO_2) pellets and zirconium-based alloy cladding). Different concepts of ATF are under investigation, such as fuel with coated claddings, doped UO_2 pellets, iron-chrome-aluminum-based (FeCrAl) cladding, silicon carbide (SiC) cladding, uranium nitride (UN) and uranium silicide (U_3Si_2) pellets [2]. Based on current concept, the ATF can be categorized as near term and longer term technologies. The near term and longer term are often associated to level of technology maturity and expected deployment timeframe for utilization in the existing reactors fleet. Near-term ATF concepts are associated to technologies which rely on existing data, models, and methods for its safety evaluation, such as coated cladding, FeCrAl cladding, and doped UO_2 pellets; on the other hand, longer term ATF concepts still need substantial new data, models, and methods, concerning to UN fuel, metallic fuel, and SiC-based cladding.

3. ATF Fuel Assembly Reactivity with Burnable Poison

The neutronic assessment of an ATF fuel assembly aims to verify the neutronic reactivity behavior throughout the burnup. The AP-1000 reactor fuel assembly [3] is simulated considering the following data: 17x17 geometric array with 264 fuel rods (enrichment 4.45wt% of ^{235}U), 24 guide tubes, 16 UO_2-Gd_2O_3 burnable poison rods and one instrumentation tube, according to the schematic diagram presented in Figure 1. The UO_2-Gd_2O_3 burnable poison rod contains 6% by weight of Gd_2O_3 and 94% by weight of UO_2 with 1.7% enrichment of ^{235}U and has the same dimensions as the fuels rods; guide tubes have internal radius of 0.56134 cm and external radius of 0.61214 cm. The ATF fuel assembly reactivity simulations were performed using SERPENT [4], a Monte Carlo code, considering different cladding and fuel combinations.

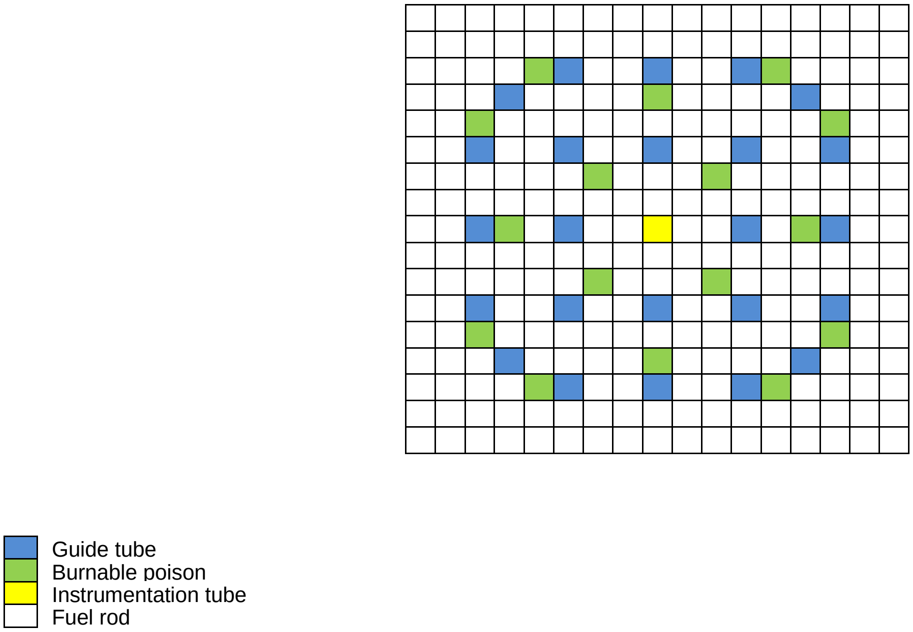

Figure 1: ATF fuel assembly based on AP-1000 reactor design.

The studied ATF fuel assembly considers different combinations of cladding materials (ZIRLO, FeCrAl, and SiC) and fuels (UO_2, UO_2-BeO, UN, and U_3Si_2), and the reference case for comparison is a standard fuel (UO_2) with ZIRLO as cladding material. The Figures 2, 3 and 4 show the behavior of neutronic reactivity along of fuel assembly burnup considering different types of claddings (ZIRLO, FeCrAl, and SiC) and fuels (UO_2, UN, U_3Si_2 and UO_2-BeO).

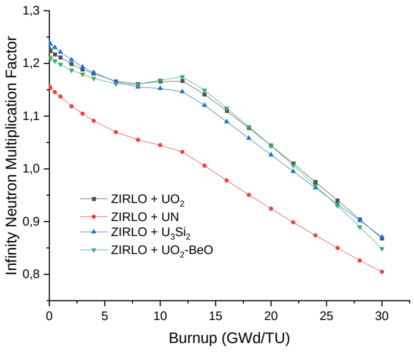

Figure 2: Infinity neutron multiplication factor as function of burnup for ATF fuel assembly (ZIRLO as cladding and different fuel materials: UO_2, UN, U_3Si_2, and UO_2-BeO).

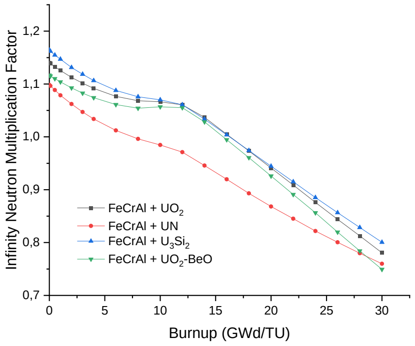

Figure 3: Infinity neutron multiplication factor as function of burnup for ATF fuel assembly (FeCrAl as cladding and different fuel materials: UO_2, UN, U_3Si_2, and UO_2-BeO).

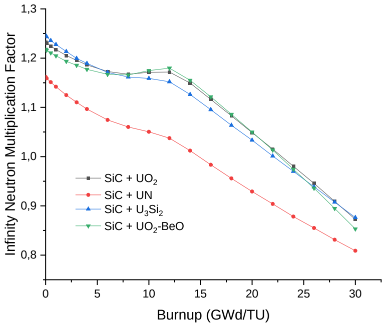

Figure 4: Infinity neutron multiplication factor as function of burnup considering ATF fuel assembly (SiC as cladding and different fuel materials: UO_2, UN, U_3Si_2, and UO_2-BeO).

Remarkably for all three cases with different cladding materials (ZIRLO, FeCrAl, and SiC), the fuel assembly with UN as fuel has a lower reactivity compared to the others fuels. The UN fuel has two isotopes of nitrogen, ^{14}N and ^{15}N with following natural abundance: 99.64% and 0.36%, respectively. The ^{14}N has a significant larger thermal neutron absorption cross section [5] compared to ^{15}N and to others nuclides, which comprises UO_2, U_3Si_2, and UO_2-BeO. The SiC cladding has a similar behavior of ZIRLO cladding and FeCrAl cladding has a neutronic reactivity penalty due to the presence of iron (Fe) isotopes in the alloy, which has a quite large thermal neutron absorption cross section.

4. Conclusions

Standard PWR fuel assemblies with burnable poison pins were simulated considering different combinations of ATF cladding and fuel materials. All numerical simulations were performed using a Monte Carlo code to obtain a neutronic reactivity along of fuel assembly burnup. Among different claddings and fuels, the UN as fuel has shown a lower reactivity along of burnup compared to others ATF systems (cladding + fuel). FeCrAl cladding presents a quite substantial neutronic penalty due to presence of Fe isotopes, which have a large thermal neutron absorption cross section. The behavior of each ATF fuel assembly with burnable poison pins along of burnup have shown a similar trend.

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