2021 International Nuclear Atlantic Conference – INAC 2021
Virtual meeting, Brazil, November 29 – December 2, 2021

ISBN: 978-65-594-1256-3

Adaptation of a 10MWe Small Modular Reactor for Thorium MOX fuel

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1. Introduction

Small modular reactors have become the object of studies by the nuclear community all over the world (1) due it's wide range of applicability, off site components manufacturing and facilitated on site installation. Different technologies are being tested by industry and government funded institutions. The use of MOX fuel in these reactors is being considered, including mixed thorium and uranium oxide fuels (2).

Thorium oxide compound has been proved to have advantages in comparison to PuO2 and UO2. It's high thermal and structural stability, high thermal conductivity, low chemical reactivity and defined oxygen potential are some of the characteristics that have led to a resurgence of thorium based fuels studies in recent years (3) (4) (5). The addition of thorium oxide has been shown to allow longer fuel cycles and more stable operation in light water reactors (6). Thorium based fuel cycles have also been proven to be less prone to proliferation related issues (7) (8) (9). Still, the main concern is the fertile nature of thorium, which must be converted in core to U233 through a neutron capture interaction. This process takes 27 days on average and hence the fuel must have a reactivity coefficient large enough to sustain initial operation before the concentration of U233 is large enough to maintain the chain fission reaction on its own.

This work is centred at the evaluation of the use of low enrichment uranium associated with thorium oxide compared to a Uranium only reactor core. A core designed for 10 MWe developed on a previous work by Neto et al is used as the basis for the study (10). An analysis with the aid of Monte Carlo method based software is made to define fissile and fertile isotopes concentrations and to demonstrate the fuel conversion capacity of the selected system.

2. Methodology

The Monte Carlo method has been used for nuclear reactor and radiological studies since it's conception for computing purposes. This technique is based on the generation of multiple stories starting from a predefined configuration for a certain geometry, environment and within physical parameters chosen by the operator. It is particularly fit for nuclear applications due to the statistic nature over which nuclear sciences have developed over the course of the past century. The need to provide results for problems involving hundreds of billions of particles generate an especially appropriate setting for statistics-based solutions in terms of confidence intervals. Thus, the method is highly dependent on the modelling and input parameters. Softwares based on Monte Carlo Method simulations like Keno VI (11) (12), which is part of the Oak Ridge Laboratory' Scale package, and MCNP have been shown to produce trustworthy results for varied reactor configurations.

The modelling was based on the geometry and component materials for a small modular reactor designed for operation at 10MWe. The data was taken from Neto, A (2020) (10). The original reactor data is shown in Table I below.

Table I: Original reactor data used for modelling and comparison (Neto, 2020) (10)

General data	
Thermal output	30MWt
Electric output	10MWe
Reactor type	SMR (PWR)
Enrichment	4 %wt – 5%wt – 16%wt
Fuel cycle duration	720 days
Materials	
Fuel	UO2 pellets
Gap	He
Cladding	Zircalloy-4
Coolant	H2O
Safety rods	Ag(80%) – In(15%) – Cd(5%)
Fuel rod dimensions (cm)	
Fuel pellet diameter	0,911
Internal cladding diameter	0,930
External cladding diameter	1,075
Fuel rod height	80,00
Pitch	1,43
Fuel elements	
Matrix	4x4
Number of fuel elements	153
Safety rods per fuel element	12
Number of fuel elements with safety rods	29
Core dimensions (cm)	
Core height	110,00
Core diameter	110,00
Effective core height	80,00
Effective core diameter	74,36

After modelling the geometry according to the data, the material inputs are then modified to set an alternative fueling scheme in order to benefit from the advantages of thorium oxide characteristics whilst overcoming the impairment of fertilization in the early stages of operation. This is made by gradually increasing the relative amount of ThO2 in comparison to UO2 and adjusting the enrichment levels for the three different regions inside the reactor core.

3. Results and Discussion

The current results indicate that the reactor would be operational in a new Th/UO2 fuel concept without modifications to the core's geometry and under the 20wt% limit for low enrichment uranium established by the IAEA. Furthermore, the preliminary results point to a longer duration of the fuel cycles without compromising the criticality, burn up and poison concentration levels inside the reactor's core.

4. Conclusions

More definite conclusions are still in the works.

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