NEUTRONIC COMPARISON OF HIGH DENSITY FUELS (U-MO-AL AND U_3SI_2-AL) FOR RESEARCH REACTORS

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ABSTRACT

The aim of this paper is to compare the infinite multiplication factor (K_∞), obtained through neutronic calculation with the code Scale 6.0, for fuel elements reflected in all directions containing U_3Si_2-Al and U-Mo-Al dispersion fuels. The U_3Si_2-Al dispersion fuels used in the calculation have a uranium density between 3.0 and 5.5 gU/cm^3 and the U-Mo-Al dispersion fuels have densities ranging from 4.0 to 7.52 gU/cm^3 and 7 and 10% Mo addition. The results show that the K_∞ calculated for U-Mo-Al fuels are smaller than that for U_3Si_2-Al fuels and increases between the uranium densities of 4 and 5 gU/cm^3 and decreases for higher uranium densities.

1. Introduction

Nuclear fuels composed by uranium metal alloys in monolithic and dispersed forms have been considered for research and power reactors due to their density properties and fast heat transfer. Among several candidates, U-Mo alloys are one of the most promising systems for plate type fuel elements owing to its broad gamma-phase stable field. This fact allows extensive fabrication capability since cubic gamma-phase shows good plasticity, higher strength and elongation [1]. Because of the high uranium density and good irradiation stability of U-Mo alloys, this fuel in the form of a dispersion in an Al matrix is the choice for the conversion of research and material test reactors currently using highly enriched uranium (HEU) to low-enriched uranium (LEU). The formation of an interaction layer between U-Mo particles and the Al matrix as a result of inter-diffusion has become a major issue for the performance of this fuel [2]. The formation of an interaction product in this dispersion fuel is unfavorable because of its low thermal conductivity and volume expansion as it consumes the Al matrix. Depending on the irradiation conditions (high burnup or high heat flux), large pores are formed at the interface of the interactions products and the Al matrix, which could eventually lead to a fuel plate failure. Many post irradiation tests have been conducted for uranium alloys with a molybdenum content between 6 to 10% by weight allowing the characterization of U-Mo-Al interaction [3], and this fuel qualification is a on-going process.

U_3Si_2-Al dispersion fuel with a uranium density of 3.5 gU/cm^3 is being considered as the fuel for the first core of the new Brazilian Multipurpose Reactor (RMB) [4]. The aim of this paper is to compare the calculated infinite multiplication factor (K_∞), obtained through neutronic calculation with the code Scale 6.0 [5], for fuel elements reflected in all directions using U_3Si_2-Al and U-Mo-Al dispersion fuels. These results will be utilized in the future to verify the core performance improvements that can be obtained for an already designed research reactor using a different fuel assembly with higher densities.

The U_3Si_2-Al dispersion fuel used in the calculation has a uranium density between 3.0 and 5.5 gU/cm^3 and the U-Mo-Al dispersion fuels have densities ranging from 4.0 to 7.52 gU/cm^3 and 7 to 10% Mo addition. The percentage by weight of molybdenum (Mo) in the dispersion changes the neutronic behavior of the fuel since the neutron absorption by Mo is considerable higher than that by Silicon (Si). Fig 1 shows a comparison between the neutron absorption cross section of Mo and Si [6].

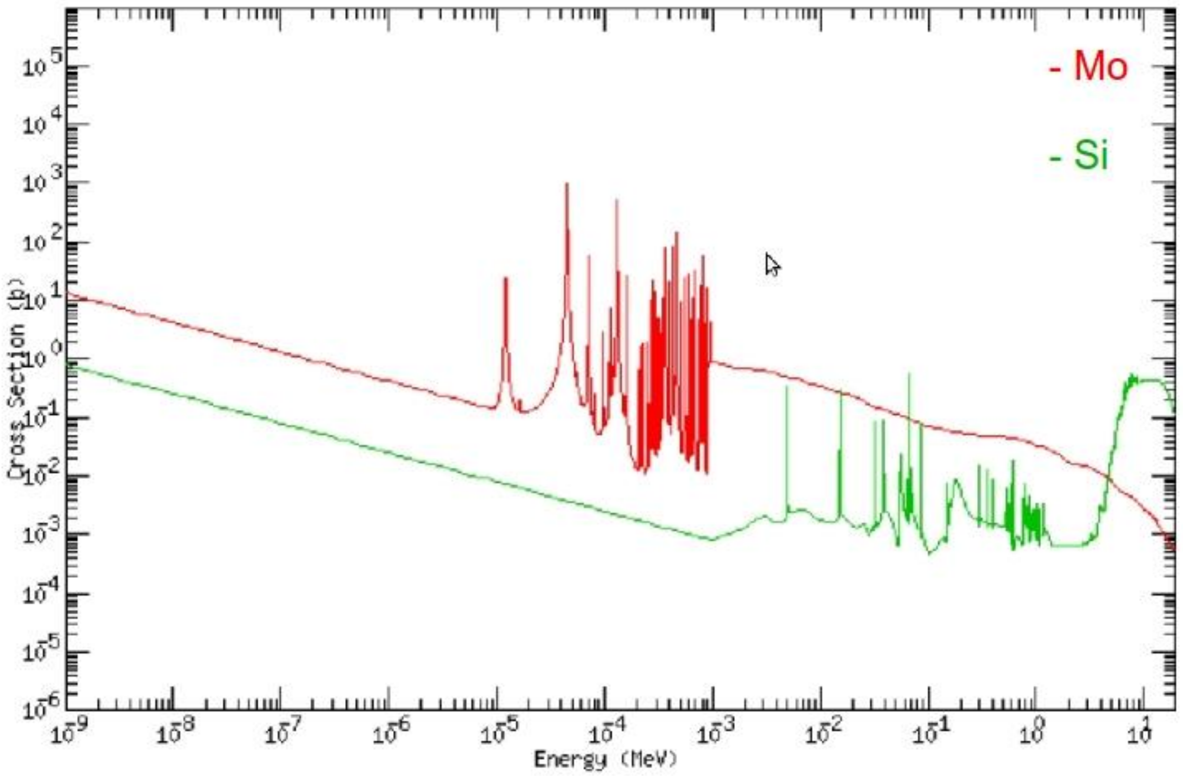

Fig 1: Neutron absorption cross section for Mo and Si.

2. Infinite multiplication factor (k_∞) calculation

2.1 Computer simulation

The computer code Scale 6.0 was used to calculate the infinite multiplication factor. The cross sections were processed with the modules Triton and Bonami that uses the Bondarenko method for calculating the self-shielding in the energy ranges of the unresolved ressonance regions. The neutron transport was calculated with KENO V.a using the Monte Carlo method for the neutron fluxes determination.

The fuel elements proposed and analyzed in this work (Fig 2) consisted of 21 rectangular aluminum coated plates and its structure is an aluminum frame where the fuel plates are fitted. The internal plates in the fuel element measure 7.049 cm x 61 cm, 0.135 mm thick, and the two external fuel plates are 0.150 mm thick. Both the U_3Si_2-Al meat and the U-Mo-Al meat are 6.5 cm x 61 cm, 0.061 cm thick. The space between the plates forms the cooling channel that is 0.245 cm thick. In the simulation this area was filled with water as well as the region around the fuel element which was modeled as a layer of 0.05 cm of water.

The concentrations used in this study are the same used in the reference [7] to simulate one U-Mo-Al plate and where only one U_3Si_2-Al uranium density was considered.

3. Results and conclusions

The calculated infinite multiplication factors (K_∞) obtained from the simulations with the code scale 6.0 are shown in Tables 1, 2 and 3. Fig 3 presents the infinite multiplication factors plotted against U_3Si_2-Al uranium density ranging from 3.0 to 5.5 gU/cm^3. Fig 4 presents the infinite multiplication factors plotted against U-Mo-Al with uranium densities from 4.0 to 7.52 gU/cm^3 and 7 and 10% Mo addition.

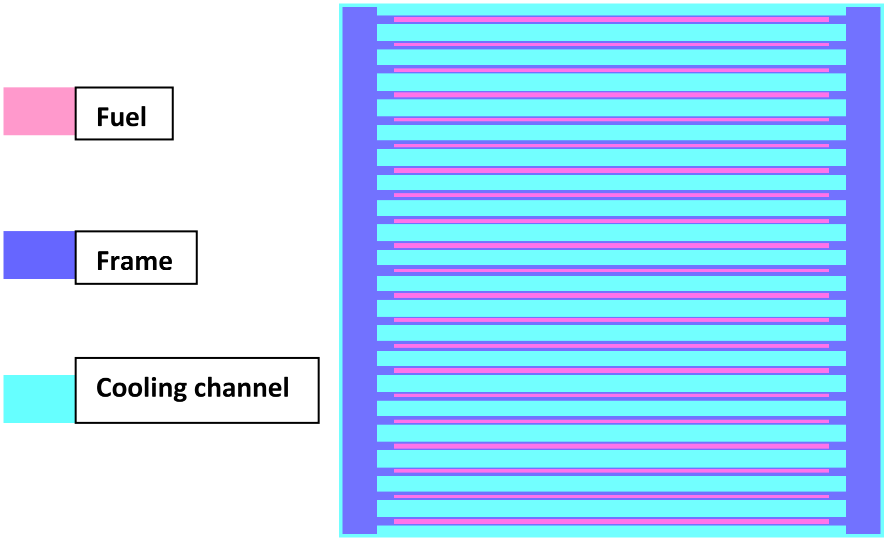

Fig 2: Fuel element cross section.

Tab 1: Infinite multiplication factors for U_3Si_2/Al fuels ranging from 3.0 to 5.5 gU/cm^3.

Uranium density (gU/cm^3)	K_∞	$^*\sigma K_\infty$
3.00	1.60245	0.00011
3.30	1.61618	0.00011
3.50	1.62388	0.00010
3.80	1.63320	0.00010
4.00	1.63843	0.00011
4.30	1.64479	0.00010
4.50	1.64847	0.00011
4.80	1.65258	0.00010
5.00	1.65558	0.00010
5.30	1.65779	0.00010
5.50	1.65925	0.00011

* Uncertainty

Tab 2: Infinite multiplication factors for U-7wt%Mo-Al fuels ranging from 4.0 to 7.52 gU/cm^3.

Uranium density (gU/cm^3)	K_∞	σK_∞
4.01	1.62851	0.00011
4.55	1.63652	0.00010
5.02	1.64365	0.00011
5.55	1.64402	0.00011
6.02	1.64499	0.00011
6.55	1.64497	0.00011
7.02	1.64440	0.00011
7.52	1.64285	0.00011

Tab 3: Infinite multiplication factors for U-10wt%Mo/Al fuels ranging from 4.0 to 7.11 gU/cm^3.

Uranium density (gU/cm^3)	K_∞	σK_∞
4.01	1.62273	0.00011
4.52	1.63037	0.00011
5.02	1.63485	0.00010
5.56	1.63746	0.00011
6.00	1.63801	0.00011
6.54	1.63793	0.00011
7.01	1.63678	0.00011
7.11	1.63657	0.00011

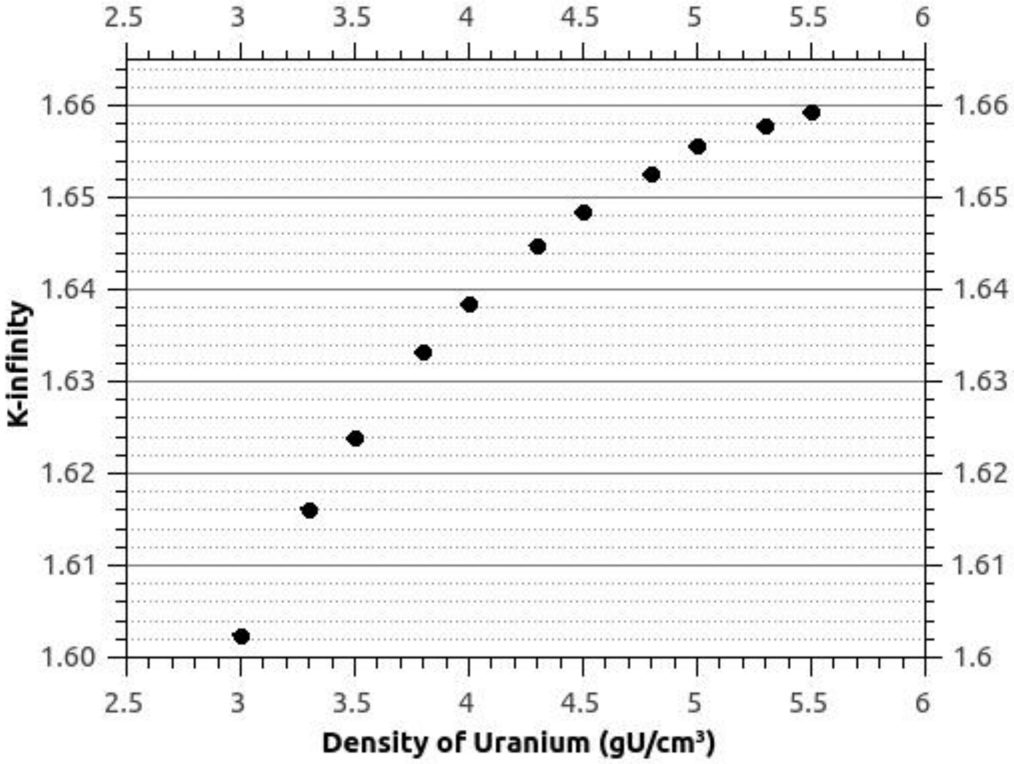

Fig 3: K∞ for U_3Si_2-Al fuels with uranium densities ranging from 3.0 to 5.5 gU/cm^3.

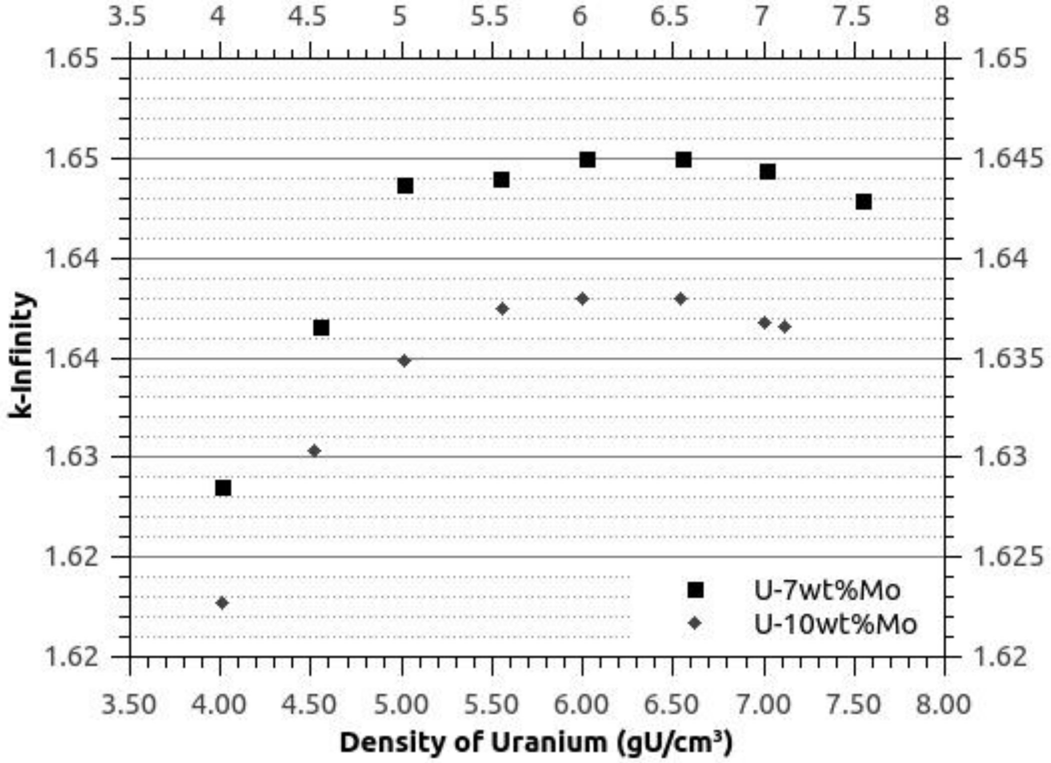

Fig 4: K∞ for U-7wt%Mo-Al and U-10wt%Mo-Al with uranium densities ranging from 4.01 to 7.52 gU/cm^3.

It can be seen from Fig 3 that the K_∞ values obtained for different uranium densities with U-10wt%Mo/Al fuels are below those obtained with U-7wt%Mo/Al fuels. This behavior was expected due to the different absorption cross section of the two materials.

The potential benefits of the high density fuel will depend on the research reactor to be upgraded. A priory, it is difficult for potential users to clearly understand what kind of economic or improvement benefits can be expected. Further works are being conducted in order to identify improvements in core performance (higher neutron fluxes) and on the impact of fuel density on the cost of the research reactor fuel cycles (to reduce the number of fuel assemblies needed for operation) [8].

The results of this work confirm those obtained in reference 7, where was examined only a generic fuel plate. In a next step It will be analysed the performance of the U_3Si_2-Al and U-Mo-Al fuels with burnup.

Acknowledgements

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4. References

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