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Neutronic Comparison of the Nuclear Fuels U_3Si_2/Al and U-Mo/Al

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ABSTRACT

The search for materials that allow the fabrication of nuclear fuels with higher uranium densities comes from the mid 50s. Today, a high density and low enriched nuclear fuel based on γ-UMo alloys is the most promising fuel to replace the U_3Si_2/Al dispersion fuel used worldwide in research and material test reactors. Alloys of uranium-molybdenum are prepared with 6 to 10% Mo addition and can be manufactured as dispersion or monolithic fuels. The aim of this paper is to compare the infinite multiplication factor (K_∞), obtained through neutronic calculation with the code Scale 6, for aluminum coated plates reflected in all directions containing U_3Si_2/Al and U-Mo/Al dispersion fuels. The U_3Si_2/Al dispersion fuel used in the calculation has an uranium density of 4 gU/cm^3 and the U-Mo-Al dispersion fuels have densities ranging from 4 to 7.52 gU/cm^3 and 7 and 10% Mo addition. The results show that the K_∞ calculated for U-Mo/Al fuels is lower than that for U_3Si_2/Al fuel 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 alternatives, 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 interdiffusion 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 an on-going process.

U_3Si_2/Al dispersion fuels with an uranium density of 4 gU/cm^3 is being considered as the fuel for the first core of the new Brazilian Multipurpose Reactor (RMB). The aim of this paper is to compare the calculated infinite multiplication factor (K∞), obtained through neutronic calculation with the code Scale 6 [4], for fuel plates 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 an uranium density of 4 gU/cm^3 and the U-Mo-Al dispersion fuels have densities ranging from 4 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 Si. Figure 1 shows a comparison between the neutron absorption cross section of Mo and silicon (Si) [5].

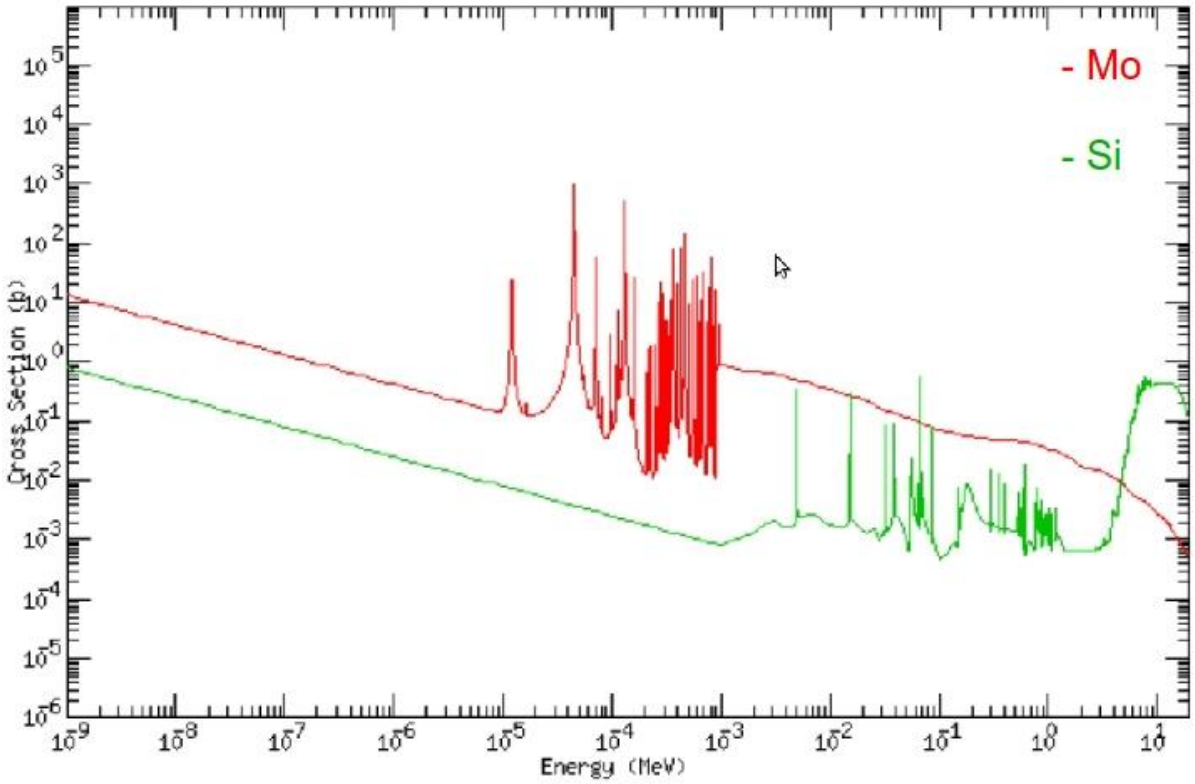

Figure 1: Neutron Absorption Cross Section for Mo and Si.

2. INFINITE MULTIPLICATION FACTOR (K_∞) CALCULATION

2.1. Computer Simulation

The computer code Scale 6 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 calculate with KENO V.a using the Monte Carlo method for neutron fluxes determination [4].

The fuel plates proposed and analyzed in this work are retangular aluminum coated plates. Each plate measures 1 cm x 4 cm, 1.52 mm thick. The U_3Si_2/Al and the U-Mo/Al core fuel is 1 cm x 4 cm, 0.76 mm thick, and the water layer 0.133 cm thick. The simulation considers the plate reflected in all directions (infinite reactor).

2.1.1. Isotopic Concentration

Table 1 shows the isotopic concentration in atoms per barn-centimeter (atom/b.cm) used for U_3Si_2 with the uranium density of 4 gU/cm^3 and the impurities considered in the fuel meat.

Table 1: Isotopic Concentration and Impurities for U_3Si_2/Al Fuel.

Element	Component	Concentration (atom/b.cm)
U-234	Nuclear Fuel	1.90096E-5
U-235		1.90740E-3
U-238		7.63374E-3
Si		6.62574E-3
Al		4.01749E-2
Cu-63	Impurity	3.14348E-5
Cu-65		1.40109E-5
Cr-50		1.02216E-6
Cr-52		1.96889E-5
Cr-53		2.23230E-6
Cr-54		5.54550E-7
Mg		4.52422E-4
Fe-54		3.14144E-6
Fe-56		4.92696E-5
Fe-57		1.13844E-6
Fe-58		1.50360E-7
Mn		1.81962E-5
Ti		2.31980E-6
B-10		2.04457E-7
B-11		8.22951E-7
Cd		4.94051E-8
Co		1.13083E-6

Tables 2 and 3 show the isotopic concentration for the U-Mo/Al fuels having densities ranging from 4 to 7.52 gU/cm^3 and, respectively, 7 to 10% Mo addition. The impurities concentrations were considered in all cases the same of the U_3Si_2/Al fuel.

Table 2: Isotopic Concentration for U-7wt%Mo/Al Fuel.

Element	4.01	4.55	5.02	5.55	6.02	6.55	7.02	7.52
U-234	2.0161E-5	2.2850E-5	2.6714E-5	2.7890E-5	3.0242E-5	3.2930E-5	3.5282E-5	3.7803E-5
U-235	2.0112E-3	2.2793E-3	2.6648E-3	2.7821E-3	3.0168E-3	3.2849E-3	3.5196E-3	3.7710E-3
U-238	8.0493E-3	9.1226E-3	1.0665E-2	1.1135E-2	1.2074E-2	1.3147E-2	1.4086E-2	1.5092E-2
Mo-92	2.9229E-4	3.3126E-4	3.6536E-4	4.0433E-4	4.3843E-4	4.7740E-4	5.1150E-4	5.4804E-4

Mo-94	1.7831E-4	2.0209E-4	2.2289E-4	2.4666E-4	2.6747E-4	2.9124E-4	3.1204E-4	3.3433E-4
Mo-95	3.0366E-4	3.4415E-4	3.7957E-4	4.2006E-4	4.5549E-4	4.9597E-4	5.3140E-4	5.6936E-4
Mo-96	3.1484E-4	3.5682E-4	3.9355E-4	4.3553E-4	4.7226E-4	5.1424E-4	5.5097E-4	5.9032E-4
Mo-97	1.7840E-4	2.0219E-4	2.2300E-4	2.4679E-4	2.6760E-4	2.9139E-4	3.1220E-4	3.3450E-4
Mo-98	4.4617E-4	5.0566E-4	5.5771E-4	6.1720E-4	6.6925E-4	7.2874E-4	7.8079E-4	8.3656E-4
Mo-100	1.7450E-4	1.9777E-4	2.1812E-4	2.4139E-4	2.6175E-4	2.8501E-4	3.0537E-4	3.2718E-4
Al	4.5067E-2	4.3170E-2	4.0442E-2	3.9612E-2	3.7951E-2	3.6054E-2	3.4393E-2	3.2614E-2

Table 3: Isotopic Concentration for U-10wt%Mo/Al Fuel.

Element	**4,01**	**4,52**	**5,02**	**5,56**	**6.00**	**6.54**	**7.01**	**7.11**
U-234	2.0158E-5	2.2697E-5	2.5236E-5	2.7934E-5	3.0156E-5	3.2854E-5	3.5234E-5	3.5710E-5
U-235	2.0108E-3	2.2641E-3	2.5174E-3	2.7865E-3	3.0082E-3	3.2773E-3	3.5148E-3	3.5623E-3
U-238	8.0478E-3	9.0616E-3	1.0075E-2	1.1152E-2	1.2040E-2	1.3117E-2	1.4067E-2	1.4257E-2
Mo-92	4.3139E-4	4.8573E-4	5.4008E-4	5.9781E-4	6.4536E-4	7.0310E-4	7.5404E-4	7.6423E-4
Mo-94	2.6317E-4	2.9632E-4	3.2948E-4	3.6470E-4	3.9371E-4	4.2893E-4	4.6001E-4	4.6622E-4
Mo-95	4.4817E-4	5.0463E-4	5.6109E-4	6.2107E-4	6.7047E-4	7.3045E-4	7.8338E-4	7.9396E-4
Mo-96	4.6468E-4	5.2321E-4	5.8175E-4	6.4394E-4	6.9516E-4	7.5735E-4	8.1222E-4	8.2320E-4
Mo-97	2.6330E-4	2.9647E-4	3.2964E-4	3.6488E-4	3.9390E-4	4.2914E-4	4.6024E-4	4.6646E-4
Mo-98	6.5850E-4	7.4145E-4	8.2441E-4	9.1254E-4	9.8512E-4	1.0733E-3	1.1510E-3	1.1666E-3
Mo-100	2.5754E-4	2.8999E-4	3.2243E-4	3.5690E-4	3.8529E-4	4.1976E-4	4.5017E-4	4.5625E-4
Al	4.4226E-2	4.2328E-2	4.0431E-2	3.8415E-2	3.6755E-2	3.4739E-2	3.2960E-2	3.2604E-2

3. RESULTS AND CONCLUSIONS

The calculated infinite multiplication factor (K_∞) obtained from the simulations with the code scale 6 are shown in Tables 4 and 5. Table 4 shows the values obtained for U-7wt%Mo/Al fuel and Table 5 for U-10wt%Mo/Al fuel. For U_3Si-2/Al the values 1.65782 and 0.00012 were obtained for K_∞ and $*\sigma K_\infty$, respectively.

Table 4: Infinite Multiplication Factors for U-7wt%Mo/Al fuel ranging from 4 to 7.52 gU/cm^3

Density Uranium (gU/cm^3)	**K_∞**	**$*\sigma K_\infty$**
4.01	1.64642	0.00012
4.55	1.65203	0.00012
5.02	1.65634	0.00012
5.55	1.65596	0.00012
6.02	1.65561	0.00012
6.55	1.65439	0.00012
7.02	1.65270	0.00013
7.52	1.65059	0.00012

* Uncertainty

Table 5: Infinite Multiplication Factors for U-10wt%Mo/Al fuel ranging from 4 to 7,52 gU/cm^3

Density Uranium (gU/cm^3)	K_∞	σK_∞
4.01	1.64040	0.00012
4.52	1.64581	0.00012
5.02	1.64827	0.00012
5.56	1.64905	0.00013
6.00	1.64865	0.00012
6.54	1.64727	0.00012
7.01	1.64517	0.00012
7.11	1.64478	0.00012

Figure 2 presents the infinite multiplication factors plotted against uranium density for all studied fuels in this paper. The top line represents the K_∞ value obtained for U_3Si_2/Al.

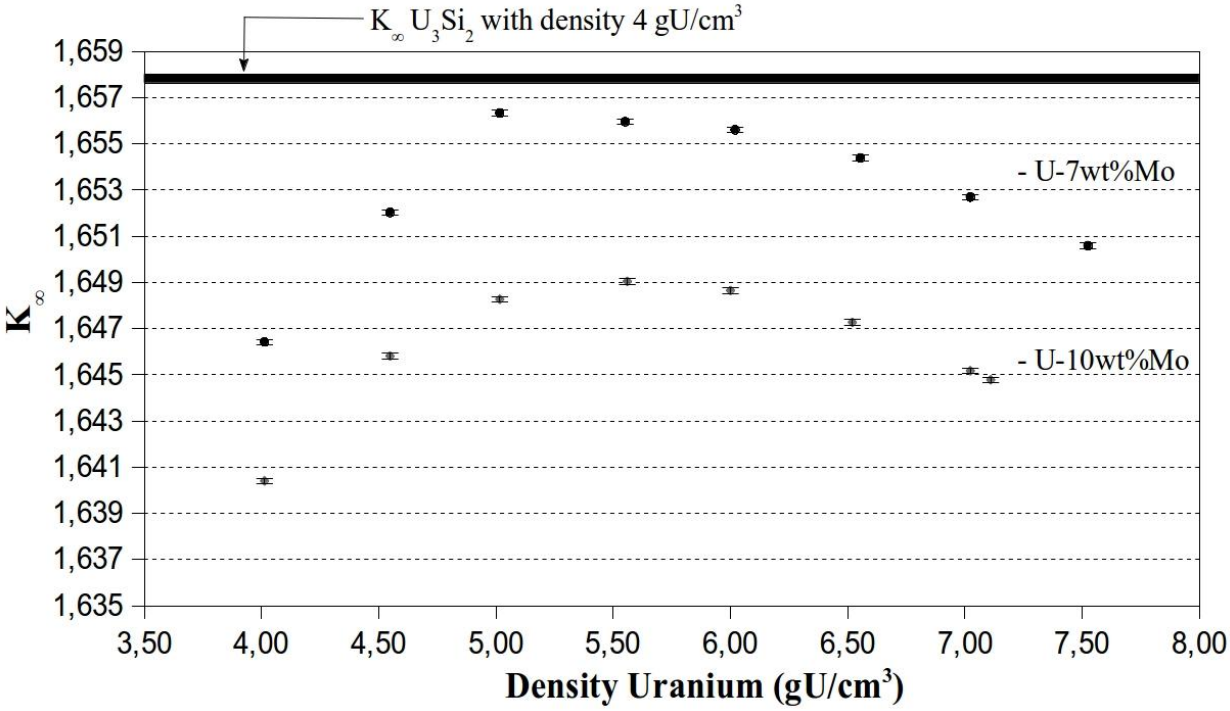

Figure 2: K_∞ for U_3Si_2/Al fuel (4 gU/cm^3) and for U-7wt%Mo/Al and U-10wt%Mo/Al with uranium densities ranging from 4.01 to 7.52 gU/cm^3

It can be seen from Figure 2 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) [6].

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