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NUCLEAR CRITICALITY SAFETY PARAMETER EVALUATION FOR URANIUM METALLIC ALLOY

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ABSTRACT

Nuclear criticality safety during fuel fabrication process, transport and storage of fissile and fissionable materials requires criticality safety analysis. Normally the analysis involves computer calculations and safety parameters determination. There are many different Criticality Safety Handbooks where such safety parameters for several different fissile mixtures are presented. The handbooks have been published to provide data and safety principles for the design, safety evaluation and licensing of operations, transport and storage of fissile and fissionable materials. The data often comprise not only critical values, but also subcritical limits and safe parameters obtained for specific conditions using criticality safety calculation codes such as SCALE system. Although many data are available for different fissile and fissionable materials, compounds, mixtures, different enrichment level, there are a lack of information regarding a uranium metal alloy, specifically UMo and UNbZr. Nowadays uranium metal alloy as fuel have been investigated under RERTR program as possible candidate to became a new fuel for research reactor due to high density. This work aim to evaluate a set of criticality safety parameters for uranium metal alloy using SCALE system and MCNP Monte Carlo code.

1. INTRODUCTION

Nowadays, the RERTR program are considering different types of high density uranium alloy[1,2,3,4] and some of them are being under irradiation as mini plate in order to evaluate their performance. All the irradiation programs and results might reach and define an important and potential candidate to be a next fuel for the research reactor. After the definition, the fuel must be fabricated according to technical specification as safety manner in fuel fabrication facilities. One of the important activities involved during the fabrication is a safety against a possible criticality accident hazards. In order to fulfill some lack of important data related to criticality[5-10], this work aim to determine the criticality safety parameters for two different uranium alloys (UMo and UNbZr), which has been extensively studied under RERTR scope.

The criticality safety analysis activity is always mandatory for any nuclear fuel fabrication facilities. Every criticality safety analysis activities comprises an evaluation considering compliance with standards[11-19], using validated computer codes and methodologies. The criticality safety analysis essentially defines an amount of fissile and fissionable material and conditions that can be handled in the installation without compromising safety.

As standard methodology previously presented in the reference [20], this works aim to obtain a set of safety parameters: mass, volume, an infinite cylinder diameter and infinite slab thickness for UMo and UNbZr uranium alloys.

2. CRITICALITY SAFETY PARAMETERS

The criticality safety parameters are always obtained from the critical parameters for a specific fissile and fissionable mixture. The critical parameters are obtained for configurations where the effective neutron multiplication factor is set to be equal to 1.000 and afterwards safety parameters can be derived.
The relationship between critical and safety parameters normally consider some degree of conservatism due to possible problem related to sizing, weighing during the fabrication process, the usual relationship are presented below :

Safety Spherical Mass = 45% of Critical Spherical Mass
Safety Spherical Volume = 80% of Critical Spherical Volume
Safety Dimension = 90% of Critical Dimension

The methodology developed at CTMSP and IPEN to evaluate a critical parameters is based on SCALE system [21], and additionally the MCNP[22] Monte Carlo code was utilized to verify the obtained results as independent way.
Table 1 present a sequence available and correspondent modules involved to perform different calculations. The specific sequence applied to the criticality safety is denominated CSAS (Criticality Safety Analysis Sequence), which has different combinations of the functional modules depending of the purpose of the analysis.

Table 1: Calculation Sequence Available in the SCALE4.4a

Sequence	Search	Associated Modules
CSASI	No	BONAMI→NITAWL-II→ICE
CSASIX	No	BONAMI→NITAWL-II→XSDRNPM→ICE
CSASN	No	BONAMI→NITAWL-II
CSAS1X	No	BONAMI→NITAWL-II→XSDRNPM
CSAS25	No	BONAMI→NITAWL-II→KENO-V.a
CSAS2X	No	BONAMI→NITAWL-II→XSDRNPM→KENO-V.a
CSAS4	Yes	BONAMI→NITAWL-II→KENO-V.a→MODIFY
CSAS4X	Yes	BONAMI→NITAWL-II→XSDRNPM→KENO-V.a→MODIFY

The approach adopted in this work to obtain the critical parameter has two steps, one step to obtain a fissile mixture concentrations which gives highest reactivity, and another step to perform a search for critical dimension considering concentration obtained in previous step.
The first step of the evaluations starts using the CSAS1X sequence, which gives the infinite neutron multiplication factor of the given system (cell calculation). The CSAS1X sequence is considered for each different fissile mixture in order to obtain the infinite neutron multiplication factor as function of moderation ratio (density). The results gives the highest multiplication factor for a specific mixtures, the **Figures 1, 2, 3 and 4** shows the behavior of the infinite multiplication factor as function of density for two different level of enrichment and two different uranium alloys (UMo and UNbZr). The maximum of the curve represents the optimum degree of moderation, which gives the highest infinite neutron multiplication factor. The second step of the evaluation considers the previous results obtained from infinite neutron multiplication factor calculations, which the densities of the mixtures were

determined. The CSAS4 sequence were performed to a search of specific critical dimensions for each one of the mixtures considered, the critical dimension is obtained by an iterative and successive calculations starting from an arbitrary dimension of the system, which gives the correspondent neutron multiplication factor and it is compared to the critical multiplication factor (k_{ef}=1.0000), depending on the neutron multiplication factor obtained, subsequent calculation will be performed changing automatically the dimension, others successive calculations were performed up to reach a critical dimension

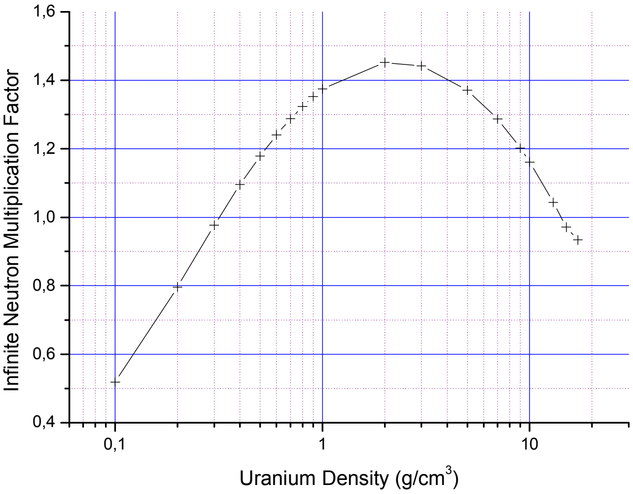

Figure 1: Infinite Neutron Multiplication Factor of the U-5Nb-3Zr + H_2O Mixture (5% enrichment)

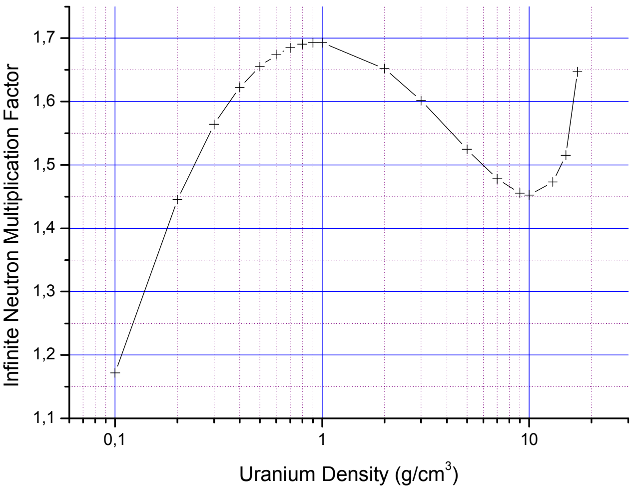

Figure 2: Infinite Neutron Multiplication Factor of the U-5Nb-3Zr + H_2O Mixture (20% enrichment)

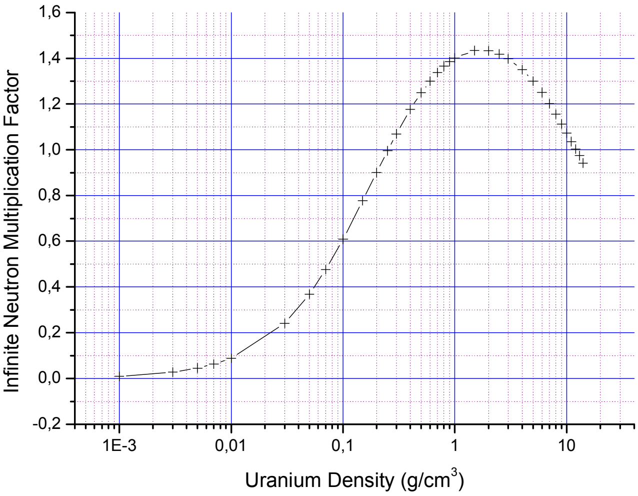

Figure 3: Infinite Neutron Multiplication Factor of the U-10Mo + H_2O Mixture (5% enrichment)

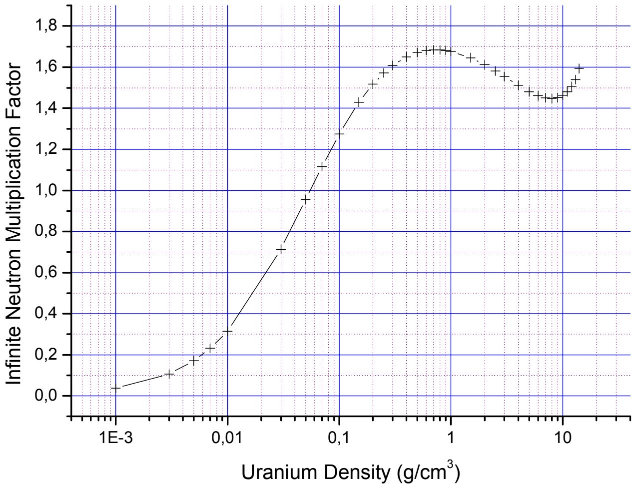

Figure 4: Infinite Neutron Multiplication Factor of the U-10Mo + H_2O Mixture (5% enrichment)

The KENO-Va [23] module is a multigroup Monte Carlo code used to determine effective neutron multiplication factor (K_{eff}) of the system with specific geometry, all calculations taken to perform a search of critical dimension were performed considering 30.0 cm of the ordinary water as reflector. The calculations were performed using 10000 neutron particles for each generation and 203 generations. The cross section library considered in the all evaluations was 44GROUPNDF5.

All calculations performed with the SCALE code were compared with calculations performed with the Monte Carlo code MCNP. The geometric modeling and dimensions were taken same as utilized in KENO-Va calculations and 5000 number of neutrons per cycle and 250 numbers of cycle.

3. RESULTS

Table 2 shows the safety parameters obtained according to methodology presented for two uranium alloys (U-5Nb-3Zr and U-10Mo).

Table 2: Safety parameters for different uranium alloys considering 5% and 20% of ^{235}U enrichment degree.

Mixture	Enrich(%)	M_S (kg)	V_S (liter)	D_S (cm)	L_S (cm)
U-5Nb-3Zr	5	18.06	20.00	22.07	10.76
	20	2.52	2.72	15.91	6.50
U-10Mo	5	15.05	21.99	23.02	11.12
	20	2.00	8.40	16.11	6.71

V_S = Safety volume (Sphere)
D_S = Safety diameter of infinite cylinder
L_S= Safety thickness of infinite slab

Additional calculations were performed as independent verification of the results obtained. The MCNP Monte Carlo code was used to obtain an effective neutron multiplication factor considering the critical dimension obtained from the SCALE system.
Since, each geometry with correspondent dimension was obtained as critical (k_{eff}=1.0000), and using same concentrations, a series of Monte Carlo calculations were performed using MCNP code. The MCNP calculations should reproduce the k_{eff} close to unit (k_{eff}=1.000). The geometrics modeling adopted were an infinite cylinder, sphere and infinite slab with 30.0 cm of ordinary water as reflector. The **Table 3** shown the comparison of results obtained for each uranium alloy with two different enrichment level.

Table 3: Comparison results between the codes MCNP and SCALE for uranium alloys (UMo and UNbZr) considering 5% and 20% of ^{235}U

Mixture	Enrich (%)	Code	Sphere	Cylinder	Slab
U-5Nb-3Zr	5	SCALE	0.99999±0.00067	1.00008±0.00062	1.00019±0.00055
		MCNP	1.00241±0.00083	1.00350±0.00078	1.00344±0.00074
	20	SCALE	1.00002±0.00072	1.00001±0.00072	0.99989±0.00066
		MCNP	0.99769±0.00093	0.99832±0.00098	0.99064±0.00085
U-10Mo	5	SCALE	1.00000±0.00060	0.99980±0.00070	1.00000±0.00060
		MCNP	1.00075±0.00075	0.99678±0.00078	1.00085±0.00068
	20	SCALE	0.99992±0.00070	1.00010±0.00070	1.00020±0.00070
		MCNP	0.99827±0.00087	0.99871±0.00091	1.00113±0.00088

4. CONCLUSIONS

This work contributes to lacking data of criticality safety parameters related to binary uranium alloy (UMo) and ternary uranium alloy (UNbZr) for two different level of enrichment. The data obtained can be utilized to design new equipment and recipient which will handle this type o nuclear fuel and can limit amount of material to be storage and manipulated during the all fuel fabrication process. The methodology applied to perform all calculations is already well established at CTMSP and has been applied for several different facilities of fuel cycle.

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