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Epithermal Lead-Cooled Micro-Reactor using Fuel-Moderator Assemblies

S.M. Lee[1], M. Mattar[3] and E.L.L. Cabral[2]

[1] smlee@ipen.br , [2] elcabral@ipen.br,
[1,2,3] Instituto de Pesquisas Energéticas e Nucleares
Av. Prof. Lineu Prestes, 2242, 05508-000, São Paulo, SP, Brazil

1. Introduction

This work consists on the analysis of an epithermal micro-reactor core cooled by liquid lead, capable to generate 30MW of thermal power for five years without any fuel replacement. A model of the reactor core is elaborated and simulated using the MCNP code. An epithermal reactor in relation to fast reactors has the advantage of facilitating reactivity control and requiring a smaller amount of fuel (Uranium 235). An epithermal reactor compared to thermal reactors has the advantage that the fuel lasts longer, avoiding frequent fuel replacement. This work aims to calculate the effective multiplication factor, k_{eff}, of the selected reactor core and evaluate the duration of a fuel load. At this stage, further issues such as how to achieve the above-mentioned power and maintain the criticality of the core during the operation are out of concern.

2. Methodology

This reactor core is similar to the SEALER (Swedish Advanced Lead Reactor) [1] fast reactor, which is cooled by lead, but moderator is add to slow down the neutrons in order to have an epithermal reactor. The reactor core consists of 30 fuel assemblies, 4 control assemblies and 3 shut-down assemblies as shown in Figure 1.

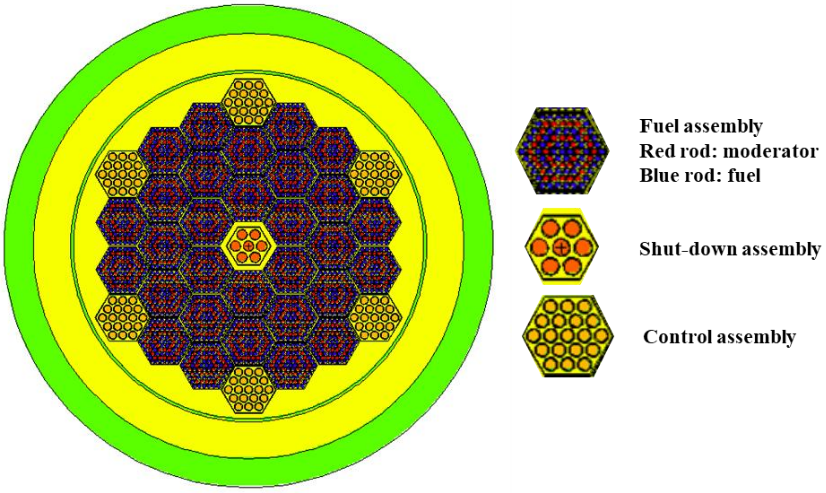

Figure 1: Radial configuration of the core.

Each fuel assembly is composed of 55 fuel rods plus 36 moderator rods; the fuel rods comprise 19.75% enriched uranium oxide while the moderator rods contain beryllium oxide. The dimensions and material compositions of the cladding tubes of all 91 rods are the same. The configurations of the fuel rods, shut-down and control rods, as well as their assembly arrangements including hex-can are the same of the SEALER reactor [1]. Some of the parameters of the selected model are listed in Table I.

Table I: Main parameters of the core [1],[3],[4].

Component	**Specification**
Fuel composition / density	UO_2 / 10.48 (g/cm^3)
^{235}U enrichment	19.75 wt%
Moderator Composition / density	BeO / 3.02 (g/cm^3)
Fuel/Moderator pellet diameter	13.40mm
Fuel column height	1106mm
Fuel insulation pellet material	YSZ
Fuel insulation pellet height	2×10 mm
Fuel lower shield height	50mm
Fuel gas plenum height	350mm
Fuel/Moderator end cap material	SS316L
Fuel/Moderator Upper end cap height	20mm
Fuel/Moderator Lower end cap height	50mm
Fuel/Moderator rod length	1590mm
Fuel/Moderator clad surface material	Fe-10Cr-6Al-RE
Fuel/Moderator clad outer diameter	14.52mm
Fuel/Moderator clad thickness	0.50mm
Fuel assembly hex-can inner/outer flat-to-flat	160.0mm /164.0mm
Fuel assembly hex-can pitch	166.0mm
Shut-down rod pellet material	$(W_{0.48}, Re_{0.52})^{10}B_2$ (96% of ^{10}B)
Control rod pellet material	B_4C (30% of ^{10}B)
Vessel outer diameter	1676.2mm
Vessel thickness	1000.0mm

The dimensions and numbers of each component listed in the previous table allow estimating the respective total masses needed for constructing the core. Some of them are shown in Table II.

Table I: Total mass of materials of the core [4].

Material	**Estimated mass** (kg)
UO_2	2677.90
^{235}U	466.06
BeO	498.44
^{9}Be	179.44
30% enriched B_4C	141.96
$(W_{0.48}, Re_{0.52})^{10}B_2$	89.62
Total ^{10}B	41.62

The model elaborated using the parameters of Table I is simulated using MCNP code (version 6.2) [2] with both control and shut-down assemblies completely withdrawn. The objective of the simulation is to calculate the effective multiplication factor, k_{eff}, of the core during the burn-up process until it equals to or drops below 1, supposing the core generates 30MW(th) constantly, all the time. Nevertheless, any criteria for determination of reactivity worth of both control and shut-down assemblies are not performed at this stage yet. The main purpose of this evaluation is to verify if the selected reactor is able to generate 30MW(th) during at least five years.

3. Results and Discussion

In Table II are shown the k_{eff} value and other parameters of the core at the beginning of life calculated using the MCNP code (KCODE card). From the results of Table III, it can be seen that most of fissions are caused by epithermal neutrons (68.43%) followed by fast neutrons (31.43%), while the fissions caused by thermal neutrons are negligible.

Table III: Parameters at the initial state.

k_{eff}	1.04880 ± 0.00009	
Generation time (ns)	936.83290 ± 8.00383	
Rossi-α (1/ns)	-7.31806E-06 ± 1.65492E-07	
β_{eff}	0.00686 ± 0.00014	
Percentages of fissions caused by neutrons in *E*	***E*** < 0.625 eV	0.14%
	0.625 eV < ***E*** < 100 keV	68.43%
	100 keV < ***E***	31.43%

Furthermore, the k_{eff} values of the core with the control and/or the shut-down assemblies totally inserted into it are presented in Table IV below.

Table IV: K_{eff} values of the core with totally inserted control and/or shut-down assemblies.

Totally inserted assemblies	Control (6) and Shut-down (1) assemblies	Control (6) assemblies	Shut-down (1) assembly
k_{eff}	0.90956 ± 0.00009	0.98512 ± 0.00009	0.98169 ± 0.00009

The simulation of burn-up process using the BURN card of the MCNP code provides the variation of the value of k_{eff} with time as shown in Figure 2. As can be seen in Figure 2 the k_{eff} remains larger than 1 up to 1989 days, namely 5 years and 5 months and 14 days.

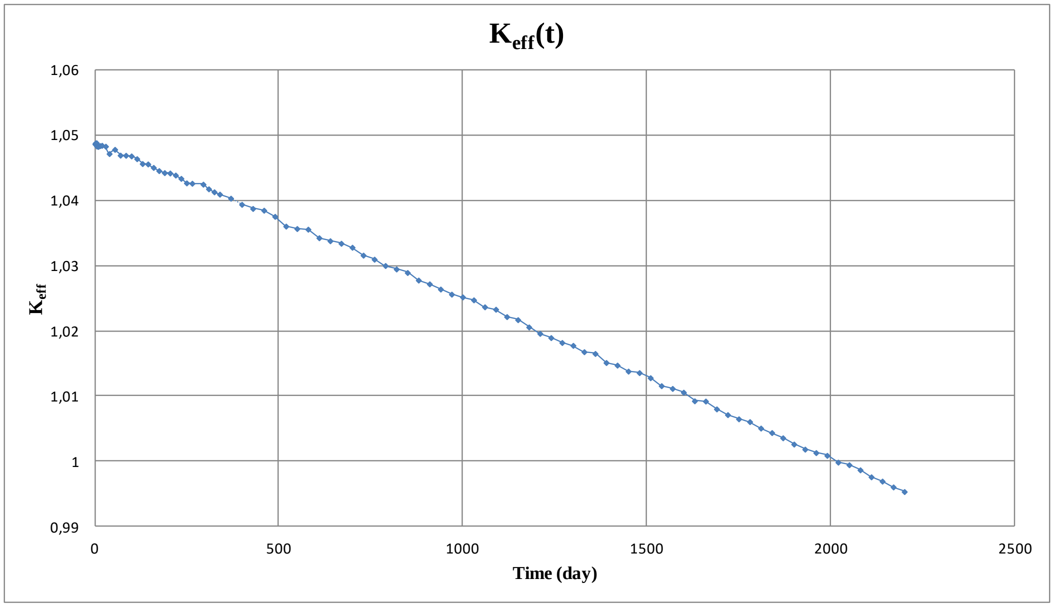

Figure 2: Variation of the effective multiplication factor, k_{eff}.

4. Conclusions

The reactor core analyzed meets the requirements specified in terms of criticality and duration of the fuel, thus further analysis can proceed. It was demonstrated that the control and shutdown assemblies were able to ensure a safe shutdown state of the reactor core. However, at this stage, no other criteria have yet been applied to these components. Therefore, other positions and material composition of the control and shutdown assemblies must be studied and, if necessary, even the configuration of the entire core can be changed.

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