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Investigation of the influence of various reflector elements material types on the core nuclear parameters of the 2 MW Triga Mark-II research reactor using the Monte Carlo code

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Abstract: The influence of variation in the kind of material of neutron reflector elements on the core neutronic parameters of the Moroccan Triga Mark-II research reactor was examined. The comparison was made between three kinds of reflector element materials: graphite, beryllium, and beryllium oxide. MCNP5 Monte Carlo computations of the effective neutron multiplication factor (k_{eff}) of the reactor according to the number of reflector material elements inserted in the reactor core for these three reflector elements materials families were carried out. The results found could be used in order to increase the k_{eff} parameter without changing the size of the reactor.

Key words: Triga Mark-II core, neutronic parameters, reflector elements materials, MCNP5 code

1. Introduction

In nuclear research reactors, different kinds of materials are employed as neutron reflectors in the reactor core. The use of reflectors in the reactor core provides some advantages such as reduction in the critical size of the reactor core as well as reduction in the critical mass of the fuel. The reflector has the same properties as a moderator such as a smaller atomic weight, a higher diffusion cross section, a higher slowing-down capacity, and a lower capture cross section. Substitution of the reflector material type in the reactor core has a strong influence on the safety or the nuclear parameters of the reactor core [1].

The majority of studies have been carried out on the influence that the changes in the neutron reflector material kind have on the nuclear parameters of miniature neutron source reactors and other research reactors [1–3].

To assess the effect that different reflector elements materials types have on the neutronic parameters of the Moroccan 2 MW Triga Mark-II research reactor such as the k_{eff} parameter, the graphite reflector elements were substituted by beryllium and beryllium oxide reflector elements. Figures 1–3 illustrate the results given by Monte Carlo code MCNP5 simulation of Triga Mark-II core geometry with beryllium, beryllium oxide, and graphite reflector elements, respectively.

The 2 MW Triga Mark-II reactor is the only nuclear research reactor in Morocco and reached its first criticality on 2 May 2007. This reactor has been constructed for basic research on the characteristics of materials, education and training, production of radioisotopes, and studies of different fields of nuclear research. Triga Mark-II is a light water cooled and moderated, graphite reflected reactor. Its core configuration includes

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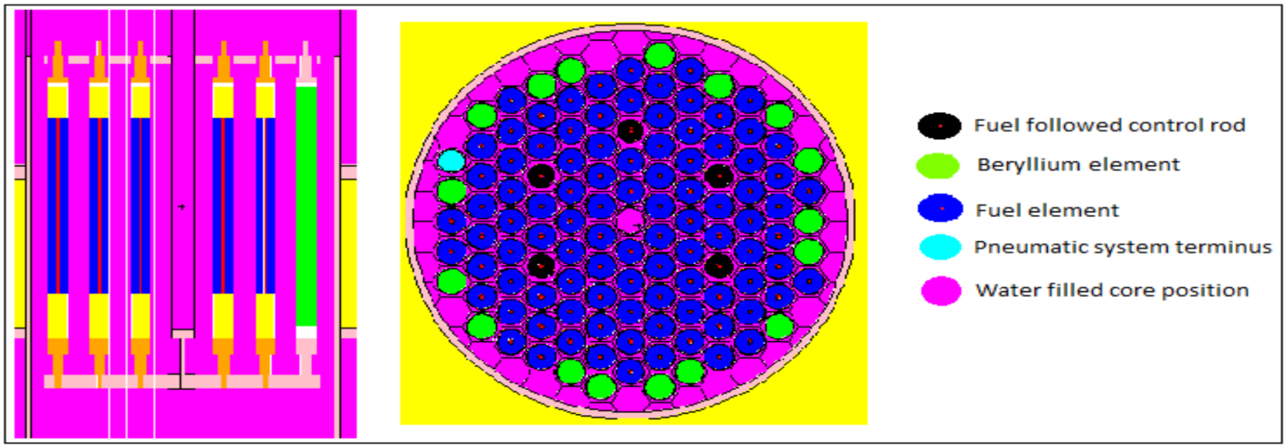

Figure 1. Axial and radial representation of the Moroccan Triga reactor core with beryllium reflector elements using MCNP5 code.

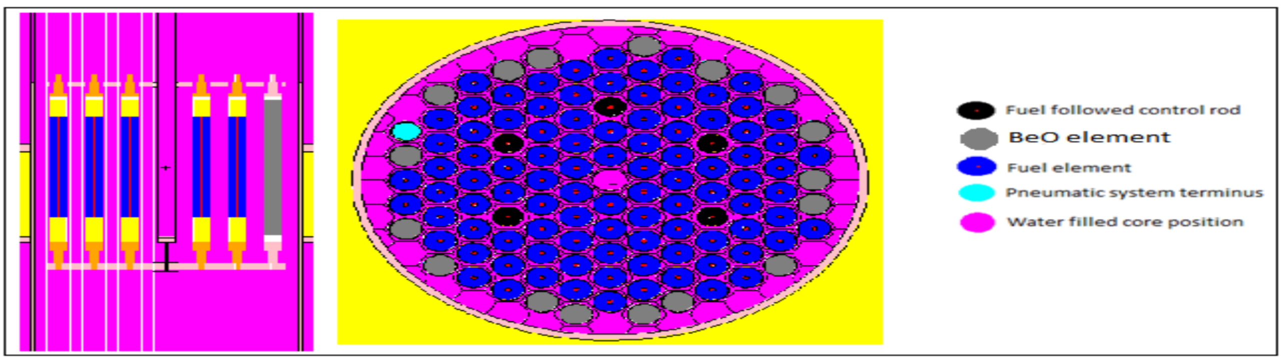

Figure 2. Axial and radial representation of the Moroccan Triga reactor core with beryllium oxide reflector elements using MCNP5 code.

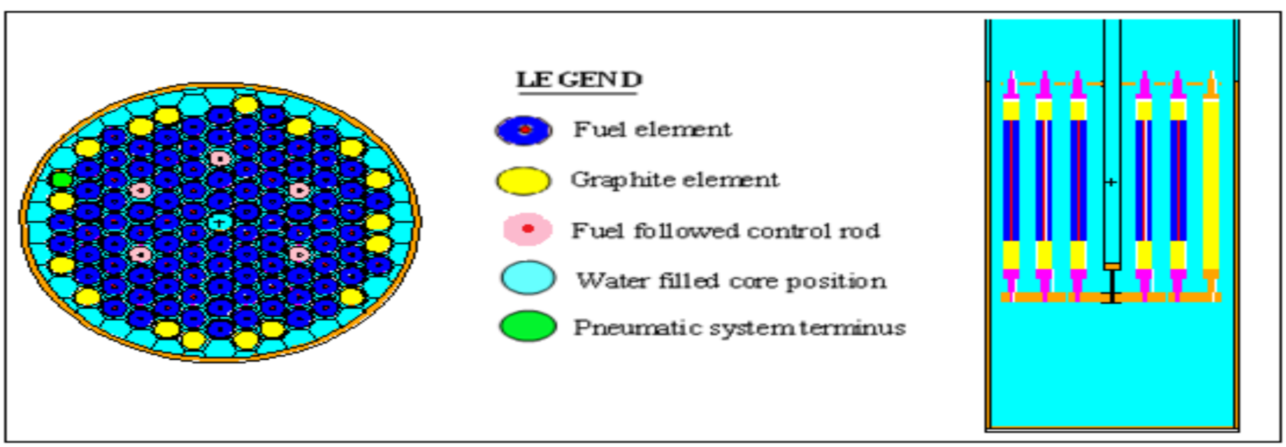

Figure 3. Radial and axial representation of the Moroccan Triga reactor core with graphite reflector elements using MCNP5 code.

ninety-six standard fuel elements, five fuel follower control rods, seventeen graphite reflector elements, one central thimble, and one pneumatic system terminus. The core is put into a water filled aluminum tank of 2.44-

m diameter and 8.84-m depth and is surrounded by an annular graphite reflector. This tank is surrounded by concrete bio-shielding. The fuel elements are a homogeneous alloy of zirconium hydride and uranium enriched at about 20% in ^{235}U, embedded in stainless-steel cladding. The hydrogen/zirconium atom ratio is of the order of 1.65 [4].

The values of the k_{eff} parameter, which were computed and compared for each reflector element material type, are given in this research.

2. Materials and methods

One of the most fundamental evaluation quantities in the computation of a nuclear design is the effective neutron multiplication factor. It is expressed mathematically as follows:

$$k_{eff}=\frac{P}{A+L},$$

where P, A, and L are respectively neutron production, absorption, and leakage. This expression of k_{eff} is interpreted as the ratio of the number of neutrons that will be born in the reactor core in the next generation to those that are lost from the current generation. Consequently, the state of the reactor core depends on the k_{eff} value ($-k_{eff}>1$: Supercritical, $-k_{eff}=1$: Critical and - $k_{eff}<1$: Subcritical) [5].

In the present work, to study the assessment of the effect of each type of reflector element material inserted into the reactor core on the k_{eff} nuclear parameter of the Triga Mark-II research reactor, a Monte Carlo simulation of this reactor was carried out by using MCNP5 code and the continuous energy cross section data were from the ENDF library. The k_{eff} parameter was determined using the KCODE card of MCNP5. The simulations were performed with ten thousand cycles of iterations on a nominal source size of ten thousand particles per cycle in order to decrease statistical error estimates. Initial one hundred cycles were skipped to ensure to have a homogeneous neutron source distribution. The value of the k_{eff} parameter was computed in the critical Moroccan Triga reactor operational condition. The computation of this value for each reflector element material type was also made by taking into consideration both prompt and delayed neutrons. Moreover, all the reactor core components were modeled. The neutronic model for the Moroccan 2 MW Triga Mark-II research reactor was in three dimensions. The number of reflector material elements in the core for which the k_{eff} parameter was computed was varied from zero to seventeen elements for each type of reflector material. The reflector elements have the same dimensions as fuel elements but they are completely filled with graphite or beryllium or beryllium oxide and the cladding composition being an aluminum alloy as can be seen in Figures 1–3. Table 1 gives some physical parameters of the reflector, fuel, and fuel follower rods of the Triga Mark-II reactor.

3. Results and discussion

In all the cases, the computed value of k_{eff} for the core without insertion of reflector material elements is equal to 0.99215. Table 2 illustrates the computed values of k_{eff} as a function of number of beryllium reflector elements in the reactor core. The results go from 0.99299 to 1.00611 for the core with insertion of one and seventeen beryllium elements, respectively. The computed k_{eff} parameters according to the number of beryllium oxide reflector elements in the core are reported in Table 3. The results are in the range of 0.99285 to 1.00552 for the core with insertion of one and seventeen beryllium oxide elements, respectively. The computed values of k_{eff} for graphite reflector elements are 0.99266 to 1.00021 for the core with insertion of one and seventeen graphite

Table 1. Physical parameters of the reflector, fuel, and fuel follower rods.

Parameters	Reflector element	Fuel element	Fuel follower element
Outer radius	1.8823 cm	1.8823 cm	1.72 cm
Fuel radius	-	1.82769 cm	1.665 cm
Fuel height	-	38.1 cm	38.1 cm
Thickness of cladding	0.05461 cm	0.05461 cm	0.055 cm
Radius of zirconium rod	-	0.3175 cm	0.3175 cm
Inner radius	1.82769 cm	-	-
Amount of uranium U-ZrH (wt %)	-	8.5	8.5
Cladding	Aluminum alloy	-	-
Cladding density	2.7 g/cm^3	-	-
Graphite density	1.75 g/cm^3	-	-
Beryllium density	1.85 g/cm^3	-	-
Beryllium oxide density	3.025 g/cm^3	-	-

Table 2. MCNP5 computed values of k_{eff} for beryllium reflector elements.

Number of reflector elements inserted in the core	Computed values of k_{eff}	Number of reflector elements inserted in the core	Computed values of k_{eff}	Number of reflector elements inserted in the core	Computed values of k_{eff}
0	0.99215	6	0.99612	12	1.00218
1	0.99299	7	0.99672	13	1.00266
2	0.99328	8	0.99818	14	1.00350
3	0.99362	9	0.99902	15	1.00401
4	0.99455	10	1.00041	16	1.00513
5	0.99511	11	1.00110	17	1.00611

elements, respectively [6]. All the computations of k_{eff} are found with statistical error ± 8 pcm. These results of computations are also recapitulated in Figure 4.

As can be seen from the tables and Figure 4, the MCNP5 computed values of k_{eff} increase with the addition of reflector material elements in the reactor core for all the types of reflector element materials (Be, BeO, and graphite). The rise in the value of the k_{eff} parameter is principally related to the presence of these reflector materials in the reactor core. Moreover, the number of neutrons returned to the core depends on the reflector material elements location, the power distribution in the reactor core, and the returning probability.

The quality of the reflector material changes from one reflector material to another depending on the diffusion and capture cross-sections of the reflector material kind [7]. The highest values of the k_{eff} parameter are those relating to the elements made up of beryllium. That is, the beryllium elements were assessed to be good elements among the treated reflector element families for the reason that seventeen beryllium elements

Table 3. MCNP5 computed values of k_{eff} for beryllium oxide reflector elements.

Number of reflector elements inserted in the core	Computed values of k_{eff}	Number of reflector elements inserted in the core	Computed values of k_{eff}	Number of reflector elements inserted in the core	Computed values of k_{eff}
0	0.99215	6	0.99593	12	1.00193
1	0.99285	7	0.99668	13	1.00237
2	0.99342	8	0.99797	14	1.00320
3	0.99388	9	0.99861	15	1.00372
4	0.99457	10	1.00008	16	1.00465
5	0.99493	11	1.00057	17	1.00552

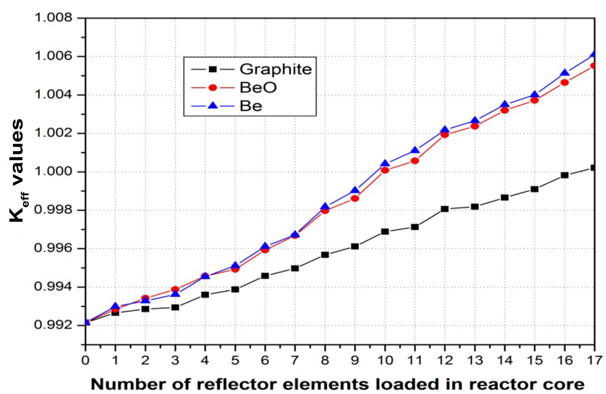

Figure 4. Values of the k_{eff} parameter vary according to the number of graphite, beryllium oxide, and beryllium reflector elements materials in the reactor core.

provided the significant effective multiplication factor 1.00611. They were followed by beryllium oxide elements and graphite elements with the following k_{eff} parameters: 1.00552 and 1.00021, respectively. The difference in reactivity between the seventeen beryllium elements and seventeen beryllium oxide elements is in the order of 58.32 pcm, while the difference in reactivity between the seventeen beryllium elements and seventeen graphite elements is 586.3 pcm. It can be deduced that the seventeen graphite elements would be substituted by ten beryllium elements. This difference in reactivity is mainly related to the good reflection characteristic of beryllium, its supplementary neutrons contribution, and its unique structural and chemical combination, atomic number, and neutron capture cross-section properties [8]. The elements made up of beryllium are consequently the best reflector material elements from the economical and safety points of view for the Moroccan reactor results.

Beryllium oxide would be the second adequate reflector material for the nuclear reactor. However, it has a disadvantage when utilized as a reflector material in nuclear power reactors, particularly in high power reactors, since the oxygen content has an influence on the corrosion of nuclear materials at high temperature.

4. Conclusion

In this simulation study, the influence that variation in neutron reflector element material type has on the k_{eff} parameter of the Moroccan reactor was investigated using MCNP5 Monte Carlo code. It was shown that the beryllium reflector elements were the most efficient elements in these reflector element material families (beryllium, beryllium oxide, and graphite) since seventeen beryllium elements provided significant k_{eff}, equal to 1.00611. They were followed by beryllium oxide elements and graphite elements with the following k-effective parameters: 1.00552 and 1.00021, respectively. The elements made up of beryllium are consequently the best reflector material elements found in this study. Moreover, the results of this study showed that it is possible to increase significantly the value of k_{eff} without changing the physical dimensions of the Moroccan Triga reactor.

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