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PARAMETRIC STUDY FOR ENHANCING THE RADIOISOTOPE PRODUCTION IN THE IEA-R1 RESEARCH REACTOR

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ABSTRACT

In this work a parametric study was carried to increase the production of radioisotopes in the IEA-R1 research reactor. The changes proposed to implement in the IEA-R1 reactor core were the substitution of graphite reflectors by beryllium reflectors, the removal of 4 fuel elements to reduce the core size and make available 4 additional locations to be occupied by radioisotope irradiation devices. The key variable analyzed is the thermal neutron flux in the irradiation devices. The proposed configuration with 20 fuel elements in an approximately cylindrical geometry provided higher average neutron flux (average increment of 12.9 %) allowing higher radioisotope production capability. In addition, it provided 4 more positions to install irradiation devices which allow a larger number of simultaneous irradiations practically doubling the capacity of radioisotope production in the IEA-R1 reactor. The insertion of Be reflector elements in the core has to be studied carefully since it tends to promote strong neutron flux redistribution in the core. A verification of design and safety parameters of the

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proposed core was carried out. The annual fuel consumption will increase about 17 % and more storage space for spent fuel will be required.

Keywords: **IEA-R1, research reactor, radioisotopes**

1. INTRODUCTION

The demand for radiopharmaceuticals and industrial radioisotopes in Brazil is mostly supplied by imports including the important radiopharmaceuticals ^{99m}Tc, ^{131}I and ^{177}Lu used in more than 80 % of nuclear medicine procedures worldwide [1]. Part of the local production is carried out at IPEN through material irradiations in the IEA-R1 reactor, a 4.5 MWth open-pool type research nuclear reactor. The shutdown of the Canadian NRU reactor in 2009 and the consequent shortage of these radiopharmaceutical in the world market prompted CNEN to start the project of the Brazilian Multipurpose Reactor (RMB) aiming at decrease imports of radiopharmaceuticals in the country [2,3]. Since the RMB project is far from completion any action to increase the production of radioisotopes in the country can be considered relevant.

One possible alternative is to increase radioisotope production in the IEA-R1 reactor [4] through design changes in the core that increase the neutron flux in irradiation positions. In a previous IEA-R1 reactor upgrade an irradiation element made of Be (EIBe) was inserted in the core center increasing the number of irradiation positions in that reactor [5,6]. The radioisotope production in any reactor can be achieved through design changes that increase the thermal neutron flux in its several irradiation devices and an important constraint is the maximum power level of the core that is limited by the existing reactor heat removal system. The IEA-R1 reactor has currently 4 irradiation devices with 1 located in the left side of the core, 2 located in its right side and 1 located in its core center and two types of reflector elements (Be and grafita as neutron reflector material) [4,7].

In general, there are three basic design alternatives to increase the core thermal neutron flux in the IEA-R1 reactor without raising its core power level: reduce the core size so that the core power density is increased and consequently the thermal neutron flux increases in the irradiation devices, increase the number of locations to insert irradiation devices, especially in the proximity of the core where the neutron flux tends to be higher, and try to increase core thermal neutron flux by altering the configuration of Be and grafita reflector elements. These design changes may affect the reactor safety, operational routine and economics and require engineering analyses and verification experiments, especially regarding the actual gain in neutron flux in the irradiation positions [5-8].

This work presents the initial results of the ongoing study for enhancing the radioisotope production in the IEA-R1 reactor. The changes proposed to implement in the IEA-R1 reactor core are the substitution of graphite reflectors by beryllium reflectors, the removal of 4 fuel elements to reduce the core size and make available 4 additional locations to be occupied by radioisotope irradiation devices. The key variable analyzed is the thermal neutron flux in the irradiation devices, and a preliminary verification of design and safety limits is carried out, including temperature and power defect, temperature coefficients of reactivity, xenon poisoning, kinetics parameters, core excess reactivity, shutdown margins and consumption of fissile material and fuel cycle length.

We start in sect. 2 presenting the data and methods emphasizing the parametric approach adopted in this work, in sect. 3 we present the results, in sect. 4 the discussions and finally in sect. 5 we present the conclusions.

2. DATA AND METHODS

Sect. 2.1 presents details of the IEA-R1 reactor core, sect. 2.2. presents the parametric approach adopted in this work to determine possible core design alternatives to enhance the radioisotope production in the IEA-R1 reactor, sect. 2.3 presents which safety and design parameters of the proposed new core configuration are verified and sect. 3 presents the calculational methods.

2.1. IEA-R1 reactor

The IEA-R1 reactor core is a 5x5 square matrix with 24 Material Test Reactor (MTR) type fuel elements surrounded by reflector elements and thermal power level of 4.5 MWth [4,9]. Figure 1 presents a schematic of the IEA-R1 reactor core having 20 standard fuel elements and 4 control/safety elements with inner spaces allowing control and safety rod movement for reactor control and shutdown. The reflector elements use graphite, beryllium and water as reflecting materials. The empty core positions are filled with water that act as neutron reflectors. All radioisotope irradiation is performed using irradiation devices in specific positions in the core center (EIBe) or in the reflector region (EIF, EIBRA1 and EIBRA2) [4].

Figure 2 shows the standard and control/safety fuel elements manufactured by IPEN. The standard fuel elements have 18 fuel plates (dark plates) positioned in an Aluminum structure (white parts). The control/safety fuel elements have 12 fuel plates, and the fork type fuel rods penetrate their side empty spaces for core reactivity control during operation. The external dimensions of both fuel elements are the same. The white plates serve as structural components or guides for the control rods.

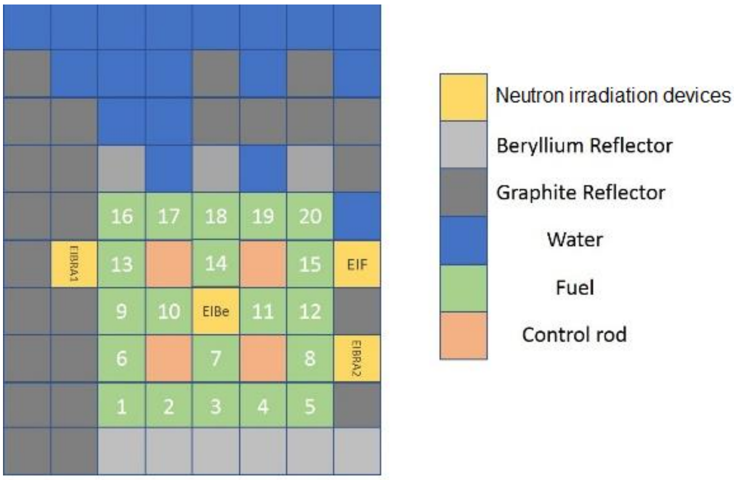

Figure 1: Schematic of the IEA-R1 reactor core (configuration E01). This configuration has 9 Be reflector elements, 25 Graphite reflector elements, 18 water reflectors, and 4 irradiation elements (EIBe, EIBRA1, EIBRA2 and EIF).

The control rods, consisting of an Ag-In-Cd alloy (80-15-5 wt%) are of the fork type with a thickness of 0.31 cm, width of 66 cm and active length of 65.1 cm. Figure 4 shows an axial view of the fuel element. The average length (or height) of the fuel plate is 62.5 cm, with 60 cm active length and 1.25 cm aluminum at the top and bottom of the plate.

The control rod material is an alloy with 80 % Ag, 15 % In and 5 % Cd (% weight). Silver is composed of two isotopes, ^{107}Ag and ^{109}Ag with abundances of 51.83 % and 48.17 %, respectively. Indium is also composed of two isotopes, ^{113}In and ^{115}In with abundances of 4.28 % and 95.72 %, respectively.

The fuel plate has specific mass of 3.0 gU/cm³ consisting of an alloy of U_3Si_2-Al, with 19.9 % enrichment of ^{235}U, with the mass of each plate being equal to 15.58 g of ^{235}U and Aluminum mass of each plate equal to 46.8 g. The dimensions of the fuel plate are 0.076 cm thick, 6.26 cm wide and 60 cm high [4,5].

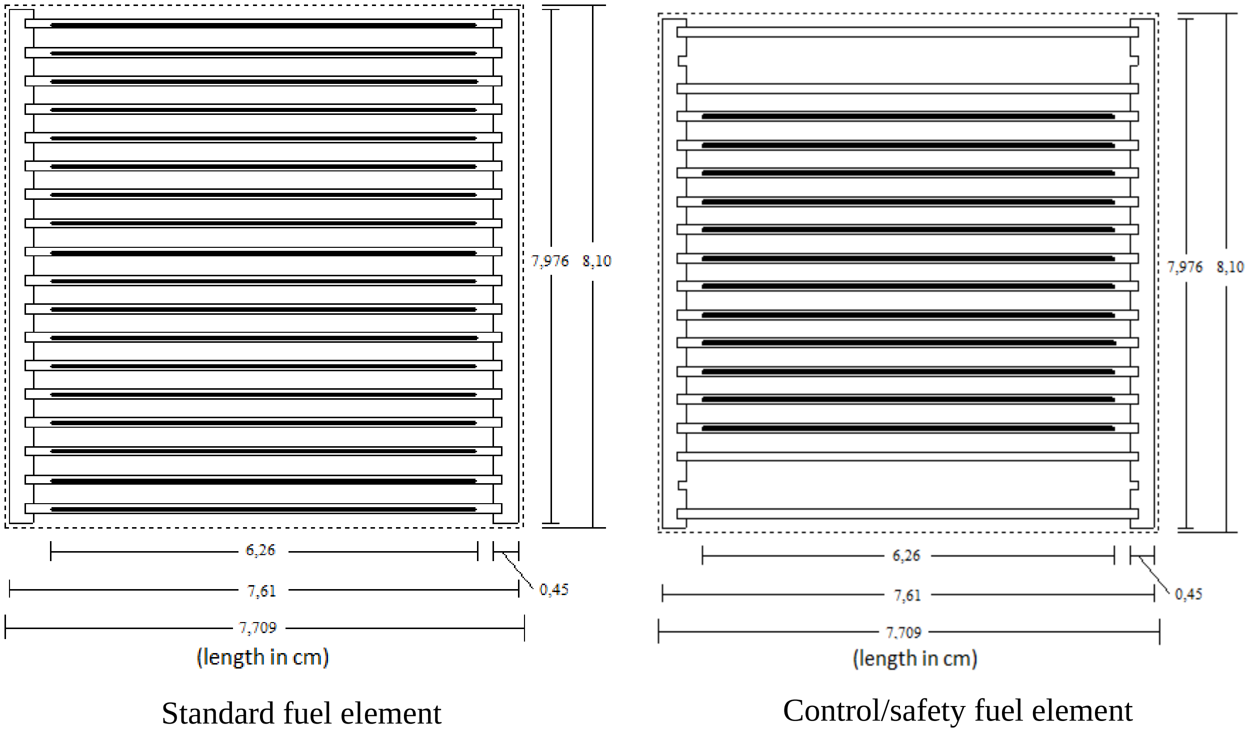

Figure 2: Cross view of the standard and control fuel elements. The external dimensions of both fuel elements are similar [4].

2.2. Parametric study and core model

For the isotope of interest of IPEN, ^{177}Lu, the key variable to enhance the radioisotope production is the thermal neutron flux in the irradiation locations. The parametric study for determining possible core configurations that may enhance the radioisotope production in the IEA-R1 reactor considered three different design alternatives: increase the neutron flux in the irradiation locations through conducting changes in the reflector and core regions, reducing the core size to increase the core average power density and consequently increase the thermal neutron flux in the core, and increase the number of irradiation locations in the proximity of the core where the thermal neutron flux tends to be higher.

Table 1 and Figure 3 present the 4 configurations considered in this parametric study. To increase the neutron flux in the reactor core we considered: a) change the number and type of reflector elements in the core (configurations E02 and E03); b) reduce the core by removing 4 fuel elements from the core (configurations E04 and E05); and c) change the geometry of the core making it approximately square (config. E04) and approximately cylindrical (E05).

Table 1: Configurations considered in the parametric studies with variations in the number of fuel elements, core geometry (square or cylindrical), and number and type of reflector elements, and number of irradiation devices.

Configuration	**Number of reflectors**	**Core geometry**	**Number of irradiation devices**
E01 (Reference)*	Fig. 1 – 9 Be reflectors and 25 graphite reflectors	Standard core – square with 24 fuel elements	4
E02	Fig. 3 – 18 Be reflectors and 16 graphite reflectors	Square core with 24 fuel elements	4
E03	Fig. 3 – 34 Be reflectors	Square core with 24 fuel elements	4
E04	Fig. 3 – 9 Be reflectors and 25 graphite reflectors	Square core with 20 fuel elements	8**
E05	Fig. 3 – 9 Be reflectors and 25 graphite reflectors	Cylindrical core with 20 fuel elements	8**

* Based on the standard IEA-R1 core configuration number 263 [9]
** Additional 4 locations to install irradiation devices

The locations where the 4 fuel elements were removed can, in principle, receive irradiation devices to produce radioisotopes. Thus configurations E04 and E05 may have 8 irradiation devices. The addition of more 4 irradiation positions approximately doubles the IEA-R1 reactor capacity to produce radioisotopes if one considers that the new and existing irradiation positions have equivalent thermal neutron flux levels.

In configuration E02 the number of Be reflectors increased and of graphite reflectors decreased; in configuration E03 the core is reflected only by Be reflectors; in configuration E04 we kept the original reflector configuration of the core, removed 4 fuel elements trying to continue with a square core and inserted in their positions new irradiation elements; and configuration E05 is similar to configuration E04 but the core acquires a cylindrical geometry because the removed elements were located in the 4 core corners.

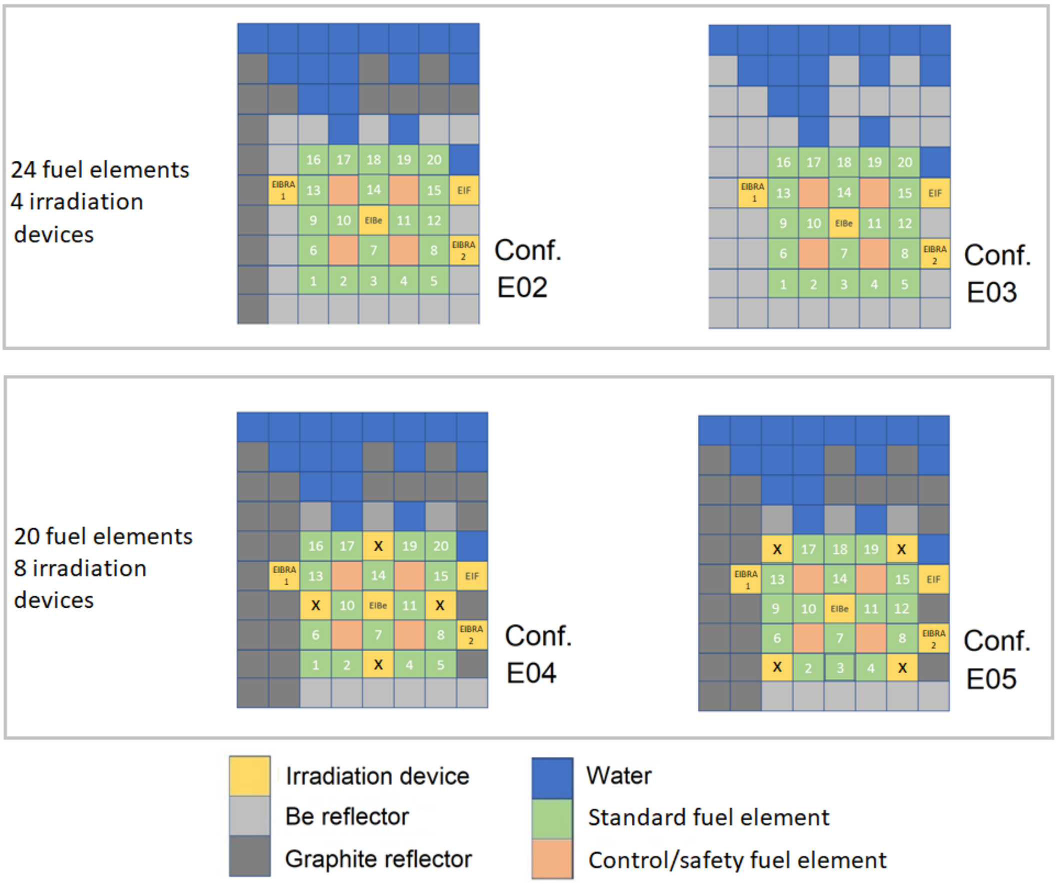

Figure 3: Set of configurations considered in the parametric study. Configurations E02 and E03 change in the reflector elements and configurations E04 and E05 repalce 4 fuel elements by additional irradiation devices (labeled with "X") to form aproximate square and cylindrical cores.

The EIBe irradiation device has two axial irradiation channels, A and B and the other irradiation devices only one channel. The locations where the fuel elements were removed were filled with water. The new irradiation locations of configurations E04 and E05 can be identified with in Figure 3 with the label “X”.

2.3. Verification of safety and design parameters

The impact on safety and design parameters of the IEA-R1 core due to the different core changes proposed in Table 1 we conduct assessments of the temperature defect, power defect, moderator and fuel temperature coefficients of reactivity, xenon reactivity, kinetics parameters (prompt neutron generation time and effective delayed neutron fraction), shutdown margin, hot channel cladding temperature distribution, and fuel consumption and transuranic generation due to 1 year fuel burnup [8-12]. We perform these evaluations for the reference IEA-R1 core (configuration E01) and the one identified as best among E02, E03, E04 and E05 for enhancing the radioisotopes.

2.4. Calculation methods

The neutronic calculations were performed with the SERPENT code, a 3-dimensional Monte Carlo code with static and burnup neutronic capabilities [14,15]. To determine the maximum cladding temperature for the best configuration among E02, E03, E04 and E05, we use the COBRA-3C-RERTR code, a subchannel analysis code for plate fuel elements [16].

To perform the several calculations some simplifying assumptions were made regarding the core model taken as representing the actual IEA-R1 core (configuration E01). All fuel elements were considered at beginning of cycle (BOC), i.e. with zero burnup, and structure and mechanical details of the fuel elements like plugs and plates were also simplified. To identify the most interesting configuration regarding isotope production configurations E02, E03 and E04 are compared against this simplified version of the reactor core. Disregarding burnup in all calculations seems adequate since it tends to equally affect all configurations.

In configurations E04 and E05 the new irradiation locations labeled with “X” were modeled with water since no information about the irradiation device design was available. Thus the thermal neutron flux in these locations are not furnished.

The evaluations considered the following core states are cold zero power (CZP) with fuel, moderator and structural materials of the reactor were at 20 °C; hot zero power (HZP) with fuel, moderator and structural materials of the reactor were at 41 °C; and Hot full power (HFP) with fuel are at 83 °C and moderator and structural materials at 41 °C [13].

3. RESULTS

3.1. Parametric results for enhancing neutron flux in the irradiation devices

Figures 4 to 8 show the thermal neutron flux distribution inside the 4 irradiation devices, namely EIF, EIBe (irradiation positions A and B), EIBRA1 and EIBRA2, for the several core configurations presented in Table 1 and Figure 3. The calculations were performed with the SERPENT code as described in sect. 2.3 with Monte Carlo model considering 8 million stories. The thermal flux distribution accounts for neutron energy below 0.625 eV and the Monte Carlo uncertainties are small and not shown in the figures.

Table 2 compares peak and average gain or loss of thermal neutron flux at the irradiation devices from configurations E02 to E05 with those from the reference configuration, E01. The results are expressed in % for average and peak variations and present Monte Carlo the uncertainties in the calculations. The two last lines present average variations for all irradiation device.

Results for configurations E02 and E03 show the impact on thermal neutron flux due to reflector changes compared to configuration E01 taken as the current core configuration design. For the EIF irradiation device in the core periphery (Fig. 4) the impact on thermal neutron flux is small with a minor reduction for configuration E03. For the EIBRA1 irradiation device, located in left side of the core (Fig. 5), configuration E02 provides an increase for the thermal neutron flux of about 10 % and configuration E03, an increase higher than 20 %. For the EIBRA2 irradiation device in the right side of the core (Fig. 6) the thermal neutron flux increases are smaller.

Configuration E02 provides an increase of about 5 % and configuration E03, of about 2 %. For the central EIBe irradiation device the impact of reflector changes on the thermal neutron flux is negative and reduce it by 4 to 8 % in configurations E02 and E03 (Figs. 7 and 8).

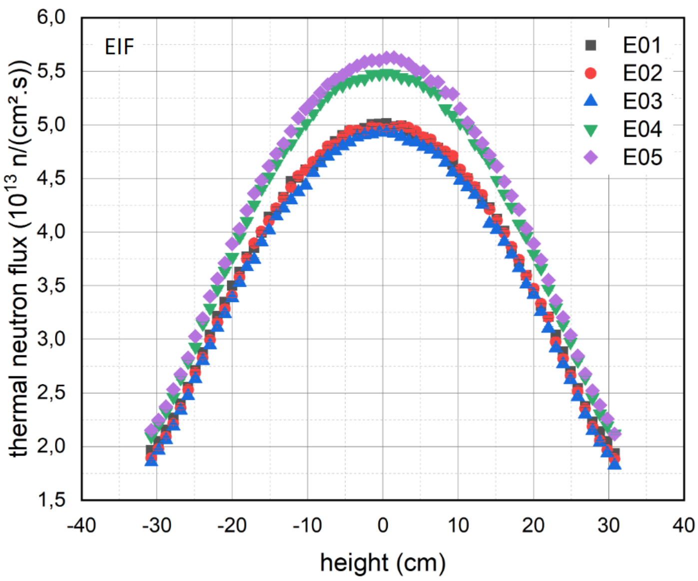

Figure 4: Thermal flux distribution at irradiation positions (EIF) for different core configurations.

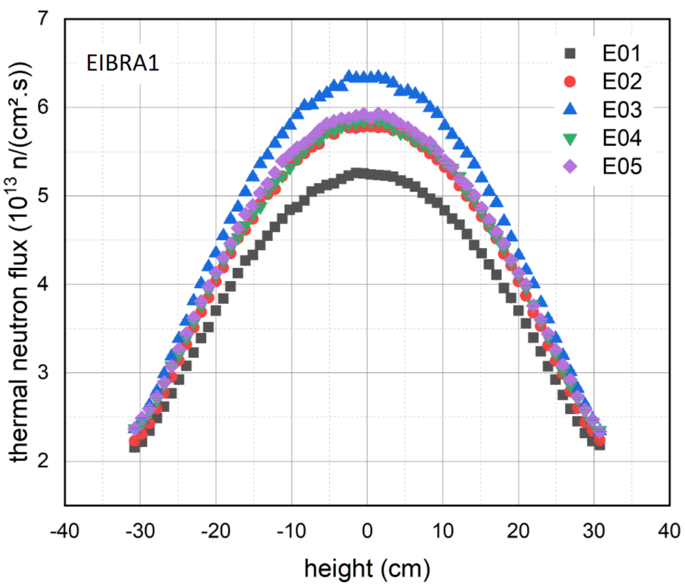

Figure 5: Thermal flux distribution at irradiation positions (EIBRA1) for different core configurations.

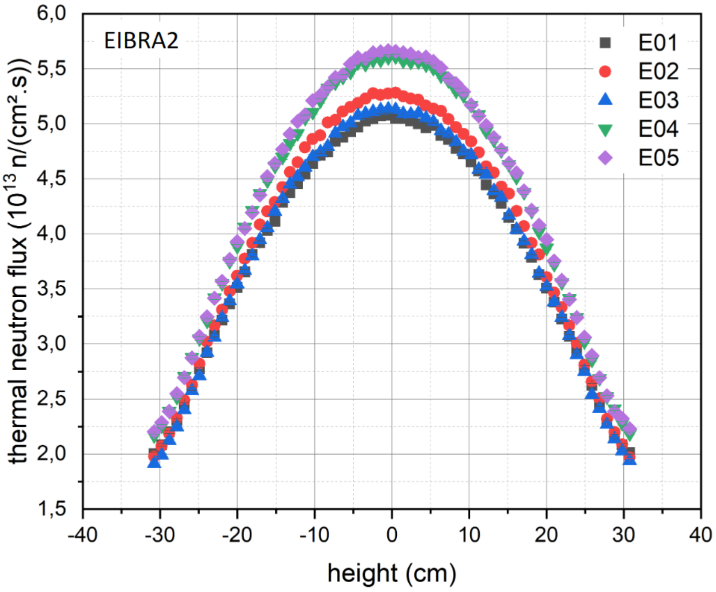

Figure 6: Thermal flux distribution at irradiation positions (EIBRA2).

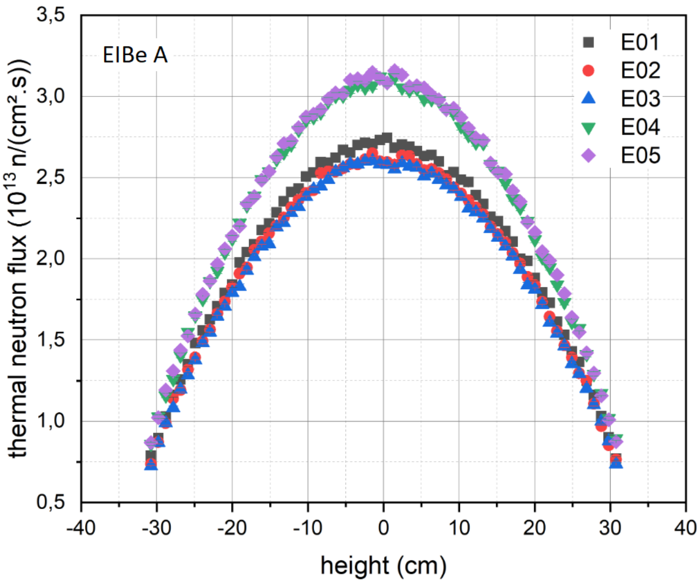

Figure 7: Thermal flux distribution at irradiation positions (EIBe A) for different core configurations.

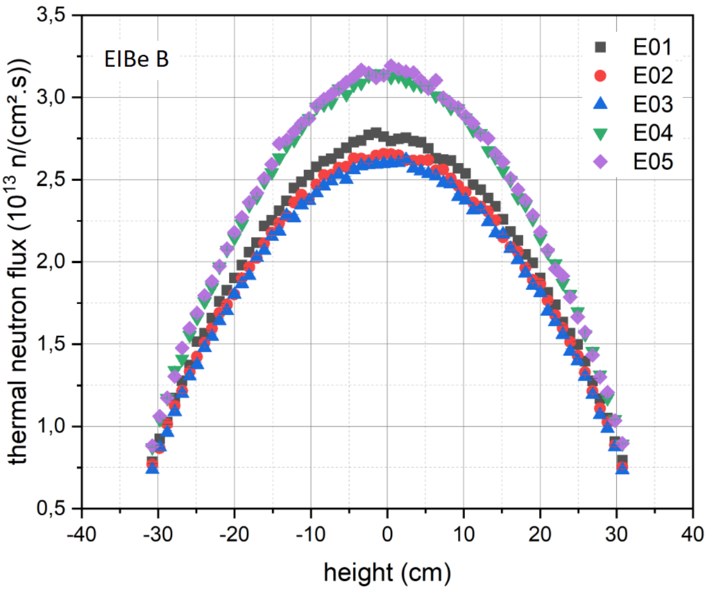

Figure 8: Thermal flux distribution at irradiation positions (EIBe B) for different core configurations.

Table 2: Thermal neutron flux variation (%) in the irradiation devices for the several configurations compared to those of configuration E01.

Neutron flux variation in % when compared to configuration E01

		E02	E03	E04	E05
EIBRA1	average	9.33 ± 0.68	18.88 ± 0.73	10.78 ± 0.69	12.20 ± 0.69
	peak	10.32 ± 0.63	20.62 ± 0.67	11.28 ± 0.63	12.74 ± 0.63
EIBRA2	average	3.54 ± 0.66	0.51 ± 0.65	10.72 ± 0.70	11.59 ± 0.71
	peak	4.03 ± 0.61	1.10 ± 0.59	10.47 ± 0.64	11.57 ± 0.65
EIF	average	-0.45 ± 0.65	-2.32 ± 0.64	9.46 ± 0.70	11.94 ± 0.72
	peak	-0.51 ± 0.58	-1.65 ± 0.58	9.34 ± 0.63	12.22 ± 0.65
EIBe A	average	-3.37 ± 1.16	-4.56 ± 1.15	13.52 ± 1.32	14.61 ± 1.33
	peak	-3.51 ± 1.03	-5.23 ± 1.01	13.63 ± 1.18	15.04 1.19
EIBe B	average	-3.93 ± 1.15	-5.85 ± 1.13	13.17 ± 1.31	14.37 ± 1.32
	peak	-4.60 ± 1.02	-5.85 ± 1.01	12.91 ± 1.17	14.65 ± 1.18
Total gain	average	1.03 ± 0.86	1.33 ± 0.86	11.53 ± 0.94	12.94 ± 0.95
	peak	1.15 ± 0.77	1.80 ± 0.77	11.53 ± 0.85	13.24 ± 0.86

Results for configurations E04 and E05 show the impact on thermal neutron flux due to core size reduction from 24 to 20 elements. For the EIF and EIBRA1 irradiation devices (Figs. 4 and 5), the removal of 4 fuel elements increases the thermal neutron flux by about 10 %. For the EIBRA2 irradiation device (Fig. 6) the thermal neutron flux increases about 20 %. For the EIBe irradiation device the neutron flux increases about 16 % in both positions.

By inspecting the figures, one sees that for the irradiation devices near the reflector (EIF, EIBRA1 and EIBRA2) the neutron fluxes are higher, varying from around 5.5×10^{13} n/cm^{2}s to 7×10^{13} n/cm^{2}s. The approximately cylindrical core configuration E05 presents the highest thermal neutron flux for all irradiation devices but the EIBRA1 for which configuration E03 is the one with highest thermal neutron flux.

In Table 2 one sees that the highest average gain of thermal neutron flux considering all irradiation devices occurs in configuration E05 (12.9 %). Table 2 allows one also to see the strong neutron reflecting effects due to increasing the number Be reflectors in the left side of the IEA-R1 reactor core. For the E03 configuration in the EIBRA1 device, located in the left side of the core, the thermal neutron flux increases in average 18.9 % while for the EIBe A, EIBe B and EIF devices, located in the center and in the right side of the core, one finds decreases of 2.3 %, 4.6 % and 5.9 %, respectively (see Table 2). The Be reflector in the configuration E03 causes a strong thermal neutron spatial redistribution in the core. Thus, the addition of Be reflector requires a detailed study and one has to observe the thermal neutron flux gain in all irradiation devices. Table 2 shows that the total gains are small for both E02 and E03 configurations (below 1.3 %) and may not be of interest.

3.2. Evaluation of safety and design parameters

In this section we verify the neutronic characteristics of configuration E05 and compare them with configuration E01 which is representative of the operating configuration 263 of the IEA-R1 reactor. The goal is to verify if the reactor's safety is maintained. Some safety and design parameters were verified for the configuration E05 with 20 fuel elements and compared with those of configuration E01, the reference IEA-R1 core with 24 fuel elements. All results were obtained with the SERPENT code as described in sects. 2.3 and 2.4 at beginning of cycle (BOC) condition.

Table 3 compares the temperature defect, power defect, xenon reactivity, kinetics parameters (effective delayed neutron fraction and prompt neutron generation time), and shutdown margin with all control and safety rods inserted into the core of configurations E01 and E05.

Table 3: Comparison of safety and design core parameters for configurations E01 and E05.

Parameter	**Configuration E01**	**Configuration E05**	**|Variation|***
Temperature defect at BOC (pcm)	-116 ± 3	-99 ± 3	17 pcm
Power defect at BOC (pcm)	-90 ± 3	-82 ± 3	8 pcm
Xenon reactivity at full power and BOC (pcm)	-2403 ± 3	-2592 ± 4	7.9 %
Effective delayed neutron fraction	0.00721 ± 0.00055	0.00717 ± 0.00055	0.6 %
Prompt neutron generation time (μs)	47 ± 3	57 ± 3	21.3 %
k_{eff} at BOC with all rods outside of the core	1.23523 ± 0.00003	1.21896 ± 0.00003	1.3 %
k_{eff} at EOC with all rods inserted in the core - shutdown margin	0.98504 ± 0.00004	0.94329 ± 0.00003	4.2 %

* absolute value

Table 4 presents the fuel and moderator temperature coefficients of reactivity obtained with the SERPENT code at temperature conditions obtained with the COBRA-3C code as described in sects. 2.3 and 2.4. The table presents in the first two columns the moderator and fuel conditions.

A thermal-hydraulic subchannel evaluation was carried out with the COBRA-3C code [11] to verify the maximum fuel plate cladding temperature in the hot channel. It was calculated using the power density distribution obtained with the SERPENT code. The maximum cladding temperature was 93 ^{o}C, which is below the melting point of the fuel plate cladding (120^{o}C). This preliminary result indicates adequate coolant condition for safe operation with the E05 configuration with the smaller 20 fuel element core.

Figure 9 presents results of burnup calculations performed for the IEA-R1 reactor for configurations E01 and E05. The burnup period was 360 days. It presents a comparison between the consumption of ^{235}U in these two configurations.

Table 4: Temperature reactivity coefficients at BOC.

Temperature (°C)		Reactivity coefficients (pcm/°C)		
Moderator	Fuel	Configuration		
		E01	E05	
20 – 40	80	-4.61 ± 0.17	-3.83 ± 0.18	Moderator
40 – 60	80	-6.40 ± 0.17	-6.03 ± 0.18	
40 – 80	80	-7.17 ± 0.08	-7.69 ± 0.09	
80	20 – 50	-1.30 ± 0.11	-1.12 ± 0.11	Fuel (Doppler)
80	50 – 100	-1.88 ± 0.06	-1.72 ± 0.07	
80	100 – 200	-1.75 ± 0.03	-1.67 ± 0.03	

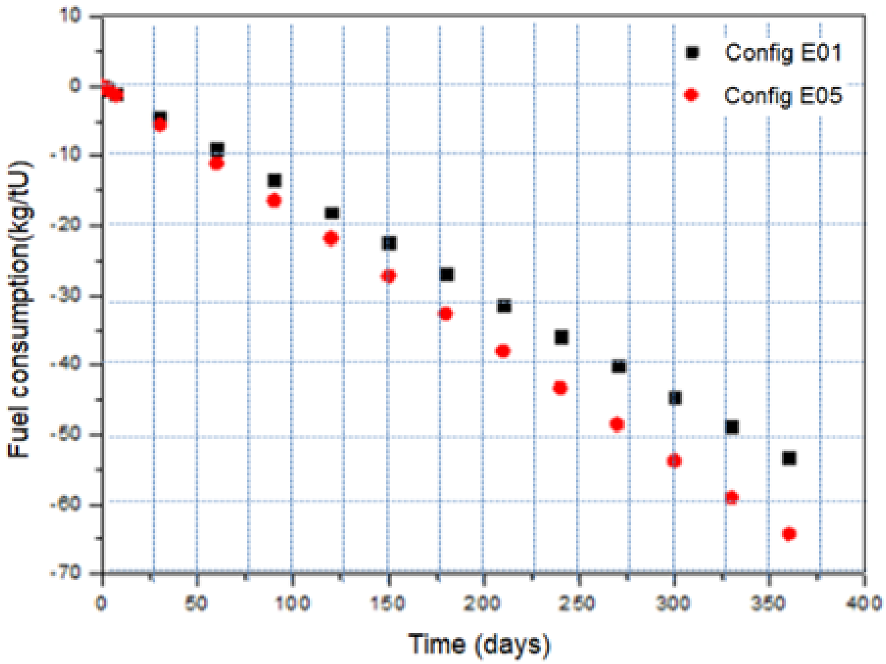

Figure 9: Consumption of ^{235}U due to burnup as a function of time.

Figure 9 indicates a higher consumption of ^{235}U per ton of fuel in the E05 core configuration as expected due to its higher power density, 65 kg^{235}U/tU and 53 kg^{235}U/tU for configurations E05 and E01, respectively. After 360 days the amount of ^{239}Pu produced increased from 3.60 to 3.90 kg^{239}Pu/tU, and the amount of ^{241}Pu increased from 0.095 to 0.145 kg^{241}Pu/tU. The net result of fissile material at EOC is a decrease of 11.2 kg fissile/tU so that the cycle length of configuration E05 is about 60 days per year smaller than that of configuration E01. See in Figure 9 the number of day between configurations E01 and E05 for fuel consumption of -53 kg^{235}U/tU.

4. DISCUSSIONS

4.1. Parametric study to improve radioisotope production

As was mentioned in sect. 2.2, this work takes two routes for enhancing the radioisotope production in the IEA-R1: increase the neutron flux in the irradiation devices through a) changes in the reflector region materials (Be or graphite) and b) reduce the core size from 24 to 20 fuel elements. The second route of investigation allows the placement of additional 4 irradiation devices in the locations where the fuel elements are removed and, additionally, increase the average core power density by 24/20 or 20 % and roughly the average thermal neutron flux in the same proportion. For this reason configurations E04 and E05 are the preferred ones to enhance radioisotope production in this reactor.

The results shown in Table 2 evidence that the Be reflector in configuration E03 causes a strong thermal neutron spatial redistribution in the core. In the left side of the core the thermal neutron flux increases substantially while in the center and right side it decreases. Thus, the addition of Be reflector requires a detailed study and one has to observe the thermal neutron flux gain in all irradiation devices.

Based on Table 2 we have that the configuration which enhances the most the thermal neutron flux in all irradiation devices is E05, the one with approximately cylindrical core, with an average gain of 12.9 %. But the difference among configurations E04 and E05 regarding average gains in neutron flux is smaller than 1.52 %. In addition, they do not require any core change regarding the reflector elements.

4.2. Verification of safety and design parameters

The preliminary verification of safety and design parameters showed that the E05 configuration causes no relevant impact on them. The power and temperature reactivity defects showed small variations with no effect on reactor operation. The temperature reactivity coefficients showed smaller reductions in relation to the temperature variation of the moderator, but remained sufficiently negative or safe operation of the reactor. There was a slight increase in the negative reactivity inserted by xenon poisoning with minor impacts on operational maneuver and fuel cycle length [9,10]. The kinetic parameters did not change much and the effective delayed neutron fraction remained practically unchanged (the difference is within the uncertainty ranges). The increase of 21.3 % in the prompt neutron generation time does not affect the reactor controllability but must be accounted for to correctly describe the reactor kinetics. This change has a subtle explanation. In the reactor, the core volume reduction due to the removal of 4 fuel elements caused conversely a volume increase of the reflector region with much less neutron absorption. This reduction in total neutron absorption increases the life time of neutrons in the reactor [11,12].

The removal of 4 fuel elements from the core decreased the k_{eff} at BOC to ~ 1.21 which is still very high and provide enough core excess reactivity for operating the reactor throughout its designed cycle. The shutdown margin, inferred from the k_{eff} with all control rods inserted, increased substantially with the E05 configuration due to its smaller core size and favors safety. As the amount of fuel has been reduced, the worth of control and safety rods increased, and safe shutdown can be assured with an extra margin. The shutdown k_{eff} for configuration E05 is ~ 0.943 while for configuration E01 is ~ 0.985.

The result of fissile material at EOC in Figure 9 showed that the fuel cycle length of configuration E05 is about 60 days per year smaller than that of configuration E01, i.e. a reduction of 16.6 % per 360 days. This reduction is basically due to the higher average power density in the core which increased by 4/24 (0.16) due to the removal of 4 fuel elements out of 24 fuel elements in the E01 configuration. Therefore, about 17 % more fuel has to be manufactured per year and the size of the storage of spent fuel has to increase accordingly.

5. CONCLUSION

The parametric evaluation conducted in this study demonstrated a significant increase in thermal neutron flux for the proposed configurations E04 and E05 with a slight advantage for the latter. The E05 configuration provides higher average neutron flux (average increment of 12.9 %) allowing higher radioisotope production capability; additionally, it provides 4 more Beryllium irradiation elements device, similar to the EIBRA1 and EIBRA 2, which allow a larger number of simultaneous irradiations. The insertion of Be reflector elements in the core has to be studied carefully since it tends to promote strong neutron flux redistribution in the core: increasing the thermal neutron flux in the left side of the core and decreasing it in the center an right side of the core.

The preliminary safe and design studies indicated that the E05 configuration meets the necessary safety requirements for operation. It showed a considerable increase in the worth of control and safety rods which contributes to the reactor safety. The results indicate a significant increase in fissile material consumption (~ 20%), an increase in the xenon poison reactivity (~ 7%), and an increment in fissile plutonium production (~ 40% ^{241}Pu and ~ 14% ^{239}Pu). These factors will cause higher fuel demand and shorter operating cycles of about 60 days per year. The decision about implementing such a change in the IEA-R1 reactor must consider in one hand the gains regarding radioisotope production, and in the other hand, the cost for manufacturing about 17 % more fuel elements and the cost for additional spent fuel storage [17].

As a future work we plan to model with e detail the extra 4 irradiation devices in the core, conduct an economic cost/benefit analysis considering gains of radioisotope production and costs of fuel manufacturing and spent fuel storage. More detailed thermal-hydraulic studies should also be performed to complete a safety analysis.

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