Investigation of some possible changes in Am-Be neutron source configuration in order to increase the thermal neutron flux using Monte Carlo code

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Abstract. Am-Be neutrons source is based on (α, n) reaction and generates neutrons in the energy range of 0-11 MeV. Since the thermal neutrons are widely used in different fields, in this work, we investigate how to improve the source configuration in order to increase the thermal flux. These suggested changes include a spherical moderator instead of common cylindrical geometry, a reflector layer and an appropriate materials selection in order to achieve the maximum thermal flux. All calculations were done by using MCNP1 Monte Carlo code. Our final results indicated that a spherical paraffin moderator, a layer of beryllium as a reflector can efficiently increase the thermal neutron flux of Am-Be source.

1. Introduction
The neutrons are unstable particles that with the protons form the atomic nuclei. Free neutrons can be produced by the cosmic rays showers but also dedicated neutron sources as neutron generators, research reactors and spallation sources are used to produce them artificially [1]. Nuclear reactors are known as the best source of neutrons and can supply high neutron fluxes, but the high technology involved, the safety and security concerns, the costs and their huge dimensions make it impossible to use reactors in many applications [2]. (α, n) sources are a good alternative for reactors. In this kind of source a heavy nucleus emits alpha particles, absorbed by another nucleus that will produce a neutrons. The most common neutrons emitter is the beryllium, which decays in the following way [3]:

\[ \alpha + ^9Be \rightarrow ^{12}C + n \]

Am-Be source yields \(2.2 \times 10^6\) neutrons per second per curie. Its half-life is about 458 years and has low gamma emission rate. Depending on the different application, the proper energy range of the neutrons can be chosen. In this study, we focused on thermal neutrons and the goal is to increase thermal flux. Fig.1 indicates the geometry of the neutron source used in our calculations. The source is fabricated with a compacted mixture of americium oxide (AmO2) beryllium metal powder doubly encapsulated in welded stainless steel [4].

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1.1. Neutron moderators
As mentioned above, Am-Be source produces neutrons in wide energy range. In order to thermalize the fast neutrons a moderator is needed. An appropriate moderator is expected to have a very low thermal neutron cross section and a low atomic number in order to increase the neutron energy loss on each collision. Some suggested materials are C, H$_2$O, D$_2$O, Be, and Polyethylene [5].

1.2. Reflectors
In reactors a reflector material is used to return the neutrons that are leaking from the surface. This material can reduce the consumption of reactor’s fuel. A good reflector should have low absorption and high reflection for neutrons, high resistance to oxidation and irradiation [6]. Beryllium, heavy water and graphite are some good example of reflector.

2. Simulations
We used MCNP Monte Carlo code for all next simulations [7]. Results in this code are averaged and reported for one neutron. In the first step, the effect of moderator geometry on the thermal flux was investigated. Then we used different moderators to find which one is most suitable for our purpose. In the next step, the appropriate radius of the selected moderator was determined. In the final section, we investigate the effect of adding reflectors to the source configuration. The statistical error in simulations, caused by using Monte Carlo method, was less than 10% and the effect of chemically bound atoms [$S(\alpha,\beta)$] on the thermal neutron scattering is not considered.

2.1. Effect of moderator geometry on the neutron flux
According to the simple diffusion theories the leakage of neutrons is proportional to the surface area of the core and for a spherical core the surface area per unit of volume is a minimum. Therefore, for a spherical core, the fraction of neutrons that are lost by leakage is smaller than for any other geometry. To compare the effect of geometry on the thermal flux, spherical and cylindrical water moderator with the same volume were simulated and the thermal flux was determined using F4 tally, which calculates the average neutron flux in a volume [8]. Results are indicated in Fig. 2. Simulations showed that the spherical moderator allow to obtain a greater thermal flux with respect to the cylindrical one.

2.2. Selecting the best moderator
To compare different moderators, the thermal neutron flux in various materials with different radiuses was calculated using F2 tally, which counts the average neutron flux on a surface [8]. In Tab. 1 The evaluated thermal neutron flux on the surface of moderator sphere are reported. Results are depicted in Fig. 3 and Fig. 4 for six various type of moderators.
Figure 2: Comparison of the thermal neutron flux in cylindrical and spherical moderators.

Table 1. Thermal neutron flux in various materials with different radius.

| Radius(cm) | BeO     | D2O     | H2O     | Paraffin | Polyethylene | Graphite |
|------------|---------|---------|---------|----------|--------------|----------|
| 4          | 6.99E-11| 2.02E-09| 3.58E-05| 7.65E-05| 6.97E-05     | 0        |
| 5          | 7.19E-10| 1.24E-08| 7.31E-05| 1.34E-04| 1.25E-04     | 0        |
| 6          | 1.23E-08| 6.55E-08| 1.03E-04| 1.66E-04| 1.58E-04     | 0        |
| 7          | 1.08E-07| 2.32E-07| 1.21E-04| 1.74E-04| 1.68E-04     | 1.35E-11 |
| 8          | 4.91E-07| 6.27E-07| 1.26E-04| 1.66E-04| 1.62E-04     | 3.30E-10 |
| 9          | 1.49E-06| 1.36E-06| 1.23E-04| 1.49E-04| 1.47E-04     | 2.36E-10 |
| 10         | 3.50E-06| 2.52E-06| 1.15E-04| 1.29E-04| 1.28E-04     | 1.15E-09 |
| 11         | 6.71E-06| 4.16E-06| 1.04E-04| 1.09E-04| 1.09E-04     | 3.72E-09 |
| 12         | 1.11E-05| 6.29E-06| 9.14E-05| 8.99E-05| 9.13E-05     | 1.07E-08 |

Figure 3: Neutron thermal flux vs. moderator sphere radius.

Figure 4: Neutron thermal flux vs. moderator sphere radius.

According to the results on the surface of a paraffin sphere of radius of 7 cm, the thermal flux is maximum.

2.3. Determination of the optimized radius for the moderator
In order to reduce the effect of fast neutrons in the paraffin, the radius was increased by 0.2λ, where λ is the neutron mean free path for paraffin [9]. The radius is selected in order to have the thermal flux almost equal to the non-thermal one: as reported in Fig. 5 this happens for a radius of 31.42 cm.
2.4. Reflectors
To find the most efficient reflector, the Am-Be source and its surrounding paraffin moderator were embedded in different reflectors. As a first step, the effect of adding different thicknesses of reflectors to a sphere of a paraffin of radius of 31.42 cm was investigated. Neutron flux on two detectors which were located at 7 cm and 31.42 cm was calculated. Results indicate that adding the thickness of reflectors to this radius of paraffin can not affect the thermal flux on the radius of 7 cm, but it can increase the flux on the surface of paraffin sphere of the 31.42 cm radius. The thermal flux obtained on the surface of paraffin sphere of radius 31.42 cm with different reflectors are reported as a function of thickness in Fig. 6.

**Figure 5:** Comparison of fast and thermal flux of different moderator radiuses.

**Figure 6:** Neutron flux graph vs. radius.

Comparing the results, it is founded that the beryllium is the best reflector.
Since adding the reflector to a sphere of 31.42 cm of moderator cannot make any increase in the radius of 7 cm, the reflector effects in the case of a paraffin sphere of a radius of 7 cm were investigated. In this section, three reflectors were chosen and the results are depicted in Fig. 7.
Figure 7: Effect of adding different thicknesses of three reflectors.

The simulations show that the addition of a reflector layer can lead to an increase in the flux of thermal neutrons. As we expected, beryllium had the greatest effect on the flux of thermal neutrons.

2.5. Finding the Effective radius of the reflector
To find out how the thickness of the reflector will affect the neutron fluxes, we increased the radius of the Be and calculate both thermal and non-thermal fluxes on the surface of the paraffin sphere of 7 cm. Results are reported in Fig. 8.

Figure 8: Effect of adding different thicknesses of Be reflector.

The results showed that the addition of beryllium initially led to an increase in the flux of thermal and non-thermal neutrons but the effect starts to be less evident for a reflector radius greater than 30 cm, while the differences among the thermal flux and the not-thermal one are quite constant. Finally a paraffin sphere of a radius 7 of cm with a 30 cm of beryllium proves to be the best solution. Fig. 9 indicates the final suggested geometry in MCNP code.
3. Conclusion

The performed simulations indicated that using a spherical moderator instead of common cylindrical moderators can lead to an increase in thermal neutron flux. Among the different moderators, paraffin produced the highest flux of thermal neutrons in the surface of a sphere of 7 cm radius, where we suggest to put the end of the irradiation site. Moreover, beryllium was established as the best neutron reflector to increase the thermal flux of an Am-Be neutrons source.

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