Distributions of neutron flux from (p, n) reaction on the liquid lead target for accelerator driven subcritical reactor (ADSR)

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Abstract. This paper presents the results of calculating the distributions of neutron flux in an accelerator driven subcritical reactor (ADSR) with thorium fuel. The simulated ADSR consists of 90 fuel rods and 10 graphite reflector rods. All objects are placed in liquid lead. MCNP5 program is used to calculate energy distributions of the neutron flux, axial distributions and radial distributions inside the core of the ADSR. The results show that the neutron fluxes of 25°, 45°, 60° and 85° angles are similar; axial distributions of neutron flux decrease gradually; the neutron fluxes are the largest between 0.3 and 0.5 MeV. The radial distributions of neutron flux decrease gradually from center, and the largest value is between 30 and 40 cm. The results also show that the neutron fluxes are different with different radii. The results are important for the design and operation of the ADSR.

1. Introduction

The idea of accelerator driven subcritical reactor (ADSR) was mentioned by Furukawa et al. [1], Bowman et al. [2] and Rubbia et al. [3]. ADSR works on the basic principle of giving proton beams from the accelerator to the target inside a nuclear reactor in a subcritical state. In recent years, the using of thorium as fuel for ADSR has received great attention. The design of the target and to improve the conversion efficiency in thorium fuel are the two main issues of ADSR. There have been many studies on the calculations of energy distributions, angular distributions, neutron yields on different targets, corresponding to different levels of neutron energy [4][5][6]. Some studies suggested using mixture of lead-bismuth as fuel and coolants [7]. The biggest difficulty in using thorium fuel is: natural thorium does not contain fission fuel as natural uranium. There are proposals to use thorium in combination with 235U or 239Pu in converting 232Th into 233U fission nuclear [7], or research reported by Rubbia et al. [3] for ADS using thorium as a fuel.

In this paper, thorium is used as a fuel. The source of neutrons is created by the proton beam interacts with the liquid lead. Here, liquid lead is both a target and a coolant.

2. Calculation and results

In this paper, the MCNP5 program [8] is used to simulate the basic structure of an ADSR. There were some studies that simulated the structure of an ADSR. Hassanzadeh et al. [9] used the MCNPX program to simulate the structure of ADSR according to the model of TRIGA reactor, containing 102 fuel rods enriched with 20% uranium.

In this paper, an ADSR is simulated with 90 thorium fuel rods and 10 reflectors made of graphite; all fuel rods and reflectors are placed in the liquid lead – as shown in Figure 1. Here, liquid lead is both a spallation target for (p,n) reaction and a coolant.
Figure 1. The positions of fuel rods and reflectors inside ADSR are simulated by MCNP5. (a) and (b) are the cross-sections of the ADSR, (c) and (d) are internal structures.

The outermost is the reflective layer with graphite. Details are described in Table 1.

Table 1. Structure parameters of the ADSR.

| Description           | Value    |
|-----------------------|----------|
| Height of core        | 72.000cm |
| Diameter of core      | 56.000cm |
| Height of fuel rods   | 68.370cm |
| Diameter of fuel rods | 1.818cm  |
| Height of reflectors  | 68.370cm |
| Diameter of reflectors| 1.818cm  |
| Thickness of reflectors| 1.818cm |

This structure is based on the TRIGA reactor [9] shown in Figure 2.
Figure 2. ADSR is simulated by Hassanzadeh [9].

Neutron sources are built from [5,6], intensity of proton beam is 10mA. The MCNP5 program is used for simulating the structure of ADSR, tally Fmesh4 is used in calculations, 1.0x10^6 source histories are used in our MCNP5 simulations, combining with equation from [9]:

\[ \Phi = \frac{2 \times 10^{-3} \text{C/s}}{mA} \times \frac{1p}{1.6 \times 10^{-19} \text{C}} \times F4 \times Y_{nP} \]

In which, \( \Phi (\text{ncm}^{-2}\text{s}^{-1}) \) is neutron flux, F4 is tally of MCNP, \( Y_{nP} \) is the neutron yield.

2.1. The energy distribution of neutron flux
The results are shown in Figure 3.

Figure 3(a) shows the energy distributions of neutron flux with various angles, which shows that the neutron fluxes of 25°, 45°, 60° and 85° angles are the same and the neutron fluxes decrease with the energy. Figure 3(b) shows the energy distributions of neutron flux with various lengths, which shows that the largest neutron fluxes are between 15 and 45 cm, and neutron fluxes are the largest between 0.3 and 0.5 MeV for all lengths. Figure 3(c) shows the energy distributions of neutron flux with various radii, which shows that neutron fluxes decreases gradually from center of the core.
Figure 3. Distribution of the neutron flux according to the energy of the neutron emitted.
2.2. *The axial distribution of neutron flux*

The results are shown in Figure 4.

![Figure 4(a)](image1.png)

Figure 4(a) shows the axial distributions of neutron flux with various angles. The results show that the neutron fluxes are almost the same for different angles. Figure 4(b) shows the axial distributions of neutron flux with various radii. The results show that neutron fluxes are the largest between 30 and 40 cm. The results show that neutron fluxes are different for different radii.

![Figure 4(b)](image2.png)
2.3. The radial distribution of neutron flux

The results are shown in Figure 5.

![Graph showing the radial distribution of neutron flux.](image)

**Figure 5.** The radial distribution of neutron flux.

The Figure 5 shows radial distributions of neutron flux. The results also show that neutron fluxes decreases gradually from center of the core. This is similar to the results of the energy distributions of neutron flux with various radii.

3. Conclusions

By using the MCNP5 program, a basic structure of the ADSR with thorium fuel has been simulated. The results of radial distribution of the neutron flux, axial distribution of the neutron flux and energy distribution have been calculated. The model and calculation results are reliable on the basis of comparison with published results. These results are the basis for the further studies about the Accelerator Driven Subcritical Reactor (ADSR).

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