K effective factor in the ADSR using liquid lead target and ($^{233}\text{Th}\text{UO}_2$, ($^{235}\text{Th}\text{UO}_2$), ($^{238}\text{Th}\text{UO}_2$) fuel mixture

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Abstract. The study of using liquid lead target for the accelerator driven subcritical reactor (ADSR) has been proposed by Nguyen Mong Giao, Vu Thi Diem Hang, Tran Minh Tien (International Journal of Modern Physics and Application. Vol. 2, No. 3, 2015). The calculations about neutron distribution, neutron flux distribution with thorium fuel and thorium mixture has been showed by Tran Minh Tien (Distribution of Neutrons from The Reaction (p, n) on the Liquid Lead Target in The Accelerator Driven System Reactor, J. Phys.: Conf. Ser. 1172 012066, 2019; Distributions of neutron flux from (p, n) reaction on the liquid lead target for accelerator driven subcritical reactor (ADSR), J. Phys.: Conf. Ser. 1324 012061, 2019). In this paper, the k effective factor is calculated with ($^{233}\text{Th}\text{UO}_2$), ($^{235}\text{Th}\text{UO}_2$) and ($^{238}\text{Th}\text{UO}_2$) fuel mixture.

Keywords: ADSR, liquid lead, thorium fuel, kcode.

1. Introduction

The accelerator driven subcritical reactor (ADSR) is being developed for safety, along with the ability to transmute radioactive wastes and the potential to use thorium as a fuel. Since ADSR was proposed by C. Rubbia [1], there have been many different studies around this. Many authors have studied the (p, n) reaction on the solid target [2][3][4]. We had proposed using liquid lead as a target and coolant [5], calculated neutron distribution, neutron flux distribution with different types of fuel mixture [6][7]. To further assess the stability of ADSR when using liquid lead target, thorium fuel mixture, we have calculated k effective multiply factor in the ADSR, with ($^{233}\text{Th}\text{UO}_2$), ($^{235}\text{Th}\text{UO}_2$) and ($^{238}\text{Th}\text{UO}_2$) fuel mixture.

2. Calculation and results

In this calculation, ADSR is simulated by MCNP5 program [8]. 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 [7]. Details are described in figure 1.
Figure 1: The position of fuel rods, reflectors inside ADSR is simulated by MCNP5 [7]

Details are described in table 1 [7].

| 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 reflective layer | 1.818cm |

K code calculation technique is used to calculate $k_{eff}$ for each fuel case with different ratios of thorium, uranium and oxygen.

2.1. (Th$^{233}$U)O$_2$ fuel mixture
The fuel is (Th$^{233}$U)O$_2$ mixture. The thorium ratio in the mixture is 0; 0.2; 0.4; 0.6; 0.8 and 1. This results is shown on figure 2, 3.
These results show that when thorium ratio is 0%, $k_{\text{eff}}$ changes from 0.92 to 0.98. This ratio increases to 20%, range of $k_{\text{eff}}$ is from 0.76 to 0.84; and this range is from 0.62 to 0.65 for 40%. When thorium ratio increases to 60%, $k_{\text{eff}}$ changes from 0.42 to 0.44; ranges are 0.16 to 0.18, 0.02 to 0.05 for ratios 80% and 100%.

For $^{233}$U fuel mixture, as thorium ratios increase, $k_{\text{eff}}$ will tend to decrease. Especially, when the thorium ratio is 100%, the $k_{\text{eff}}$ is close to zero, which shows that it is not advisable to just use thorium as a fuel but instead combine other fuels.

2.2. $(\text{Th}^{235}\text{U})O_2$ fuel mixture
The fuel is $(\text{Th}^{235}\text{U})O_2$ mixture. The thorium ratio in the mixture is 0; 0.2; 0.4; 0.6; 0.8 and 1. These results are shown on figure 4, 5.
These results show that when thorium ratio is 0%, $k_{\text{eff}}$ changes from 0.65 to 0.68. This ratio increases to 20%, range of $k_{\text{eff}}$ is from 0.54 to 0.57; and this range is from 0.42 to 0.44 for 40%. When thorium ratio increases to 60%, $k_{\text{eff}}$ changes from 0.27 to 0.30; ranges are 0.12 to 0.14, 0.02 to 0.03 for ratios 80% and 100%.

For U$^{235}$ fuel mixture, as thorium ratios increase, $k_{\text{eff}}$ will also tend to decrease. When the thorium ratio is 100%, the $k_{\text{eff}}$ is also close to zero.

### 2.3. (Th$^{238}$)UO$\text{}_2$ fuel mixture

The fuel is (Th$^{238}$)UO$\text{}_2$ mixture. The thorium ratio in the mixture is 0; 0.2; 0.4; 0.6; 0.8 and 1. This results is shown on figure 6, 7.
These results show that $k_{\text{eff}}$ is very low. When thorium ratio is 0%, $k_{\text{eff}}$ only changes from 0.07 to 0.08. This ratio increases to 20%, range of $k_{\text{eff}}$ is from 0.06 to 0.07; and this range is from 0.03 to 0.04 for 40%. When thorium ratio increases to 60%, $k_{\text{eff}}$ changes from 0.03 to 0.04; ranges are 0.02 to 0.03, 0.01 to 0.02 for ratios 80% and 100%.

For $^{235}$U fuel mixture, the $k_{\text{eff}}$ is also close to zero. We should not use the combination of thorium with $^{238}$U as a fuel for ADSR.
2.4. Comparison of average $k_{\text{eff}}$ between $(\text{Th}^{233}\text{U})\text{O}_2$, $(\text{Th}^{235}\text{U})\text{O}_2$, $(\text{Th}^{238}\text{U})\text{O}_2$ fuel mixture

These results of average $k_{\text{eff}}$ are shown on the table 2 and figure 8.

| Ratio of Th | $(\text{ThU}^{233})\text{O}_2$ | $(\text{ThU}^{235})\text{O}_2$ | $(\text{ThU}^{238})\text{O}_2$ |
|------------|-------------------------------|-------------------------------|-------------------------------|
| 0.0        | 0.93939                       | 0.66416                       | 0.07724                       |
| 0.2        | 0.80053                       | 0.55532                       | 0.06405                       |
| 0.4        | 0.63388                       | 0.43001                       | 0.03753                       |
| 0.6        | 0.43124                       | 0.28583                       | 0.03753                       |
| 0.8        | 0.17378                       | 0.11494                       | 0.02437                       |
| 1.0        | 0.01796                       | 0.01796                       | 0.01796                       |

Results showed that for fuel mixtures containing $\text{U}^{233}$, $k$ reached the highest value, followed by $\text{U}^{235}$ and $\text{U}^{238}$. In each case, $k$ decreases gradually according to the ratio of uranium in the fuel rod component.

The results show that thorium should only be combined with $\text{U}^{233}$, according to suitable ratios.

3. Conclusions

MCNP5 program was used to simulation an accelerator driven subcritical reactor with thorium mixture fuel. $k_{\text{eff}}$ effective multiply factor was calculated for cases of fuel. The results shown that thorium can be combined with uranium as fuel for ADSR. $\text{U}^{233}$ is the best choice in all cases. However, it is important to carefully calculate the ratio between thorium and uranium to suit each ADSR structure used.

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