Study on the Parameters of the ADS Spallation Target

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Abstract. The Accelerator Driven Systems (ADS) has obvious environment and source benefit, which has been getting more and more concern in China. In this Article, the ADS spallation targets were studied using FLUKA code. The spallation neutron yield and energy deposition were calculated with the proton bombardment of lead, bismuth and LBE targets at beam energies of 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4 and 1.6 GeV, the calculated results are in accordance with the available experimental data and the empirical formulas’ results. In addition, the effects of target geometry on the target properties were checked.

1. Introduction

The ADS system utilizes the neutrons produced in a spallation target by a high-energy proton beam to drive a sub-critical reactor containing both fissionable fuel and radioactive waste. The spallation target is ideally conceived to be high atomic number material and heavy density metals like lead, bismuth and lead-bismuth eutectic (LBE) fit the requirement extremely well. The following points are the attractive features of ADS: (1) extremely high level of inherent safety, (2) minimum production of long lived wastes, (3) ability to transmute long-lived nuclear wastes generated in normal reactors and (4) more efficient use of abundantly available natural fuel (232Th)[1]. A novel feature of ADS is the presence of a neutron spallation target in the core of the reactor, which always operates under sub-critical conditions. A proton beam (energy ~ 1.0 GeV and current ~ tens of mA) interacts with the target, which is located in the core and produces spallation neutrons that diffuse into the reactor and drive the reactor. Therefore, the spallation target is one of the most important units in the ADS. One of the critical operating conditions for the ADS spallation target is the high volumetric heat deposition rate. To overcome this problem, liquid metal targets consisting of lead, bismuth and LBE have been proposed.

2. Study on spallation target physics
The physical study on the spallation target is one of the basic researches of the ADS design. From the point of view on the engineering application, the basic problems such as spallation neutron yield, energy spectrum and energy deposition will be firstly concerned.

2.1. Spallation neutron yield

The neutron yield per incident proton is the most interesting data for the practical application in the ADS study, which is related with the incident proton energy and the target material. Figure 1 presents the neutron yield per incident proton for different target nuclei (10.2 cm D x 60 cm L) at beam energies of 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4 and 1.6 GeV. It can be seen that our calculated results are in accordance with the empirical formulas' results and the experimental data [2].

![Figure 1. Neutron yield as a function of the proton energy](image)

In consideration of the following factors [3]: the multiplication of neutrons in the target, more elastic and inelastic collisions with target nucleus will take more neutrons into resonance region in which neutron has large absorption cross section. It can predict that too large or too small target can not get the highest neutron yield.

Figure 2 shows the number of neutron per incident proton for lead target at beam energy of 1.0 GeV when fixed length L = 100 cm and changes the diameter of the cylindrical target. it can be seen that the neutron yield remained unchanged when diameter is greater than 80 cm. Figure 3 shows the neutron yield when fixed diameter of the cylindrical target D = 50 cm and changes the length L of the cylindrical target. When L is greater than 60 cm, it can be seen that the neutron yield is essentially unchanged.

To determine the appropriate size of the target is so complicated. We must consider the design of the reactor, heat dissipation, the production process of the target, neutron yield and the amount of a combination of factors. Figure 2 and Figure 3 provide references for the design of target in a way.
Neutron yield changes with the radius of the target when the length of the lead target $L = 100\text{cm}$.

Neutron yield changes with the length of the target when the radius of the lead target $R = 25\text{cm}$.

2.2. Neutron energy spectra

The reaction mechanisms of different neutron spectra and reactor materials are different. Consequently, the target of different sizes results in different energy spectra of neutrons, and thus matches with a different reactor. Therefore, a comparison of the neutron spectrum in the different target sizes is necessary. Figure 4 shows the leakage neutron spectra when we change the diameter of the cylindrical and fixed length of the lead target $L = 100\text{cm}$, we can get a conclusion that the larger the target, the softer the neutron spectrum, that is, the lower the average neutron energy.
2.3. Energy deposition

The deposited energy in the spallation target comes from the loss energy of the incident protons since their reactions with the target nuclei and the reaction energy caused by the changing of the masses [4].

![Graph of neutron/proton energy spectra with different target sizes](image1)

**Figure 4.** Energy spectra of neutron in different sizes of target

![Graph of heat deposition for different targets and proton energies](image2)

**Figure 5.** Heat deposition for p(0.2-1.6GeV)
Figure 5 presents the calculated dE/dz energy loss for various proton energies using FLUKA[5] code. It is seen from Figure 5 that the familiar Bragg peak exists rather predominantly at lower proton energies. If we choose the lower proton energies for the neutron spallation target, then the maximum power deposition will occur at this peak. With the increasing of proton energy, it is seen that the Bragg peak becomes less pronounced and at high proton energies the peak is nearly absent. As proton energy is increased, the nuclear reaction contribution begins to dominate and the number of survival protons decreases significantly with increase in the depth of penetration. This in turn leads to fewer number of high energy protons going through full range and subsequent disappearance of the Bragg peak. From this point of view it is advantageous to use 1.0GeV protons because at this energy the heat deposition develops continuously with decreasing gradient. The energy deposition is spread over larger volume of the target. Thus increasing the proton beam energy helps to spread the heat in the spallation target and to reduce the peak heating value. This feature has an implication in target cooling design.

3. Summary
In this paper, the ADS spallation targets were studied using FLUKA code. The spallation neutron yield, energy spectra and energy deposition were calculated with the proton bombardment of lead, bismuth and LBE targets at eight different beam energies. The calculated results of neutron yield are in accordance with the available experimental data and the empirical formulas’ results. The calculations show that the target geometry make an important impact on the neutron production and leakage, also show that the proton energies around 1.0GeV lead to acceptable heat production in the target because of the decreasing of the Bragg peak and the larger penetration depths with higher proton energies.

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