PARAMETERS OPTIMIZATION FOR THE GRAVITY-DRIVEN DENSE GRANULAR FLOW TARGET FOR C-ADS

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ABSTRACT

The gravity-driven dense granular flow target (DGT) concept has been chosen as the target solution for the Accelerator-Driven Subcritical (ADS) project in China. This paper presents the optimization of the parameters of the granular flow target for the C-ADS project. Systematic analyses of the neutron production efficiencies for different beam-target parameters are performed. Based on the analyses, the optimal parameters for a high neutron yield and a good neutronics performance are given. The power deposit characteristics of the granular flow target for different beam energies are discussed.

KEYWORDS
C-ADS; Spallation target; Neutron production; Optimization;

1. INTRODUCTION

A new target concept, the gravity-driven dense granular flow target (DGT), which has great potential to form the basis of tens of MW spallation target stations, has been proposed for C-ADS [1]. This kind of target configuration has many advantages, such as high heat removal ability, low chemical toxicity and radiotoxicity, and long operational life. These advantages, as well as the conceptual design of the DGT have been generally discussed in our previous work [1].

In this paper, the optimization of beam-target parameters for a high production efficiency of the total and transmutation-valuable neutrons for the gravity-driven DGT is presented. The distribution characteristics of the power deposition are discussed too. The work is performed using the GMT program which has been developed for the neutronics study and parameters design of the gravity-driven DGT [2].

2.1. Discussions and Optimization of the Beam-Target Parameters

The container of the grains of the gravity-driven DGT is a hopper, as shown in Fig. 1. In this design optimization work, the length of the beam-target interaction region which is marked out in Fig. 1 is 100 cm and the depth of the beam pipe is 60 cm. With 15 cm diameter, the proton beam spot is uniformly distributed. Millions of solid granules flow into the spallation region under gravity from the upper annular duct where the beam pipe is located. The numerical simulations of granular flow are performed using the GPU-based discrete element method (DEM) [3-4]. Indicated by the DEM simulation studies, the volume
fraction of the granular flow will varies in a range from 0.55 to 0.60 in target body, in spite of a lower value nearby the beam-target coupling interface.

Figure 1. Schematic outline of a DGT with grain injector and discharge outlet, heat exchanger, grain receiver vessel with filter and grain lift system.

2.1.1. Optimal parameters for a high neutron production efficiency

Basically, the neutron production efficiency of the DGT is determined by the proton beam energy and the target dimension. Using the dedicated GMT program, detailed simulations studies and optimization work can be performed.

Figure 2. Neutron yields per unit beam energy per proton as functions of the diameter of the granular flow target (W material) for various beam energies.
In Fig. 2, the neutron yields per GeV beam energy per proton for various beam energies are shown as functions of the target diameter for the tungsten granular flow target. As shown in Fig. 2, when the target diameter is in the range from 30 to 40 cm and the beam energy is around 1.5 or 2.0 GeV, a relatively high neutron production efficiency can be acquired.

In the circulation loop of the grains of the DGT, a magnetic lifting device instead of mechanical one will be adopted to act as the grains elevator. To meet the requirement on the grains material of the magnetic lifting, the tungsten alloy with 2% Fe and 5% Ni will be used [5]. The adoption of the alloy can overcome the brittleness of the solid grains at the same time.

The neutron production efficiencies for different beam-target parameters for the granular flow target adopts W alloy are shown in Fig. 3. It is can be seen that the neutron yields are overall less than that of pure W material. For the optimal beam energies and target diameters mentioned above, the differences will be around 10% or less. This is due to the high resonance neutron-absorption cross-sections of Fe and Ni over the neutron energy range from 0.01 to 0.1 MeV.

![Figure 3. Same as Fig. 2 except for the W alloy granular material.](image_url)

For the spallation target of ADS, the most valuable neutrons are that with energies more than 1 MeV, because of the fact that only when the neutron energies are close to or more than 1 MeV, more fission reactions instead of neutron-absorptions of the minor actinides (MA) and the long-lived fission products (LLFPs) could be induced, which means that a higher transmutation efficiency can be acquired. Therefore, the investigation into the yields of the fast and high-energy neutrons for different parameters is necessary.

As shown in Fig. 4, the yields of the neutrons above 1 MeV for 30 cm diameter are significantly more than that for 35 cm diameter. Thus, the optimal diameter for high total and transmutation-valuable neutron yields will be 30 cm or a few less. It is also can be seen from Fig. 4 that the yields for pure W and alloy are very close, which means that the adoption of the alloy material will make no big difference on the transmutation value of the neutron source provided by the target.
The yields of the neutrons above 1 MeV for the pure W and alloy granular flow target with 30 and 35 cm diameters as functions of beam energy.

2.1.2. Discussions about power deposit characteristics for different beam energies

For different beam energies, the neutron productions per GeV heat deposit are different. As shown in Fig. 5, the peak appears at 2.0 GeV and is about 14% larger than the value at 1 GeV. Compared to 1.5 GeV, 2.0 GeV beam energy also will be a better choice, especially considering the benefits of adopting a higher beam energy and a lower beam current [2].

In Fig. 6, the radial distributions of the heat deposit in unit mass for different beam energies are shown. The beam power stays at 15 MW no matter what the beam energy is. It can be seen that the larger the beam energy is, the more homogeneous the heat deposition will be. For 2.0 GeV beam energy, when a
speed of 1 m/s is set for the grains in the beam-target interaction region, the temperature rise of the alloy grains after power loading will be around 300 ◦C. It is can be estimated that a beam power of tens of MW can be easily sustained with a higher temperature rise, especially when the heat transfer between inner region and outer one is taken into account.

Figure 6. Radial distributions of the power deposition averaged in the length (100 cm) of the beam-target interaction region for various beam energies (15 MW beam power and 30 cm target diameter).

2. CONCLUSIONS

The optimization of the beam-target parameters for DGT was performed for a high neutron yield and a good neutronics performance from the perspective of transmutation efficiency. A 30 cm target diameter or kind of smaller one and a 2.0 GeV beam energy were indicated to be best choices. The characteristics of the power deposit for different beam energies were discussed and the capability of this kind of target to handle extreme high beam power was illustrated roughly.

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REFERENCES