RECENT PROGRESS ON THE GRAVITY-DRIVEN DENSE GRANULAR FLOW SPALLATION TARGET

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ABSTRACT

Research on Accelerator Driven System (ADS) was started in 1999 in China. After the fundamental physical and technological research in the first five years, a “future advanced fission energy-ADS transmutation system” was approved as a strategic leading science and technology program in 2011 to speed up the R&D of the ADS. Institute of Modern Physics, Chinese Academy of Sciences proposed the concept of gravity-driven Dense Granular-flow Target (DGT) in 2014. To analyze granular flow in the target, Discrete Element Method (DEM) codes has been developed and verified. Granular flow of large number of grains in the target was simulated on multiple GPUs. Relations of geometrical and material parameters with flow rate were investigated and significant results were achieved. For the detailed neutronics study of the target, a dedicated Monte Carlo transport program has been developed. Here, the simulation studies of the neutronics performance of the granular flow target and discussions of the parameters for this kind of target concept have been presented.

KEYWORDS
Chinese ADS; Spallation target; Neutronics study; Granular flow

1. INTRODUCTION

The concept of Accelerator Driven System (ADS) was proposed in the 1990s, aiming at acquiring clean nuclear energy and transmuting minor actinides and long-lived radioactive fission products from nuclear waste. The fundamental physical and technological research on the ADS in the National Basic Research Program of China ("973" Project) has been implemented since 1999 by a collaboration of China National Nuclear Corporation and the Chinese Academy of Sciences. Based on several rounds of high level expert consultations and assessments from 2009 to 2010, a ‘future advanced fission energy-ADS transmutation system’ was approved as a strategic leading science and technology program in January 2011 to speed up the R&D of the ADS [1]. For the spallation target design, a new concept of gravity driven Dense Granular Target was proposed in 2014. The configuration of the target is shown in Figure 1. This target has many advantages such as high heat removal ability, low chemical toxicity and radio-toxicity as well as long operational life. In this paper, the progress about the research of the DGT on aspects of granular flow study and neutronics study are presented.

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2.1 Granular flow study

Even though research on granular material has been lasting for decades, there is no comprehensive theory in this field so far that can reliably predict granular behaviors. Experiments and engineering devices are always expensive and time consuming. So far, the discrete element method (DEM) has been the most acceptable method to simulate the granular material [2, 3]. Developed DEM codes such as LIGGGHTS, EDEM have been used in granular flow simulations [4, 5]. In order to achieve very fast calculations of granular flow of hundreds of millions of grains, a heterogeneous CPU-GPU algorithm with a message passing interface (MPI) and CUDA has been developed [6]. In such simulations, each tungsten grain is modeled as a mono-sized sphere undergoing realistic frictional interactions with neighboring grains. The parallel efficiency is more than 70% when there are 512 GPUs used in the simulation and the codes are used in a series of investigations of hopper flows [2, 3, 7]. The relations of the flow rate with the geometrical and material parameters of the spallation target are shown as Figure 3 and Figure 4. The results showed that:

- If the vertical distance from the beam pipe’s bottom to the orifice is large enough, the influence of the beam pipe on flow rate can be neglected and the configuration of DGT can be regarded as ordinary hopper, where Beverloo’s Law is validated;
- Variations of the beam pipe diameter do not bring changes to the flow rate even if it is very close to diameter of the hopper;
- Both particle-particle and particle-wall frictions do affect the flow rate but density and restitution coefficient of particles do not;
- The influence of Young’s modulus on flow rate can be neglected unless very soft particles are considered.
2.2. Neutronics study

For the spallation target of ADS, besides a high-flux of neutrons, a modest neutron emission distribution is important. For solid targets, multi-layered disk design can be used to improve the homogeneity performance of neutron distribution. For a DGT, a relatively modest neutron distribution is kind of its nature [1]. What is more critical is that the optimal lateral dimension of a solid target for a high neutron yield is usually limited, especially for the materials with large neutron absorption cross-section, like tungsten. With a natural volume fraction, the granular flow target can be designed to be with a larger diameter, which is essential for the homogenization of the extreme-high beam power of ADS by using a large beam spot.

To perform the neutronic studies of the DGT, the numerical simulations of the granular flow have been done using DEM. The length of the target body is 80 cm while that of the beam pipe is 20 cm. With different
target diameters, the average volume fractions of the granular flow stay at 0.57 with small fluctuations. Based on the DEM simulation results of the granular flow, the neutronic studies are performed using the GMT program, which has been developed for the detailed neutronic simulation and design study of the DGT target concept [8].

Figure 4. Neutron yields per unit beam energy per proton as functions of beam energy for various target diameters.

Figure 5. Axial distributions of the neutron emission for various beam energies for 30 cm diameter target.
For different target diameters and beam energies, the neutron yields are shown in Fig. 4, and the neutron emission distributions for 30 cm target diameter and various beam energies are shown in Fig. 5. The results can be concluded as:

- The optimal target diameter for a high neutron yield will be around 30 cm and the optimal beam energy will be around 1.5 GeV;
- For the optimal target diameter, i.e. 30 cm, the neutron production efficiency of the beam energies from 1.0 to 2.5 GeV stays around 20 with a discrepancy less than 3%;
- For a flatter distribution, a larger beam energy can be chosen. For example, the FWHM of the distribution increases from 26 cm to 41.5 cm when beam energy increases from 0.5 GeV to 2.5 GeV.
- With a less than 1.5% decrease in neutron production efficiency, 2.0 GeV may be a better choice than 1.5 GeV, considering its flatter neutron distribution and the benefit of adopting a larger beam energy to reduce beam current.

2. **CONCLUSIONS**

The paper reported the progress of granular flow and neutronics study of C-ADS gravity-driven DGT. In both studies, corresponding codes have been developed and verified. For granular flow, relations of flow rate with target’s geometrical and material parameters are revealed. For neutronics study, the neutron yields and emission distributions for various target dimensions and beam energies are investigated to perform a general analysis of the performance and parameters of the DGT target concept. For more detailed design of the DGT, much detailed work should be done in the near future.

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**REFERENCES**