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Validation of the idea of granular flow target: A beam coupling test

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ABSTRACT

The concept of granular flow target was proposed very recently and there are many potential advantages of the target on flow constancy, energy deposition and heat removal, etc. In this work first loop of granular flow target is built and an electron beam coupling experiment is reported, which aims to test the flow constancy, energy deposition and heat removal of the granular materials. The results show a good constancy of the dense granular flow and indicate granular flow as a candidate for energy removal. Moreover, there is a consistence in flow rate and temperature rise between experimental and numerical studies. This work supports the idea of granular target and is valuable for the following ADS facilities and granular flow target design.

1. Introduction

1.1. ADS system

As the increasing urgency of energy and environment issues, traditional fossil energy is needed to be replaced by alternative energy. Due to the scale and maturity, nuclear energy is considered as one of the most promising solutions. Besides remained Uranium and Plutonium, the nuclear wastes also contain very hazardous toxics such as minor actinides and long life fission products (Salvatores and Palmiotti, 2011). Therefore, the development of clean nuclear technic requires deep processing of fuel components to make better use of fuel elements and reduce the toxics. Transmutation of these long-lived radionuclides is an option for reducing the hazards linked to the back end of the nuclear fuel cycle.

Among the new generation of nuclear technics, Accelerator Driven Subcritical System (ADS) has its unique meaning in the aspects of waste processing and safety (Hossain et al., 2015; Rubbia et al., 2001). Different from the traditional critical facilities, ADS adopts a subcritical reactor core. To operate the subcritical core, an external neutron source is applied to supply the neutrons. The external neutrons are generated from reaction between beam and heavy metal target, namely spallation reaction (Hossain et al., 2015; Krása, 2010). The reactivity control of the core could be implemented through the control of the target.

The principle of ADS leads to the process ability of nuclear waste from traditional reactors: by absorbing neutrons, the toxics transmute into less hazardous elements, while the fuel resources could be further burned. This process also generates electric power as the traditional reactors. A part of the power supports the accelerator operation while the rest goes into public grid. In such a system, the target beam power needs to reach the level of tens of MW to supply sufficient high-energy neutrons. To fulfill the commercial needs of nuclear industry, the future ADS needs to reach the power level of hundreds of MW, as the same level of traditional reactor power.

Several ADS programs have been proposed and planned worldwidely, such as J-PARC in Japan (Saito et al., 2006), HYPER in Korea (Chai, 2013) and XT-ADS in Europe (De Bruyn et al., 2007). In China, Chinese ADS (C-ADS) project, run by Chinese Academy of Science, started in 2010 and the ultimate objective for this program is to run a 1000 MW subcritical core driven by a target under 10 mA/1.5 GeV proton beam in CW (Continuous Wave) operation mode (Li et al., 2013). Recently, a 4.3 mA/5.3 MeV CW proton beam has been successfully obtained (Zhan, 2016) and a 10 mA/50 MeV superconducting proton linac as a demonstration of the ADS driver is being designed and constructed (He et al., 2011).

1.2. Concept of DGT

Besides the accelerator, spallation target is also a key component of ADS. Because the deposition of beam power inside the target causes a heat source up to the level of 10 MW within limited volume, it is a big challenge for the heat removal. Very recently, a new concept of gravity-driven Dense Granular-flow Target (DGT) was proposed (Yang and Zhan, 2015) shown in Fig. 1. The target material is a large collection of

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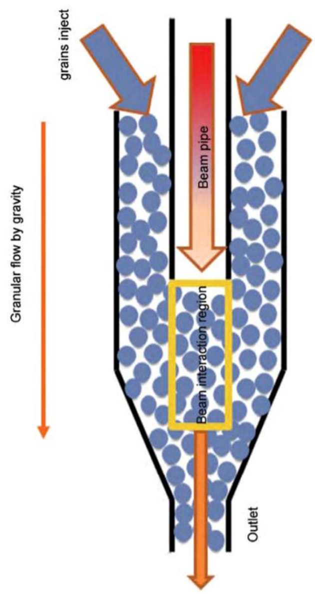


Fig. 1. A scheme of the gravity-driven Dense Granular-flow Target.

discrete solid particles, namely granular materials. Particles flow steadily in such a structure, which behave similarly like flow of sand in an hourglass. The movement of the particles make it possible to remove internal deposit heat continuously, while the candidate material has much more choices than traditional liquid targets.

This new concept will contribute to the design of the MW spallation

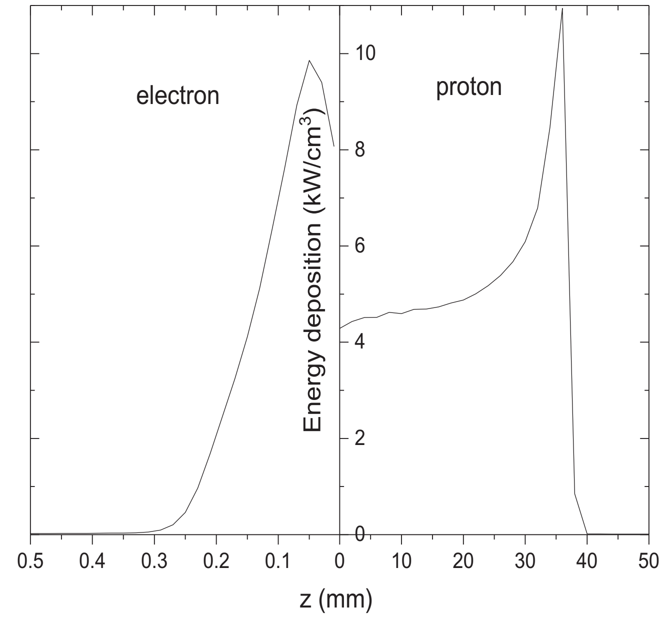
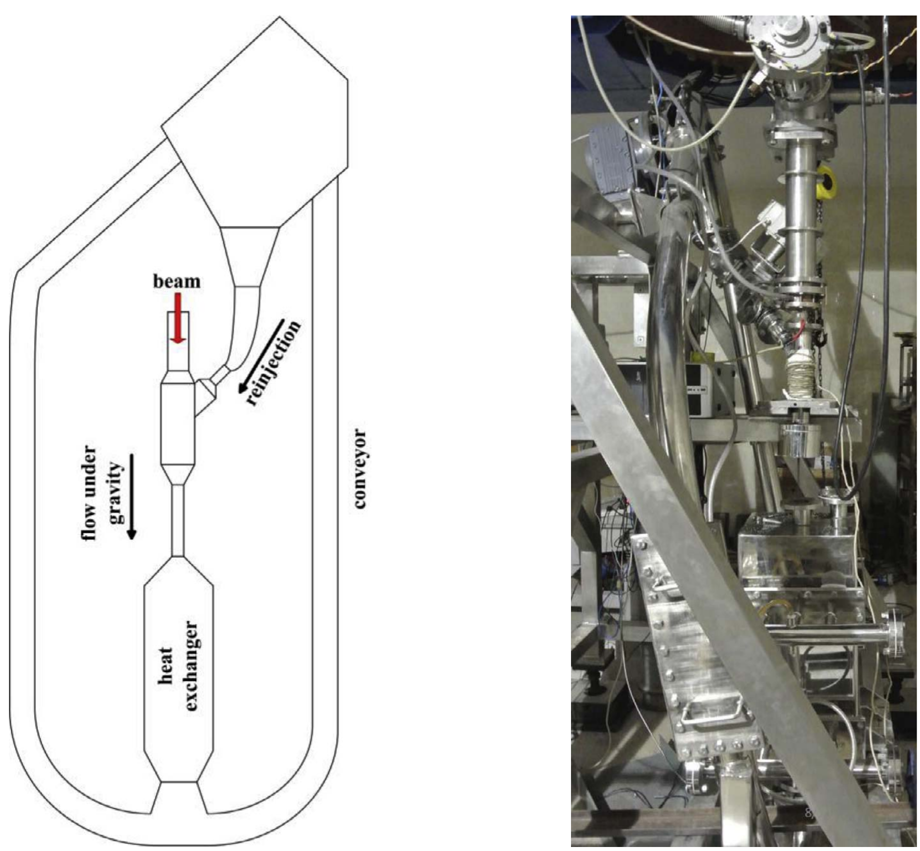


Fig. 3. Energy deposition profiles of electron and proton beams.

target for C-ADS project (Zhan, 2013). Compared to currently wide used targets, the attractions for the DGT include:

(1) The flowing behaviors of grains in DGT are analogous to the fluids (Massoudi and Phuoc, 2007) and the deposited high power will be



a b

Fig. 2. (a) A schematic of the granular loop; (b) a photo of beam coupling section.

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