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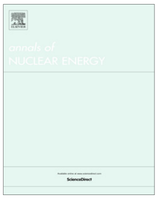

Thermal-hydraulic analysis of an integrated spallation target module in ADS

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ABSTRACT

As a key component in Accelerator Driven System (ADS), the spallation target is exposed to high irradiation intensity radiation, and a larger amount of heat is deposited on it. Therefore, the cooling of the target is a challenging task in the target design. Integrated target module with a solid beam window, and cooled by reactor primary coolant is a good contender for ADS system. The numerical analysis of two target modules was performed by using finite element code to assess the target cooling capacity. It was found that with uniform inlet velocity, the geometry modification of the inlet could improve the heat transfer effectively. But with non-uniform inlet velocity, the geometry modification of the inlet had little effect on cooling capacity.

1. Introduction

In Accelerator Driven System (ADS), a high-energy proton beam impinges on target materials to produce spallation neutrons, and these neutrons are multiplied by subcritical core to transmute long-lived fission products (LLFP) or miner actinide (MA) (Nifenecker et al., 2003). The ADS is being considered as a promising solution to transmute long-lived nuclear wastes (Cho et al., 2008). In most nuclear power stations, lager program associated with ADS R&D is been actively pursued: XADS (Cinotti and Gherardi, 2002) and MYRRHA (Abderrahim et al., 2012) in the European commission, ATW (DOE, 1999) in the USA, OMEGA (Mukaiyama et al., 2001) in Japan, and HYPER (Park et al., 2000) in Korean.

Chinese Academy of Sciences (CAS) is conducting research and development (R&D) on the Accelerator Driven System (ADS) (Zhan and Xu, 2012; Wu, 2016a). Based on years of the research in the field of advanced neutronics software (Wu et al., 2015), low radioactivity material (Huang et al., 2014), and advanced nuclear system design (Qiu et al., 2000; Wu et al., 2011), Institute of Nuclear Energy Safety Technology (INEST), CAS undertakes the R&D of the lead-bismuth eutectic (LBE) cooled reactor design and technology (Wu, 2016b; Wu et al., 2016c).

In previous studies, many projects put forward their target design, like JAEA-ADS (Kikuchi, 2009), HYPER (Song and Tak, 2003), FASTEF (Abderrahim et al., 2012), THREE BEAM CONCEPT (Knebel et al., 2000), XADS (Coors et al., 2004) and MYRRHA (Class et al., 2011). In these contributions, LBE is today the reference target material for ADS application (OECD, 2005; Bauer, 2010). And the target unit with a solid beam window cooled by reactor primary coolant, has the stable target material surface and the radioactivity production containment. It will simplify a target system that increase the neutron economy and reduce the investment cost. And there have been intensive studies on the material (Alamo, 2003), thermal hydraulics, configuration and safety analysis (Song and Tak, 2003; Coors et al., 2004; Saito et al., 2006; Tak et al., 2005).

A proton beam enters the target unit from the top, penetrates the beam window and impinges on the upward flowing LBE. In spallation region, about 60–70% of the beam power is deposited as heat in the target materials (Cho et al., 2008; Cinotti et al., 2003). It is necessary to demonstrate that the target would be cooled adequately. The beam window is a thin barrier to separate the vacuum space from the liquid LBE. Exposed to the proton beam, the window undergoes a high temperature and irradiation. From the thermal-hydraulic point of view, the main issue of the window target is the cooling capability of the window.

In this paper, the Newton's law of cooling and the Fourier law is applied to evaluate the temperature on the window. And this paper presents the numerical studies on the target systems. Two target schemes with different geometry configurations are compared by using a commercial code CFX (ANSYS Inc., 2011).

2. Description of target system

Several design concepts have been developed for the target system. One of the typical designs (Cho et al., 2008) is shown in Fig. 1.

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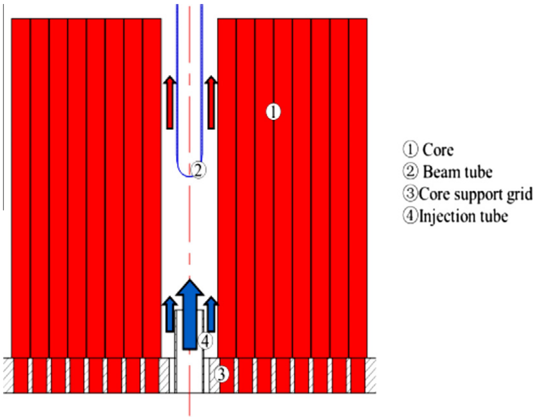

Fig. 1. Schematic view of the typical target design.

In contrast to the proposed target, the target channel surrounded by assemblies which is nearly cylinder. The target channel diameter is set at 260 mm. LBE at about 300 °C driven by the main primary pump from the flow distribution, rises in the space between the sleeve and the beam tube to remove the deposited heat. Then, the hot LBE is pumped from the hot pool, through the main heat exchange and down over pump to complete the LBE circuit. An injection tube is placed at the inlet of the target channel and divides the inlet into two zones. The velocity in the central zones is larger than that of the outer zones. The injection tube diameter and thickness are 168 mm and 10 mm, respectively. In the channel, the beam tube with a hemi-spherical window is adopted for the target. A thickness of the window about 2 mm is chosen in this scheme, and the inner diameter is about 150 mm.

Schematic view of the proposed integrated target unit is shown in Fig. 2. It is demonstrated that the target is horizontally located in the center of the reactor core, and vertically hung on the reactor cover at the top. In general, the target module consists of a cylindrical steel sleeve from outside and a co-axis cylindrical beam tube with a suitable spacing for LBE flowing. The beam tube closed by a hemi-spherical window is adopted for the target.

A uniform proton beam with radius of 50 mm is selected to perform the spallation process. Assuming the proton beam with 250 MeV power and 5 mA intensity penetrates the beam window, deposited energy as heat in spallation region is about 1.2 MW. As shown in Fig. 3, the coolant flows into the gap between the beam tube and the sleeve, and removes the deposited heat. And then, it runs out at the orifices on the sleeve side wall and mixed with the reactor coolant in the hot pool. The vertical section of the spallation area is inverted cone sharp. It allows minimizing the inactive volume of LBE in the target flow channel and increasing the window surface heat transfer.

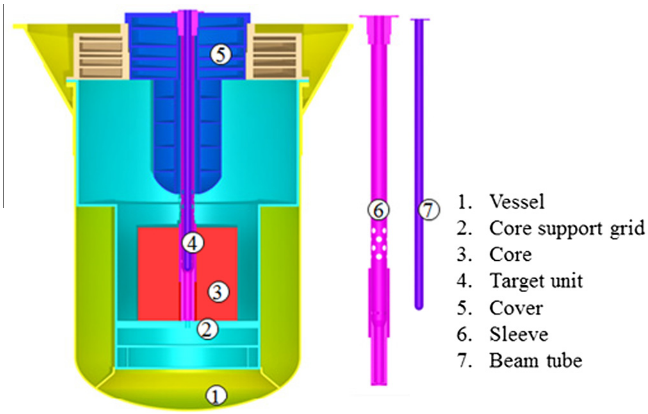

Fig. 2. Overall views of the integrated target design.

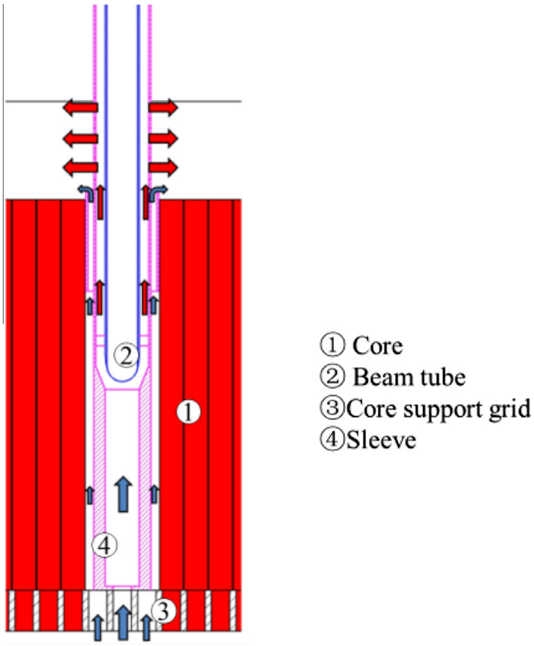

Fig. 3. Thermal hydraulic schematic view of the integrated target.

The modified 9Cr1Mo ferritic–martensitic steel (T91) is the reference window material for the present study (Tak et al., 2005). And other structure parts are made of stainless steel 316 L.

3. Theoretical methodology

The temperature of the target window can be analyzed by the Newton's law of cooling and the Fourier law. The structure of the window can be seen in the Fig. 4. r_1, r_2 is the radius of the inner and outer window surface.

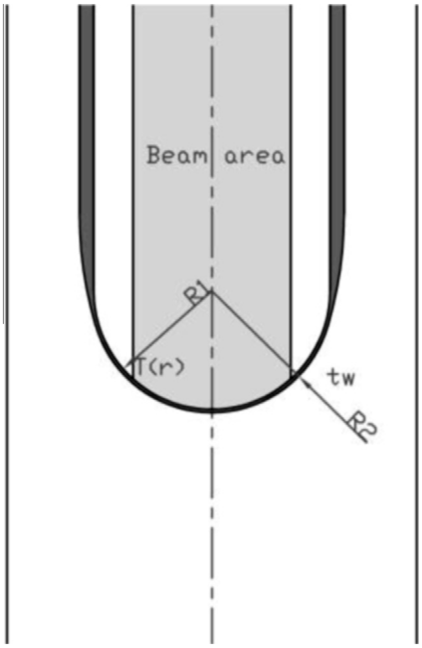

Fig. 4. The structure of the target window.