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Technical note

Preliminary analysis of radiation characteristic at upper section of Accelerator Driven Subcritical System

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ABSTRACT

Accelerator Driven Subcritical System (ADS) has attracted attention in many countries due to its high transmutation ability and inherent safety. The introduction of accelerator makes the radiation outside the reactor of the ADS, especially above the reactor cover, much more serious, due to particles leakage through beam duct and secondary radiation induced by beam losses. In this paper, the characteristic of the radiation fields at the upper section of the reactor of an ADS was analyzed. The radiation caused by penetration from reactor cover, the leakage of fission/spallation particles from beam duct and secondary particles induced from beam losses were compared. Results indicated that the leakage from beam duct and secondary radiation induced by beam losses were the main contributors and the dose rate induced by the proton beam losses should not be neglected. These results could be applied in guiding the shielding design for an ADS.

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1. Introduction

Accelerator Driven Subcritical System (ADS), a combination of accelerator, subcritical reactor core and spallation neutron target, is considered as one of the future advanced nuclear systems and has attracted many countries' attention (IAEA-TECDOC—985, 1997; OECD/NEA, 2002; Abderrahim et al., 2005; Gohar et al., 2008; Noack et al., 2008; Qiu et al., 2000; Wu et al., 2011) due to its high waste transmutation ability and inherent safety. In an ADS, charged particles bombard the target, producing a large amount of spallation neutrons with wider spectra. These neutrons will transport into core to drive the sub-critical core. However, some of spallation neutrons, accompanied with fission neutrons generated in the sub-critical core, will also leak out through void beam duct, thus increasing radiation level outside reactor (Coeck et al., 2001). Simultaneously, a part of energetic charged particles will departure the incident direction in delivering beam due to their interaction with residual gas (Safa et al., 2002). These particles will interact with the material of beam tube and other structure materials, generating secondary radiation and aggravating the radiation level outside reactor again. These factors make radiation field outside reactor of ADS different from critical fission reactor. Therefore, the study focused on the radiation characteristic of areas above the ADS reactor, which could provide suggestions for ADS shielding design.

In this paper, based on present researches in ADS technology in China, a 10 MW Lead–Bismuth Eutectic (LBE) cooled reactor coupled with a 250 MeV 10 mA proton accelerator was selected as basic design of ADS (Zhan and Xu, 2012; Wu et al., 2014, 2015). Then with Monte Carlo method, the radiation characteristic above reactor of ADS under different situations was analyzed and the main radiation contributor was found out. Based on this, a preliminary shielding proposal for the containing compartment and beam duct of ADS was put forward and analyzed.

2. Calculation model

The ADS model used in the paper was composed by a subcritical reactor, a LBE spallation target, and a 250 MeV proton accelerator with maximum current of 10 mA. The subcritical reactor consisted of reactor vessels including components inside the vessels, side biological shielding, cover, rotating plugs and containing compartment. The spallation target locates at the center of the core, and connects with the accelerator beam duct inserting the reactor from the top. At the top of reactor, a pair of eccentric rotating plugs, used to accurately refuel, is embedded into the center of reactor cover. Both cover and rotating plug are designed as multi-layer stainless steel box filled with graphite and concrete, functioning as sealing and radiation shielding. There are some ∼0.5 cm gaps reserved in

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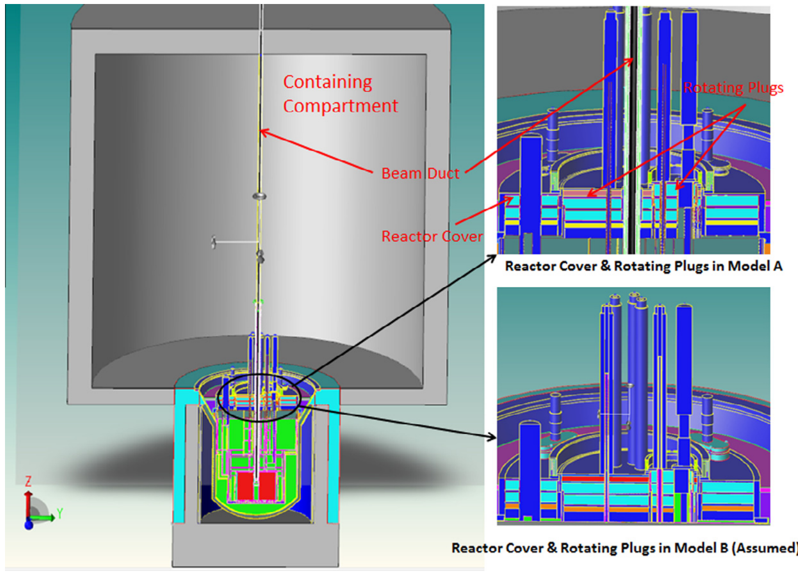

Fig. 1. Three dimensional neutronics model of lead-based ADS model A: real model with beam duct model B: assumed model with no beam duct in the cover and compartment.

case of installation error in the cover and rotating plugs, which could weak their integral shielding performance. Above the reactor cover, there is a containing compartment which is designed to contain radioactive substance leaking from reactor and to prevent them diffusing to outside. The vertical section of accelerator beam duct with lower part enwrapped with LBE circuit (Wu, 2007; Wu et al., 2012) penetrates the compartment and inserts into the core.

According to the description above, the three-dimensional neutronics model, as shown in Fig. 1, was built by SuperMC/MCAM which is a modeling module of Super Monte Carlo Simulation Program for Nuclear and Radiation Process (SuperMC) and supports the modeling of nuclear and radiation process calculation based on MC, S_N and coupled MC and S_N methods (Li et al., 2007; Hu et al., 2007).

To analyze the main contributor for radiation in compartment, two neutronics models for reactor cover and compartment were created, as shown in the Fig. 1. Model A shows the present design of cover and compartment with beam duct. Model B is an assumed model for comparison, in which the beam duct in the rotating plug is filled and no beam duct in the compartment.

3. Method and tool

In this paper, there were two kinds of radiation transport simulation: neutrons and photon coupled transport and proton transport. Both of them were carried out by Monte Carol (MC) method code.

The neutrons and photon coupled transport calculation was performed to simulate leakage and penetration of neutrons/photons inside reactor, using SuperMC with HENDL-ADS/MC data library. Variation reduction technology based on mesh weight window was employed to overcome deep penetration problem in Monte Carol-based shielding calculation. SuperMC, a CAD-based Monte Carlo program for integrated simulation of nuclear system, has been widely used in designing and analyzing fission/fusion reactor, and is regarded as preferred program for ADS neutronic analysis (Wu et al., 1999, 2014, 2015; Song et al., 2014). The analysis and visualization of data were conducted by SuperMC/RVIS which is a visualization module of SuperMC. HENDL-ADS/MC, developed by Institute of Nuclear Energy Safety Technology (INEST), Chinese Academy of Sciences (CAS) • FDS Team, is a point-wise high energy cross-section library suitable for nuclear design and shielding analysis of ADS (Chen et al., 2013).

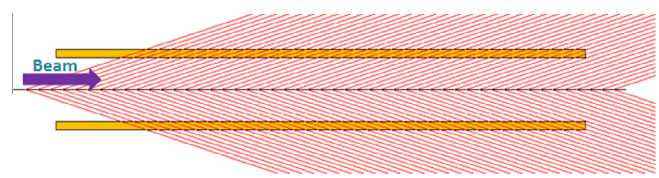

Fig. 2. Pattern of beam losses.

The proton transport calculation was conducted to simulate proton beam losses with FLUKA which is a general Monte Carlo Transport Code developed for high charge particles (FLUKA User's Manual, 2011). And it was assumed that: (Jarose et al., IPAC2014).

1. Beam Losses Pattern: uniform losses along the beam line, as depicted in Fig. 2, and particles are emitted at a shallow angle of 0.05° in reference to beam transport direction.
2. Beam Losses Level: 1 W/m which is one of design limitations for accelerator.

The effective dose was obtained by means of flux-to-effective dose convention factor recommend by ICRP 74 (ICRP Publication 74, Volume 26, 1996).

4. Characteristic analysis of radiation in containing compartment above cover

Since the radiation in containing compartment will be contributed by particles penetrating cover and rotating plugs, the fission/spallation particles leakage from beam duct and secondary particles induced from beam losses, three separated analysis, as shown in Table 1, were performed to assess their individual contribution. For conservative considerations, the reactor was assumed to be full power operated.

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