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MCNP modeling of a neutron generator and its shielding at Missouri University of Science and Technology

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The shielding of a neutron generator producing fast neutrons should be sufficient to limit the dose rates to the prescribed values. A deuterium-deuterium neutron generator has been installed in the Nuclear Engineering Department at Missouri University of Science and Technology (Missouri S&T). The generator produces fast neutrons with an approximate energy of 2.5 MeV. The generator is currently shielded with different materials like lead, high-density polyethylene, and borated polyethylene. An MCNP transport simulation has been performed to estimate the dose rates at various places in and around the facility. The simulations incorporated the geometric and composition information of these shielding materials to determine neutron and photon dose rates at three central planes passing through the neutron source. Neutron and photon dose rate contour plots at these planes were provided using a MATLAB program. Furthermore, the maximum dose rates in the vicinity of the facility were used to estimate the annual limit for the generator's hours of operation. A successful operation of this generator will provide a convenient neutron source for basic and applied research at the Nuclear Engineering Department of Missouri S&T.

1. Introduction

Recently, a deuterium-deuterium (D-D) neutron generator (model DD-109), manufactured by Adelphi Technology, was installed in the Nuclear Engineering (NE) Department at Missouri University of Science and Technology (Missouri S&T). The generator utilizes D-D fusion reactions to produce fast neutrons. The positively charged deuterium ions, generated from the plasma ion source, are accelerated and bombarded on the target by using a high electric field. The target is negatively biased to "attract" these positively charged deuterium ions. A beam current of about 5 mA–15 mA, with an accelerating potential in the range of 80 kV and 120 kV, is maintained to establish this high electric field. The accelerated D+ions strike a static 1.02 cm thick V-shaped copper target with a titanium coating of approximate thickness of 0.102 mm. During the initial period of time, the impinging D+ions form titanium hydride on the surface of the target. Subsequent bombardment of D+ions results in the production of fast neutrons with an approximate energy of 2.5 MeV through $^{2}H+^{2}H\rightarrow^{3}He+n$ fusion reactions [1–3]. Fig. 1 shows the DD-109 generator head, the high-density polyethylene (HDPE) blocks used in its shielding, and the V-shaped target where the fast neutrons are produced. In the DD-109 neutron generator installed at Missouri S&T, the target is oriented such that the open side of a V-shaped target faces up where the samples will be placed (see Fig. 1(b)).

Bombardment of D+ions also results in deposition of heat at the target. The target, therefore, has channels with fluorinert running through them. The fluorinert is specifically needed to cool the high voltage part (target) of the generator. However, the microwave plasma section (including the magnetron power supply in the rack) is cooled with water. The detailed working mechanism of the neutron generators, utilizing deuterium-deuterium and deuterium-tritium fusion reactions and their applications, has been thoroughly discussed in the literature [1–5].

The operation of this DD-109 neutron generator at Missouri S&T will provide faculties and students a convenient neutron source that can be used for various basic and applied research efforts, such as neutron activation, radiography, and material irradiation, etc. Since the neutron generator is installed in a room in a campus building (see Fig. 2), it is imperative that appropriate radiation shielding be provided to protect the public and operators of the generator from radiation exposure. It is very well known that the shielding of neutrons is a complicated problem due to the fact that both neutron and photon interactions with matter should be considered. Therefore, for sufficient reduction in neutron and

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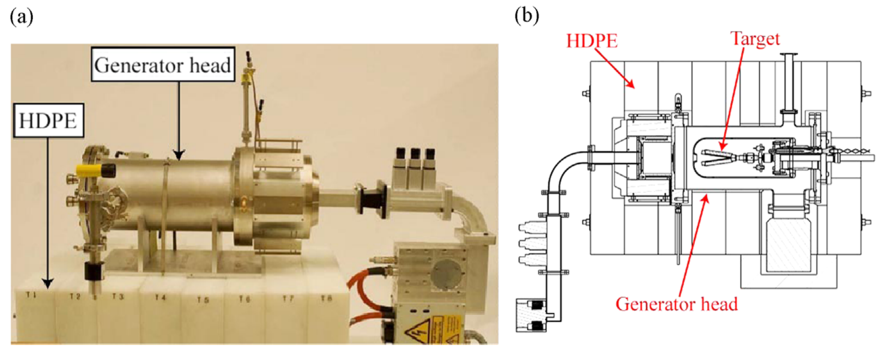

Fig. 1. (a) DD-109 generator and HDPE blocks used in shielding and (b) cutaway of neutron generator and surrounding HDPE shielding. V-shaped target of the generator (top view) is also shown (Image courtesy of Adelphi Technology, Inc.).

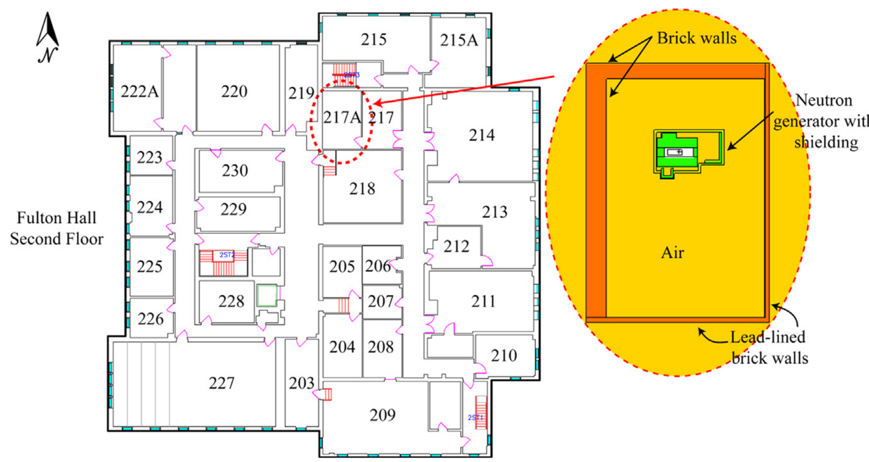

Fig. 2. Layout of second floor of the Fulton building where the generator is located. Also shown is a zoomed image of the room (217A) where the generator is installed.

photon dose rates, the generator has been shielded with high-density polyethylene, lead, and borated polyethylene (BPE). In addition, some walls of the generator room were lead-lined to limit the dose rates to the operator and the public.

In the past, various studies have been performed to design shielding for different neutron sources and generators. The MCNP [6] modeling of a deuterium-tritium (D-T) neutron generator was well studied by J. Katalenich et al. [7]. The yield of uncollided 14.1 MeV neutrons from the D-T neutron reactions, and the neutron fluxes for different beam port diameters, were estimated in this work. J.C. Liu et al. [8] discussed the optimal shielding design for a 14 MeV D-T neutron generator using the MCNP4B radiation transport code. The effectiveness of various materials and geometries in shielding the D-T generator were examined in this study. A thorough analysis of the shield design of a D-T neutron generator was also performed by D.L. Chichester et al. [9]. In their work, Monte Carlo simulations were performed to determine the effectiveness of the concrete shield in reducing the dose rates due to D-T neutron generators. The independent neutron and photon dose rates, due to 14.1 MeV neutron source terms at three different locations, were determined at various positions around the facility. The results from the MCNP5 radiation transport code and SCALE5 code were compared and discussed. The analytical calculations and Monte Carlo simulations for the design of shield walls for different neutron sources were performed by D.L. Chichester et al. [10]. The spatial profile of dose rates, due to the ^{252}Cf spontaneous fission neutron source and neutrons from D-T fusion neutron generators, were obtained at horizontal and vertical planes. The MCNP5 radiation transport code was utilized in simulating the neutron and photon radiation fields in the facility. The effectiveness of different shielding materials in reducing the neutron and photon dose rates has been discussed in [11]. The MCNP simulations were performed by assuming a point-like isotropic source emitting 1×10^8 neutrons/s of energy 14.1 MeV.

In this work, attempts were made to model the current radiation shielding of the D-D neutron generator and the installation room using MCNP. The ultimate goal of this study was to estimate the approximate dose rates in and around the facility where the generator will be operated, and to determine the maximum operation time of the generator so that the annual radiation doses to the operator and the public would be within the prescribed limits. Furthermore, an additional MCNP transport simulation, without the lead-lining of different walls and floor, was performed. The purpose of this simulation was to estimate the shielding effectiveness of lead-lining in reducing the neutron and photon dose rates.

2. Facility layout and analytical calculations

It was discussed in the previous section that, for successful operation of the neutron generator, sufficient shielding should be provided to minimize exposures to the operating personnel and public within the prescribed limits. This section describes the layout of the facility and the details of different materials used in shielding the neutron generator. Some analytical calculations were also performed to theoretically estimate the exposure rates due to the neutron source.

Fig. 2 shows the layout of the second floor of the Fulton building on the Missouri S&T campus where the DD-109 generator is currently installed. The generator is located in room 217A on this