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Development of mobile electron beam plant for environmental applications

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HIGHLIGHTS

- A mobile electron beam irradiation system mounted on a trailer has developed.
- It is designed for treatment of wastewater and flue gas on site.
- Shielding of 0.7 MeV, 30 mA accelerator has done by a Monte Carlo technique.
- It can treat up to 500 m^3/d of liquid waste at 2 kGy or 10,000 N m^3/h of gas at 15 kGy.

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ABSTRACT

Due to the necessity of pilot scale test facility for continuous treatment of wastewater and gases on site, a mobile electron beam irradiation system mounted on a trailer has developed. This mobile electron beam irradiation system is designed for the individual field application with self-shielded structure of steel plate and lead block which will satisfy the required safety figures of International Commission on Radiological Protection (ICRP). Shielding of a mobile electron accelerator of 0.7 MeV, 30 mA has been designed and examined by Monte Carlo technique. Based on a 3-D model of electron accelerator shielding which is designed with steel and lead shield, radiation leakage was examined using the Monte Carlo N-Particle Transport (MCNP) Code. Simulations with two different versions (version 4c2 and version 5) of MCNP code showed agreements within statistical uncertainties, and the highest leakage expected is 5.5061×10^{-01} (1 ± 0.0454) μSv/h, which is far below the tolerable radiation dose limit for occupational workers. This unit could treat up to 500 m^3 of liquid waste per day at 2 kGy or 10,000 N m^3 of gases per hour at 15 kGy.

1. Introduction

Radiation technologists have been investigating the use of high-energy radiation for treatment of pollutants such as wastewaters, flue gas, and sewage sludge. The major advantage of radiation technology is that the reactive species are generated in-situ during the radiolysis process without addition of any chemicals (Buxton et al., 1988). The results of practical applications have confirmed that radiation technology can be easily and effectively utilized for treating large quantities of pollutants (Pikaev, 1986; Woodsa and Pikaev, 1994; Han et al., 2002 and 2005). Even there are many advantages for environmental pollution control, very few commercial scale plants using ionizing radiation has been reported (Chmielewski et al., 2004; Gautam et al., 2005; Han et al., 2005). This is due to the difficulties in construction of pilot plant, either by cost and time, to bring the laboratory result to commercial implementation. Therefore, the needs for economic ways applying pilot scale tests are getting more and more concerns in the field.

A low energy electron accelerator in container was used for flue gas treatment in Forschungszentrum Karlsruhe, Germany (Fuch et al., 1988). Electron accelerator with the energy and power of 0.2 MeV, 150 mA was installed in the shielded container for this experiments. A larger mobile equipment to treat the wastewater was developed for wastewater treatment (Cooper et al., 1998). This system mounted on trailer consisting of pump room, process room, and control room. In the process room, a transformer type accelerator of 0.5 MeV, 20 kW is installed. This system was designed to treat up 200 m^3/d of water/slurry, however, due to the penetration limit of electron beam, it was difficult to treat larger

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amount of wastewater with uniform doses.

Due to the necessity of pilot scale test facility for continuous treatment of a certain amount of wastewater and gases on the spot, a mobile electron beam irradiation system with sufficient beam energy and power was required.

2. Design and assembling of mobile electron accelerator

A mobile electron beam irradiation system has been designed for the individual field application with self-shielded structure of steel plate and lead block which will satisfy the required safety figures of ICRP (ICRP, 2003). Design parameters are limited by the allowable total weight and height of the trailer on the road which controlled by national authorities. Therefore, the output parameter of electron beam is designed for 0.7 MeV and 20 kW with beam extraction window of 600 mm. This mobile unit can be used for on-site test of liquid waste and gaseous waste. This unit could treat up to 500 m^3 of liquid waste per day or 10,000 N m^3 of gases per hour.

Shielding of a mobile electron accelerator has been designed and examined by Monte Carlo technique. Based on a 3-D model of electron accelerator shielding which is designed with steel and lead shield, radiation leakage was examined using the MCNP code. Monte Carlo N-Particle Transport Code (MCNP) is a software package for simulating nuclear processes. It is developed by Los Alamos National Laboratory since 1957 with several further major improvements (Cashwell and Everett, 1959). It is used primarily for the simulation of nuclear processes, such as fission, but has the capability to simulate particle interactions involving neutrons, photons, and electrons. Specific areas of application include, but are not limited to, radiation protection and dosimetry, radiation shielding, radiography, medical physics, etc.

2.1. Material and thickness for primary barrier

The primary barrier mainly consists of steel structure and lead block to shield the X-rays generated inside the process room, when electrons interact with the materials, and the accelerating section. The section view of primary barrier is shown in Fig. 1. The materials and dimensions used are as follows;

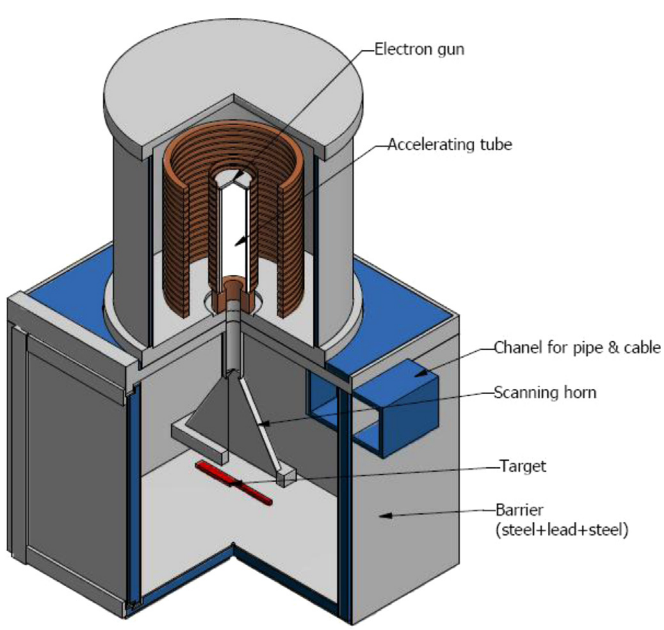

Fig. 1. Section view of electron accelerator and primary barrier.

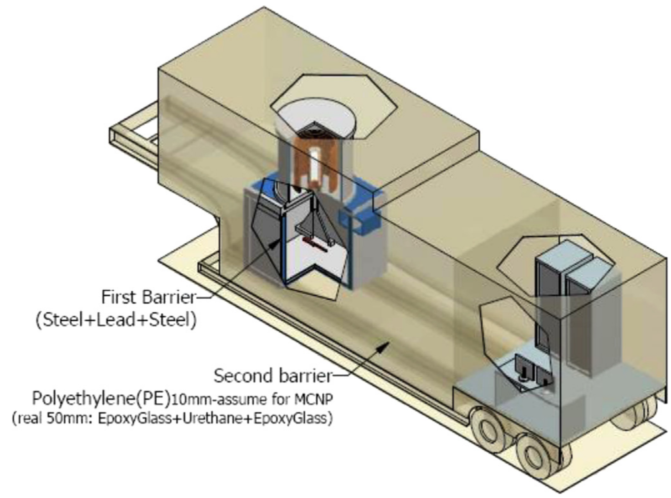

Fig. 2. Layout of primary and secondary barriers.

– wall: steel + lead + steel
– bottom: steel + lead + steel
– top: steel
– vessel: steel + lead + steel

2.2. Material and thickness for secondary barrier

The secondary barrier is the shelter which locates outside of the primary barrier, and is consist of epoxy glass and urethane. The layout of primary and secondary barriers is shown in Fig. 2 and the materials and dimensions used are as follows;

1. epoxy glass + urethane + epoxy Glass

2.3. Statement of operating assumptions

Statement of operating assumptions on which barrier calculations were based on workload and other factors. It is assumed that the workload of mobile electron beam system as 2000 h/y with the full load of beam power, and the calculations were based on such work load, utilization factor, and occupancy factors as follows;

– operating condition of electron accelerator
+ accelerating energy: max. 0.7 MeV
+ beam current: max. 30 mA
– workload
+ 2000 h per year (@ 8 h/day*5 days/week * 50 weeks/year)
– utilization factors (or beam direction factor)
+ for floor, wall and ceiling (1st radiations and 2nd radiations)
– occupancy factors
+ for all adjacent trailer vehicle(controlled area)
+ 1/16 for the public (uncontrolled area)

2.4. Calculation of radiation leakage

The radiation leakage through primary and secondary barriers is simulated by two different versions (version 4c2 and version 5) of MCNP code. The primary and secondary barriers including the trailer have been modeled to prepare input parameters for MCNP simulation. The assumptions of operating condition are as follows;

- electron source: 0.7 MeV, 30 mA, mono-directional
- target material: stainless steel
width: 52 cm, depth: 5 cm, height: 1 cm, z: 46.1 cm
- Other components including accelerator assembly, scan hood,