Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 23-24, 2019

A multi-radiation Generator system based on a 15 MeV Electron Linear Accelerator

Byeongno Lee[a*], Kyungmin Oh[a], Jinsik Ju[a], Yeongheum Yeon[a] , Moonsik Chae[a], Jungho Moon[a], Jaehyun Lee[a], namho Lee[a], Seehee Kim[a]
Radiation Equipment Research Division, Korea Atomic Energy Research Institute29, Geumgu-gil, Jeongup-si, Jeollabuk-do, Korea, 56212
[*]*Corresponding author: bnlee@kaeri.re.kr*

1. Introduction

Most radiation generating equipment have been developed for the purpose of generating one radiation in one device. In particular, it has been difficult to generate various types of radiation due to various constraints in industrial and medical purpose radiation generating devices, except large research facilities utilizing energy of several tens MeV or more. Recently, however, radiation has been utilized in various fields such as defense, medical, and basic science, and the field of radiation is becoming wider, so that the efficiency of the radiation generating apparatus becomes increasingly important [1].

In this study, we have constructed a system capable of generating three kinds of radiation in one device. The device, designed to produce neutrons, X-rays and electron beams through a single generator, was developed on the basis of a 15 MeV electron accelerator which is manufactured by KAERI. In order to control the generation of each radiation as desired by the operator, a rotating target synchronized with the RF system was installed in the beam exit of the electron accelerator. The design specification for this facility, which has just been constructed, is above 30 Gy/min at a distance of 1 m from the target for X-ray dose rate and the targeted neutron generation rate is above 10^{10} n/s. The results of this study will be used mainly in the field of basic science such as physics, chemistry, and biology in the future, and it can be applied to fields such as security search and medical care.

Table I: Specification of Electron LINAC

Items	*parameters*
Beam Energy	15.27 MeV
Beam Power(peak)	1.2 MW
Beam Current(peak)	87 mA
Resonance Frequency	2.856 MHz
Accelerating Gradient	19.8 MV/m
Diode-Gun Gap Voltage	14 kV
Capturing Coeff.	43.6 %
Repetition Rate	210 Hz
Beam Pulse width	4 us
Length of Cavity	1 m

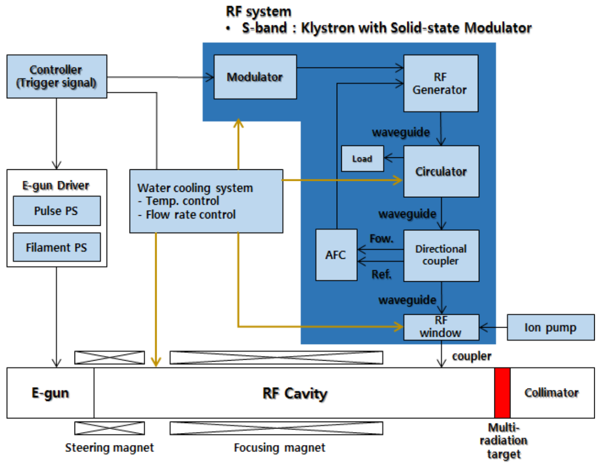

Fig. 1. Configuration and structure of 15 MeV RF LINAC

2. Design Feature

This section describes the design of a device capable of generating multiple radiation. The device is based on an S-band 15 MeV electron accelerator and consists of a rotating target for multiple radiation generation and an RF system for stable acceleration energy supply.

2.1 15 MeV Electron LINAC

The specifications of the designed 15 MeV electron accelerator are shown in Table 1. As shown in Fig. 1, the electron LINAC consists of a triode E-gun, a side-coupled accelerating tube with a resonant frequency of 2.856 MHz, and an S-band klystron as an RF generator. The specifications of the RF system are shown in Table 2. With a pulse width of up to 18 μs and a repetition rate of up to 660 Hz, the device delivers RF output to the accelerator through an average output of 60 kW Klystron.

Table 2: Specification of RF system

Items	*parameters*
RF generator	Klystron
Radio-frequency	2.856 MHz
RF Average Power	60 kW
RF Peak Power	5 MW
Max. Pulse width	18 μs
RF pulse Rep. Rate	1 – 660 Hz
Modulator Avg/Peak power	164 kW / 13 MW
Pulse Flatness(zero to peak)	±1.5%

2.2 A target for Multi-radiation

As the energy of the electron beam exceeds 10 MeV, a significant flux of neutrons is generated and neutrons of various distributions can be generated according to the type and thickness of the target material [2]. In this study, we aimed to design an optimized target that simultaneously generates electrons, x-rays and neutrons using a single device based on high power electron LINAC. We compare the neutron generation rates of the tungsten and lead thicknesses, which are promising as neutron targets, through the MCNP code, and the results are shown in Table 3.

Table 3: Target Specification for Multi-radiation

Items	*Parameters*
Material	Tungsten
Thickness	2mm in X-ray
	30mm in Neutron
X-ray dose-rate	>30 Gy/min at 1m
Neutron Generation rate	>10^{10} n/s at spot

By using a rotating target to design multiple targets to collide with electron beams while alternating materials, it is possible to highlight each radiation generation more effectively than the existing designs [3]. The outline of the target system designed through this study is shown in Fig.2. Consisting of a vacuum chamber, a magnetic motor and a jig for the target installation, the device is designed to accommodate a total of three target materials and can be rotated at a maximum speed of 6000 rpm by using AC servo motor. In addition, a photo sensor was added to identify the real-time position of each target substance, and the type of radiation to be generated was selected.

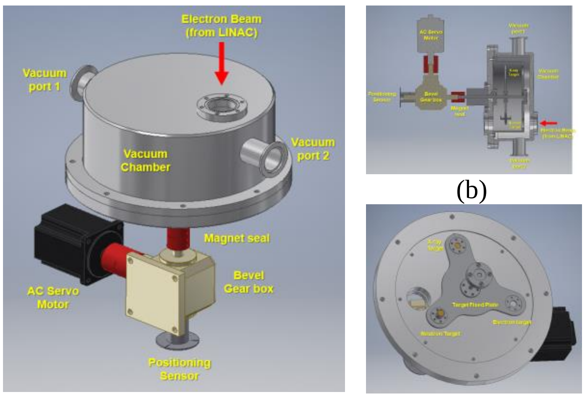

Fig. 2. A rotating target system designed for multiple radiation generation; (a) overall appearance, (b) cross section, (c) rotation part of targets

2.3 Construction of demonstration facility for Multi-radiation generation system

Fig. 3. A demonstration facility for generating multiple radiation.

Using the electron accelerator, RF system, and rotating target introduced in the previous sections, we constructed a system for generating multiple radiation in the shielding room possessed by the Advanced Radiation Technology Institute of KAERI. Fig. 3 shows an established demonstration facility for generating multiple radiation, which is located in a shielding room surrounded by a concrete wall with a thickness of 2 m or more. Because of the use of high energy radiation above 15 MeV, the inside of the shielding room can not be accessed while the equipment is in operation and it is controlled in a control room in a separate space.

The RF modulator is located outside the shielded room to prevent the malfunction of the electronics due to the high dose of radiation. The RF power is supplied from the modulator to the accelerating tube by connecting the WR-284 standard waveguide about 25 m.

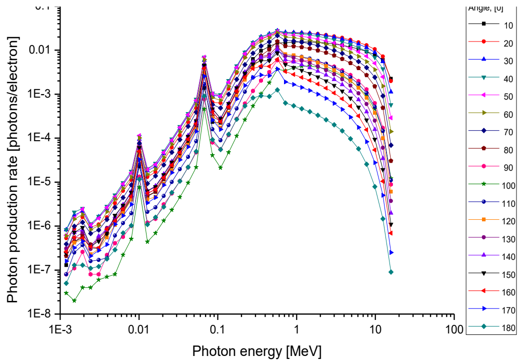

Fig. 4. The energy spectrum of the photons generated per electron by the 15 MeV electron accelerator with 2mm W target

2.4 Multi-radiation Analyzing based on MCNP

Based on the material and thickness information of the selected target, MCNP analysis for generating multiple radiations was performed. Fig. 4 shows the energy spectrum of photons generated per electron by the 15

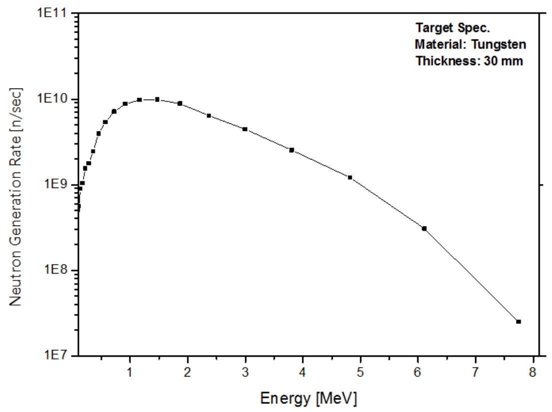

Fig. 5. The energy spectrum of the neutrons generated per second by the 15 MeV electron accelerator with 30 mm W target

MeV electron accelerator with 2 mm tungsten target, and In Fig. 4, neutron flux is measured at 10-degree intervals in consideration of the characteristics of neutrons emitted in all directions. Fig. 5 shows the energy spectrum of neutrons generated per second with 30 mm sten. Fig. 5 shows the calculation of neutron sum for each energy generated regardless of angle. Based on the results shown in Fig. 4, the formula for calculating the X-ray dose-rate at a distance of 1 m from the source term is shown in Equation 1.

$$J_x = C \cdot \eta \cdot D \cdot I_p \cdot E^n \quad (1)$$

Jx is the dose rate in Gy / min from the target focus, C is the capture coefficient, η is the photon conversion efficiency, Ip is the peak beam current in mA, D is the duty factor, E is the electron beam in MeV energy, and n are electron energy factors. Based on this equation, it can be confirmed that a maximum dose rate of 100 Gy/min 1m away from target spot point occurs when the electron accelerator specification of Table 1 is applied. Fig. 4 also shows that the number of neutrons per second generated at the spot point of the target material exceeds the target 10^{10} n/s[4].

3. Result and Conclusions

Through the 15 MeV high energy electron accelerator and a Multi-radiation target system, three types of radiation, X-rays, electrons and neutron, simultaneously acquiring equipment have been constructed in one equipment. The multi-beam radiation generator designed in this study can generate X-rays of up to 100 Gy/min at a distance of 1 m from the target and also generates 10^{10} n/s of neutrons at the target spot point.

At present, the installation of the single-body multi-radiation generator has been completed and measurement tests for each radiation are expected. We will prepare a measuring device in the first half of 2019 and conduct three-kind radiation measurement experiment. The results obtained from this experiment are expected to be used in the future development of three-dimensional(3D) CT equipment capable of materials-decomposition for industrial use.

ACKNOWLEDGEMENT

This work was supported by Nuclear R&D program through the National Research Foundation of Korea, funded by the Ministry of Science and ICT (NRF-2019M2A2A4A05031483, NRF-2017M2A2A4A01070610) and also supported by Radiation Equipment Fabrication Center in KAERI.

REFERENCES

[1] Gerhart Lowenthal, Peter Airey, Practical Applications of Radioactivity and Nuclear Radiations, Cambridge university press, 2001.
[2] A Wasilewski, S. Wronka, Monte-Carlo simulations of a neutron source generated with electron linear accelerator, NUKLEONIKA, Vol.51(3), p. 169-173, 2006.
[3] Byeongno Lee, et al., Design of Single-body Multi-radiation Generator Based on Electron Accelerator, Transaction of the KNS spring meeing, 2018.
[4] S. Lee, et al., Design of Target for Multi-radiation Generator Based on Monte-Carlo, KAERI/TR-7194, p.29-35, 2018.