Design of a Multi-radiation Target for Electron Linear Accelerator

Byeongno Lee[a*], Kyungmin Oh[a], Jinsik Ju[a], Soomin Lee[a, b]
[a]*Radiation Equipment Research Division, Korea Atomic Energy Research Institute29, Geumgu-gil, Jeongup-si, Jeollabuk-do, Korea, 56212*
[b]*Department of Nuclear Engineering, Hanyang University., 222 Wangsimri-ro, Seongdong-gu, Seoul, Korea, 04763*
[*]*Corresponding author: bnlee@kaeri.re.kr*

1. Introduction

In this study, we proposed a target system which can generate various kinds of radiation by using one electron accelerator. The device is designed to rotate different types of targets using a motor and a vacuum chamber to sequentially generate different types of radiation each time. Further, this apparatus can generate only one type of radiation if the target is stopped at a specific position. There are three types of radiation that we want to generate using this target device: neutrons, X-rays, and electron beams, respectively. The electron beam uses a method of utilizing the electron beam generated from the electron accelerator as it is without installing any material on the rotating target. The X-ray target dose rate is above 30 Gy/min per minute at a distance of 1 m from the target and the target rate of neutrons is above 10^{10} n/s.

2. Design Feature

In this section, we describe the design of a 15 MeV electron accelerator and the design of a target system that generates multiple radiation. The accelerating tube for the 15 MeV electron accelerator was designed by computer simulation using Finite Element Method (FEM), and the multiple radiation generating target was designed using MCNP[1].

2.1 15 MeV Electron LINAC

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
Gun Type	diode
Gun Gap Voltage	14 kV
Capturing Coeff.	43.6 %
Repetition Rate	210 Hz
Beam Pulse width	4 us
Length of Cavity	1 m

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 E-gun, a side-coupled structure accelerating tube with a resonant frequency of 2.856 MHz, and an S-band klystron as an

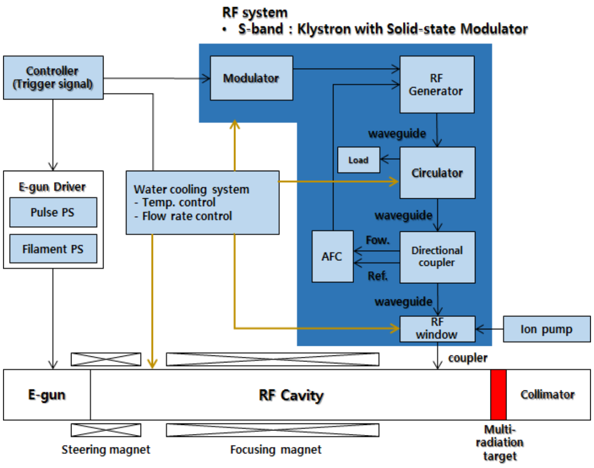

Fig. 1. Configuration and structure of 15 MeV RF LINAC

RF generator. The specifications of the RF system are shown in Table 2. With a pulse width of up to 18 us 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 us
RF pulse Rep. Rate	1 – 660 Hz
Modulator Average power	164 kW
Modulator Peak power	13 MW
Pulse Flatness(zero to peak)	$\pm$1.5%

2.2 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 flux	$>10^{10}$ 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, an photo sensor was added to identify the real-time position of each target substance, and the type of radiation to be generated was selected.

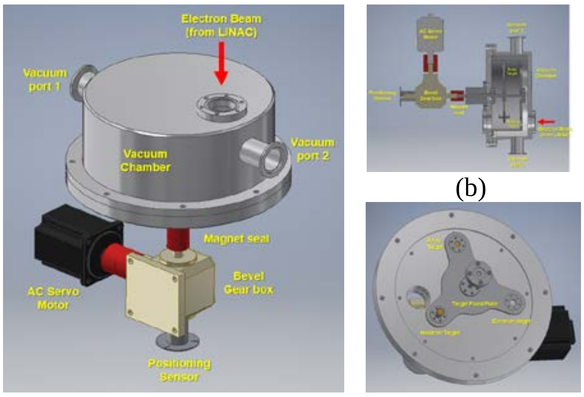

Fig. 2. A rotating target system designed for multiple radiation generation; (a) overall appearance, (b) cross section, (c) rotation part of targets

2.3 Multi-radiation Analyzing

Based on the material and thickness information of the selected target, MCNP analysis for generating multiple radiations was performed. Fig. 3 shows the energy spectrum of photons generated per electron by the 15 MeV electron accelerator with 2 mm tungsten target, and Fig. 4 shows the energy spectrum of neutrons generated per second with 30 mm tungsten. Based on the results shown in Fig. 3, the formula for calculating the X-ray dose-rate at a distance of 1m 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

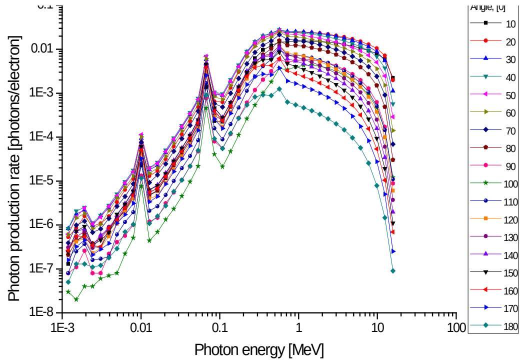

Fig. 3. The energy spectrum of the photons generated per electron by the 15 MeV electron accelerator with 2mm W target

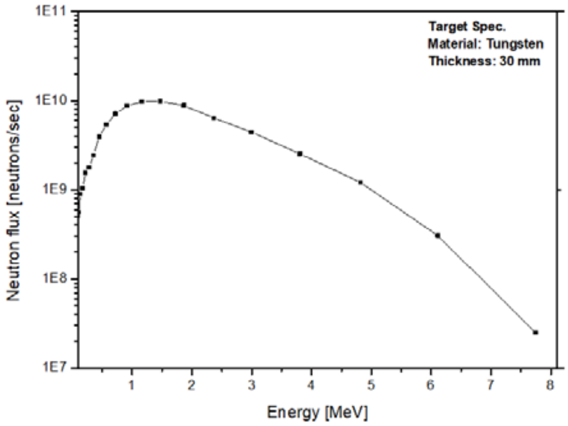

Fig. 4. The energy spectrum of the neutrons generated per second by the 15 MeV electron accelerator with 30 mm W target

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 designed 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.

Currently, 15 MeV accelerators and rotary target systems are in production and will be installed in KAERI Radiology Apparatus Center in November this year.

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REFERENCES

[1] https://mcnp.lanl.gov/
[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.