RADIATION CHARACTERIZATION OF THE UNLV ACCELERATOR FACILITY

Matthew Hodges, Alexander Barzilov, and Yi-Tung Chen
Department of Mechanical Engineering, University of Nevada, Las Vegas
4505 S. Maryland Parkway, Las Vegas, NV 89154
Hodgesm@unlv.nevada.edu, Alexander.Barzilov@unlv.edu, Yitung.Chen@unlv.edu

Daniel Lowe
Accelerator Facility, University of Nevada, Las Vegas
4505 S. Maryland Parkway, Las Vegas, NV 89154
Daniel.Lowe@unlv.edu

ABSTRACT

The particle accelerator facility at the University of Nevada, Las Vegas (UNLV) was commissioned in January of 2015. A Varian M6 linear electron accelerator was installed at the facility to carry out research projects that involve irradiation of samples and imaging of large objects. Before experiments may be performed in the facility, the accelerator's photon yield and its contribution to the resulting radiation doses within the facility must be studied. An investigation was performed to characterize the source terms for the bremsstrahlung converter and the radiation background associated with operation of the accelerator. Both the angular and energy distributions for a photon flux generated by the interaction of a 6-MeV electron beam with converter materials were determined. The resulting photon source was used in conjunction with the M6 collimators to determine the beam profiles and the radiation doses at the facility building.

KEYWORDS
Linac, MCNP5, Bremsstrahlung converter, Dose rate

1. INTRODUCTION

An M6 electron linear accelerator (linac) was installed at the UNLV accelerator facility in January of 2015 [1]. The M6 linac is capable of producing bremsstrahlung photons generated by the interaction of a 6-MeV electron beam impinging on a heavy metal target. This study is concerned with the computational modeling of the bremsstrahlung photon spectra produced by the linac, as well as the resulting biological dose rate equivalents that would be expected in the accelerator facility building.

2. COMPUTATIONAL MODEL OF ACCELERATOR FACILITY

2.1. Accelerator Facility

The building of the UNLV accelerator facility consists of three main areas: the entry room, the shielding maze, and the accelerator bay. Entry to the facility is located in the southwest corner of the building. The large entry room is shielded from radiation generated by the M6 linac by two concrete walls. The linac is positioned about 1.8 meters from the southern wall of the facility. There is a wooden table directly north...
of the linac for various materials to be placed during experiments. The building has 15 centimeter thick concrete walls and floors, with the ceiling being made of 20 centimeter thick concrete. The accelerator facility building is enveloped by earthen berms (greater than 30 meters to the north, and about 4.6 meters to the east). The control room for the accelerator center is located about 4.5 meters south of the southwest corner of the building (it was not included in this study). The M6 linac module inside the accelerator bay is shown in Fig. 1.

The linac generates bremsstrahlung photons through the interaction of electrons with a heavy metal (tungsten alloy) target. Lead shielding within the M6 linac reduces the overall radiation output during operation. There are several layers of shielding both behind and around the target assembly. During normal operation of the linac, the bremsstrahlung photons are shaped into a horizontal fan beam through the use of tungsten collimators. These collimators form the desired fan beam shape by shielding all but a small fraction of the total photon yield. The use of shielding and collimator materials greatly reduces the radiation that is output by the linac during normal operation.

2.2. MCNP5 Model

MCNP5 code [2] was used to determine the flux of the photons produced by the linac for 6 MeV operation. The energy and angular distributions of expected photons were computationally determined. Biological dose rates were investigated for two scenarios. The first scenario was designed to determine the maximum possible dose rates that occur within the accelerator facility. This calculation was performed by simulating the operation of the linac without the use of collimators or the back shielding. The second scenario assumes the linac is operated with collimators but without the back shielding. Dose rates were determined for each scenario.
The geometry for the accelerator facility components in the MCNP5 model was set up according to the specifications described in Fig. 2. Material compositions in the model were used according to the Compendium of Material Composition Data for Radiation Transport Modeling [3]. The M6 linac source definition assumed a normally distributed (both in spatial and energy dimensions) electron beam impinging upon the bremsstrahlung converter target (created according to Varian proprietary drawings). Geometries for the collimator and shielding components were created according to the design dimensions and measurements performed first hand. A total of 50,000,000 particle histories were simulated in each scenario in order to minimize the statistical relative error associated with the Monte Carlo computational results.

3. RESULTS

3.1 Bremsstrahlung Photons

Due to the normalization of MCNP5 results to one starting particle, it is necessary to understand the actual number of starting electrons. Multiplication of the computed normalized results (fluxes or dose rates) by the specific number of starting particles provides the total result for such beam current. For the M6 linac, the DC averaged current was determined to be $3.4 \times 10^{14}$ electrons/sec.

F4 tallies were used to compute the angular and energy distributions of the bremsstrahlung photons at 1 cm behind the accelerator target. Photon fluxes were calculated in 10-degree conical angular increments and 200 equal energy intervals covering the range up to the maximum energy of the starting electrons. The photon spectra for incident 6-MeV electrons are shown in Fig. 3.
The results in Fig. 3 show that the largest photon flux occurs within a conical angle of 10° from the beam axis. For this angle range, and for energies below 3 MeV, this corresponds to a photon flux of more than $3 \times 10^{11}$ photons/cm$^2$. The lowest fluxes occur at angles greater than 80° with values expected between $3 \times 10^8$ and $3 \times 10^{10}$ photons/cm$^2$. The statistical errors associated with the individual energy bins are below that of the MCNP5 established guidelines for acceptability (under 10% for F4 tally predictions) for all photon energies.

### 3.2 Dose Rates within the Accelerator Facility

The computed photon source terms were then utilized to determine the human biological dose rate equivalents within the accelerator facility using the ANSI/ANSI 6.1.1-1977 photon flux-to-radiation dose conversion [4]. Dose rates were calculated within the accelerator building during operation of the M6 linac under two extreme scenarios – (1) without collimators and without shielding (simulating the maximum possible radiation output and dose rates), and (2) operation with collimators but without the rear shielding.

Dose rate calculations were performed for each of the scenarios of linac operation. Footprints of the computed dose rates due to bremsstrahlung photon production were generated at the height of the accelerator target (1.2 m from the ground). F5 tallies were used to determine the individual dose rates throughout the facility. The statistical relative error for all computed dose rates were below the MCNP5 established guidelines for acceptability (under 5% for F5 tally predictions). The accelerator facility maximum dose rate footprint (without any back shielding or collimator pieces) due to the M6 operation is shown in Fig. 4.

![Figure 3. Bremsstrahlung Photon Flux for 6-MeV Linac.](image)
The maximum dose rate occurs closest to the linac target and is upwards of $10^7$ rem/hr. The dose rate decreases as the distance from the linac increases. A 1 m north of the accelerator, the dose rate is about 42000 rem/hr while at the experimental table, the dose rate is about 1400 rem/hr. Dose rates in the southern corners of the accelerator bay are about 210 rem/hr, while dose rates in the northern corners are about 580 rem/hr. The dose rate in the center of the concrete maze is about 9 rem/hr, and the dose rate at the center of the entry room is 1.4 rem/hr.

It was shown that the earthen berms (located directly to the north and east of the accelerator facility) keep external dose rates below the Nuclear Regulatory Commission (NRC) limits for the general public (2 mrem/hr) [5]. As these berms provide sufficient shielding during the maximum possible radiation production, they also provide shielding for any other subsequent scenario. A section of the earthen berms (northeast corner of Fig. 4) was removed in the model in order to examine the effectiveness of the facility walls alone, in containing the radiation produced within the building. In the absence of these earthen berms there would exist the radiation leakage out of the facility resulting in a dose rate of about 3 rem/hr. In reality, there are not separate dirt berms as shown in the model, but rather one large earthen berm that completely envelops the northern and eastern areas of the facility. The berms serve as natural shielding and are successful in the minimizing of radiation exposure to the outside environment even under maximum M6 linac bremsstrahlung production.

A second extreme scenario is the operation of the linac with collimators but without back shielding. This calculation was performed to study the shielding effects provided by the collimators. The computational results for operation of the linac under this configuration are shown in Fig. 5.
It was shown that the collimators shape the emitted radiation into a fan beam and reduce the radiation in the northern corners of the accelerator bay. Beam dose rates range from about 40600 rem/hr, at 1 m north of the target, to 1150 rem/hr at the sample table. The dose rates in the northern corners of the accelerator bay are reduced to about 8 rem/hr while the dose rates in the southern corners as well as the shielding maze remain constant with those in scenario 1. The dose rate in the center of the entry room is reduced to about 0.4 rem/hr.

4. CONCLUSIONS

The MCNP5 code was utilized to compute the bremsstrahlung photon flux produced by the M6 linac at the UNLV accelerator facility. This photon source was used to determine the dose rates within the building for two extreme operating conditions. The maximum possible radiation dose rate within the facility was modeled for the operation of the linac without collimator or shielding components. The presence of the collimator greatly reduces the radiation dose within the facility. It was determined that the concrete maze walls reduce the radiation dose in facility entryway. The earthen berm successfully minimizes radiation exposure outside the building and ensures that doses are below NRC limits for the general public (2 mrem/hr). Future studies will involve modeling radiation flux and dose rates within the accelerator facility under operation at various energy levels as well as comparison of computational and experimental data.

REFERENCES