Sensitivity Study of Accelerator Placement in a Shielded Radiation Therapy Vault for a Preclinical FLASH Radiotherapy System

Andrew Rosenstrom[1,2], Mario Santana Leitner[2], Sayed Rokni[2], Shaheen Dewji[1], Billy W. Loo Jr.[3]

1) Nuclear & Radiological Engineering & Medical Physics Programs Georgia Institute of Technology, North Ave NW, Atlanta, GA 30332

2) Radiation Protection Department, SLAC, MS 48, 2575 Sand Hill Road, Menlo Park, CA 94025

3) Department of Radiation Oncology and Stanford Cancer Institute, Stanford University School of11Medicine, 875 Blake Wilbur Drive, Stanford CA 94305

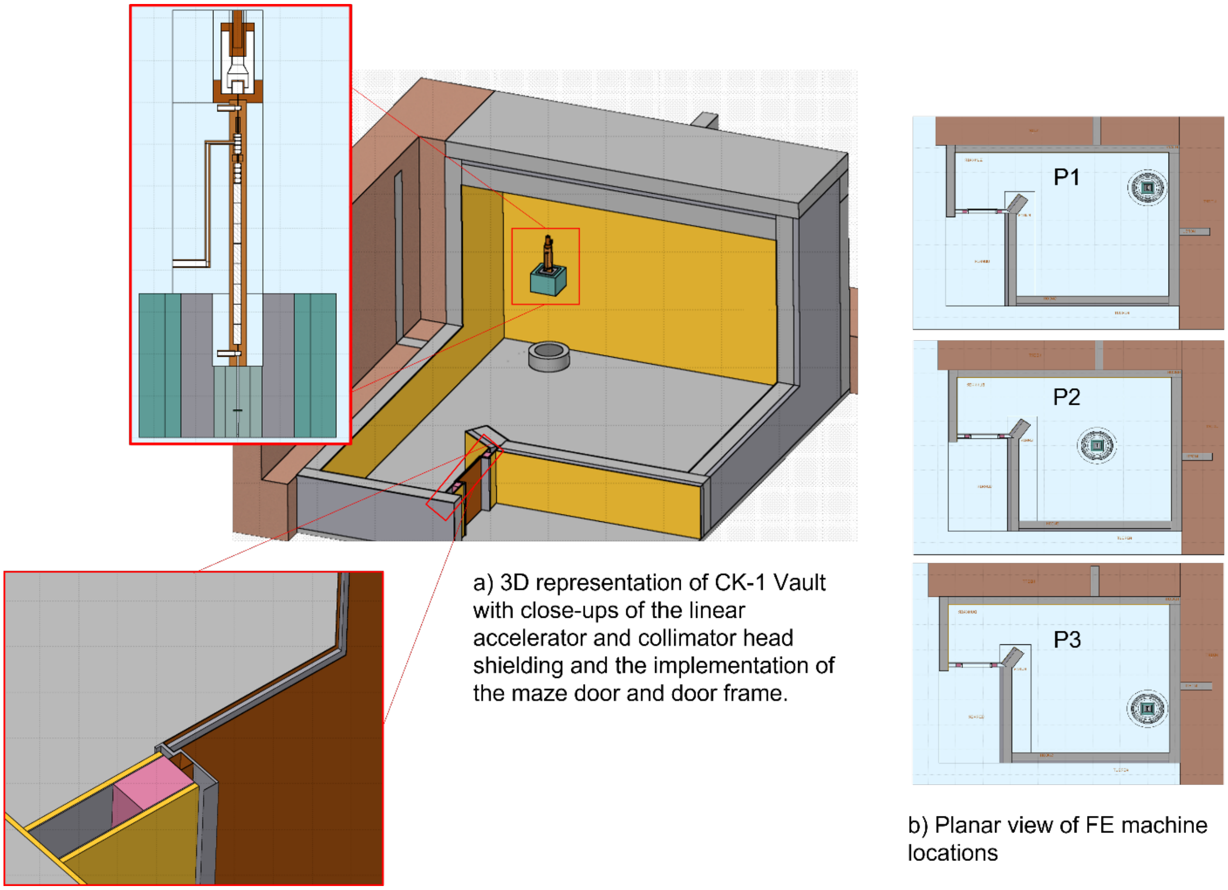
Purpose: A new external beam radiotherapy modality attempts to take advantage of the so-called "FLASH effect" [1]. The FLASH effect has been observed at high dose rates, greater than 35Gy/s [1] and consists of an increased therapeutic index for radiotherapy treatments. Conventional dose rates are typically two to three orders of magnitude lower. The FLASH effect is an important innovation in radiotherapy because it represents a new biological mechanism that can increase the therapeutic index as opposed to more precise operation of radiotherapy systems. The biological mechanism(s) underlying the FLASH effect are at this time undetermined~\cite{review}; however, the effect has been seen using ionizing radiation typically associated with external beam radiotherapy, i.e., ions, electrons, and photons [1, 2].

My work focuses on the design and optimization of the radiation safety systems of the FLASH-EXACT (FE) device, which is a preclinical accelerator system being developed to study the FLASH effect with clinically relevant photon beam energies and dose distributions. Expanding on the energy range used by Gao et al. [2] the FE device will be used with photons >10MeV at a high average power of 12.76 kW.

The design and optimization of the preclinical system using MeV photons pose several radiation protection challenges. Photons above 10 MeV exceed the neutron separation energy for high-Z materials; therefore, the assessment and shielding of neutrons are required to protect the patient, operators, and the public. Given the high power and desired workload of 6800 Gy/w for the experimental system, a significant number of neutrons will be produced. To increase access to FLASH-capable systems, shielding is optimized so that the FE device can be safely housed inside a radiation vault.

One aspect of the optimization of radiation protection system is the placement of the device inside of the radiation vault. The device can be placed to take advantage of existing shielding and therefore lessen the shielding located in the collimator head. As the device will be housed inside a shielded radiation therapy vault (called CK-1) located at the Stanford Cancer Center, the optimization of machine placement was performed for this radiation vault geometry.

Methods: The Monte Carlo code FLUKA is a versatile tool for radiation transport simulation [3]. Using FLUKA the CK-1 Vault geometry was implemented based on the vault schematics; a representation is shown in Figure 1. In order to assess the difference between locations in the vault. The effective dose as well as the effective dose from photons and neutrons was scored using the ICRP74 effective dose coefficients. Two electron beam energies used to create bremsstrahlung radiation for sample irradiation were selected for study as they represent the minimum and maximum energies that could be used, 10 MeV and 12.5 MeV respectively. The results were normalized such that for each beam energy the total workload at the isocenter was 6800 Gy/w; this accounts for changes to the dose rate at the isocenter which is affected by the beam current and bremsstrahlung production. Three locations were selected for testing as shown in Figure 1 based on the potential locations for which the waveguide could be routed. Three implementations of the vault door were considered: the design from the schematics, and with addition of 5 cm of regular polyethylene or 5 wt% borated polyethylene.



a) 3D representation of CK-1 Vault with close-ups of the linear accelerator and collimator head shielding and the implementation of the maze door and door frame.

b) Planar view of FE machine locations

Figure 1: The implementation of the CK-1 Vault in FLUKA as well as the three positions under consideration.

Results: One of the primary areas of interest is the control room located outside of the maze door. This area will be always occupied during operation. As shown in Table 1, there was statistically significant variation in the effective dose rate outside of the maze door, where the operators are located with the best location being position 3.

Table 1: The effective dose rate in mSv/w outside the maze door in the operational control room. Simulations were conducted until uncertainty was less than 1%.

Energy [MeV]	P1 (Upper Right)			P2 (Center)			P3(Lower Right)		
	Bare	Poly	5 wt% Bpoly	Bare	Poly	5 wt% Bpoly	Bare	Poly	5 wt% Bpoly
10	0.013	0.005	0.0018	0.013	0.0023	0.0015	0.009	0.003	0.0012
10 (neutrons only)	0.008	0.003	0.0006	0.006	0.0007	0.0005	0.0037	0.0025	0.0005
12.5	0.07	0.035	0.0045	0.07	0.01	0.0065	0.045	0.007	0.0045
12.5 (neutrons only)	0.058	0.025	0.003	0.055	0.005	0.0025	0.035	0.003	0.002

Conclusion: A preclinical FLASH radiotherapy system is being developed in order to study the FLASH effect with clinically relevant photon energies and dose distributions. It is planned to be housed inside the

CK-1 vault on the Stanford Campus. As a part of the radiation protection system optimization the placement of the device inside the CK-1 vault was optimized to reduce the collimator head shielding. It was found that position 3 was the best location for the machine placement based on the effective dose rate from photons and neutrons in the control room.

Relevance for CIRMS: This work is a part of the dissertation focusing on the design and optimization of accelerator based preclinical FLASH radiotherapy system that will advance the understanding of an important biological mechanism that increases the therapeutic index in cancer treatments. This work relates to CIRMS because it combines novel medical applications of radiation with the development of radiation protection systems such that the dose received by personnel is as low as reasonably achievable. The first author plans to continue working with the radiation physics group at SLAC National Accelerator Laboratory after the completion of the dissertation.

References:

[1] Esplen, Nolan, et. Al., "Physics and biology of ultrahigh dose-rate (FLASH) radiotherapy: a topical review", Physics in Medicine \& Biology 65, 23 (2020), pp. 23TR03.

[2] Gao F, et. al. First demonstration of the FLASH effect with ultrahigh dose rate high-energy X-rays. Radiother Oncol. 2021 Nov 11;166:44-50. doi: 10.1016/j.radonc.2021.11.004.

[3] Ferrari, Alfredo et. Al., "FLUKA: A multi-particle transport code (Program version 2005)", (2005).