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# LOW ENERGY LINAC FOR ELECTRONIC BRACHYTHERAPY*

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*Abstract*

The use of electronic brachytherapy (EB) has grown rapidly over the past decade. It is gaining significant interest from the global medical community as an improved user-friendly technology to reduce the usage of Ir-192. However, the present EB machines all use electron beams at energies of 100 kV or less to generate the X-ray photons, which limits their use to low dose-rate brachytherapy. We focus on the development of a compact and light weight 1 MeV linac to generate and deliver >250 kV X-ray photons to the patient. The device is intended to retrofit to existing brachytherapy applicators. In this paper we will report progress on this project.

## MOTIVATION

The purpose of this effort is to deliver a prototype High Dose Rate (HDR) Electronic Brachytherapy (EB) machine to replace the radioactive sources, e.g. Ir-192, that are commonly used in brachytherapy. Permanent implant brachytherapy generally makes use of radioactive "seeds." These tiny seeds are about the size of a rice grain (~5 mm long) and are implanted using ultrasound or another form of imaging guidance. Take, for example, Ir-192, which has a short half-life of only 74 days. The short half-life means it has a higher specific activity, and it is exclusively used for HDR brachytherapy. On the other hand, the short half-life of a material like Ir-192 means frequent replacement of the sources, and the increased possibility of interception by criminals during shipment and replacement. In contrast, particle accelerators have been successfully employed as a replacement technology for radionuclide radiation sources in many applications. X-ray generators have been broadly used for clinical radiation therapy [1]. However, their design is complicated and too bulky for some space-limited applications like EB. Miniature DC high-voltage X-ray generators can be made to the size of centimeters, and have been evolving over the last decade, with Xoft being the primary example [2]. However, with only 50 kVp bremsstrahlung, they are not a suitable substitute for the main thrust of HDR (high-dose-rate) brachytherapy, which currently uses Ir-192.

Euclid Techlabs proposed a novel design of an electron accelerating structure with two important features that are necessary for use in EB, particularly aiming for the retrofitting of existing EB applicators: a very small transverse size and very high dose delivery stability. In this project, we leverage this with a cost effective 1 MeV metallic brazeless accelerator, which was successfully tested before [3]. The design has been further improved since then. The enabling factor for the proposed approach is that for the case of a minimum weight accelerator, the beam current is a miniscule ~1 µA at the target, which can deliver enough dose (1Gy/min @ 1cm) for EB treatment management plan (TMP). Using Bremsstrahlung radiation, the proposed 1 MeV electron beam will generate broad energy spectrum photons up to 1 MeV with a mean energy of 250~450 keV (depending on the applied target material), compared to the 380 keV narrow spectrum line of Ir-192. This is far more energetic than the current EB source. In order to generate such a powerful radiation dose, in comparison with the state-of-the-art 50 kV DC accelerator-based EB system, this proposed RF accelerator-based EB system has a much larger size. However, one can imagine that the size and weight can easily be managed using modern robotic technology. Figure 1 illustrates this concept. A higher energy electron beam can be focused to a pencil beam to retrofit to the existing applicators.

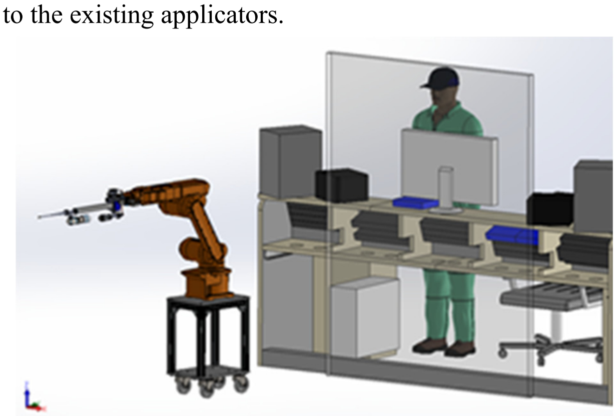

Figure 1: Artist's view of an RF accelerator-based EB system.

## ACCELERATOR DESIGN

To achieve the compactness, the electrons are produced by a field emission cathode, which can generate high quality bunch electrons with proper designed bunching cavities. Figure 2 shows the profile of accelerating field along the axis. The significant high field at the cathode location help improve beam quality of the emitted electrons and prompt acceleration. With optimization, it can achieve nearly 90% of beam transmission passed through the 8-cell accelerating structure without an external focusing

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element. The accelerator delivers a particle's energy spectrum at the 1 to 1.14 MeV range with 250 kW (peak) of RF power. Figure 3 illustrates the relative beam losses over the accelerating structure.

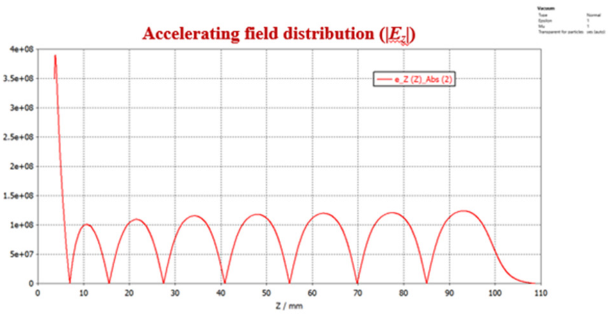



Figure 2: Accelerating field profile for the EB accelerator (CST simulation, normalized to 1J of stored energy) as the beam proceeds from left to right.

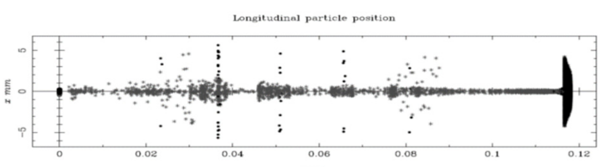



Figure 3: The simulated particle position along the accelerator.

## RADIATION SIMULATIONS

Presently we only consider a straight applicator, the simplest but commonly used EB applicator. The energetic beam will be transported through a ~10cm long medical drift tube (MDT) inside the applicator. The effect of a medical drift tube with a larger outer diameter and wall thickness on the dose was studied for the case of a 2 mm thick gold disk target and 0.3 mm thick stainless steel sealing cap. Figure 4 shows the simulation result using the Brachy module of GEANT4. It can be seen that the MDT effectively attenuates the back-scattered electron energy, removing this high dose region along the MDT. The size and shape of the equi-dose contour lines at ≈1 Gy/s, with beam current of 1.6uA.

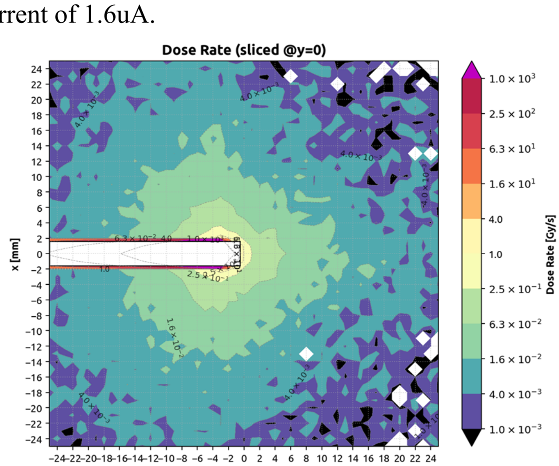



Figure 4: x-z slice of the simulated dose rate around the end of MDT.

Figure 5 shows the percent depth dose curves for the EB machine and Ir-192 as produced by the treatment planning software. The profiles are very similar up to 2 cm from the source.

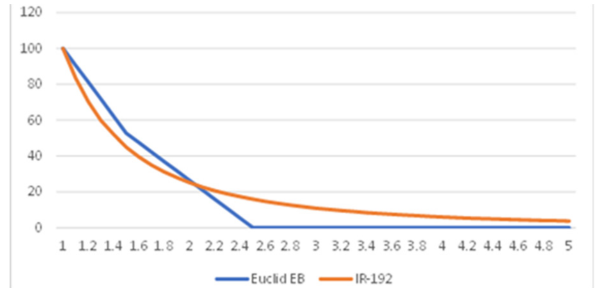
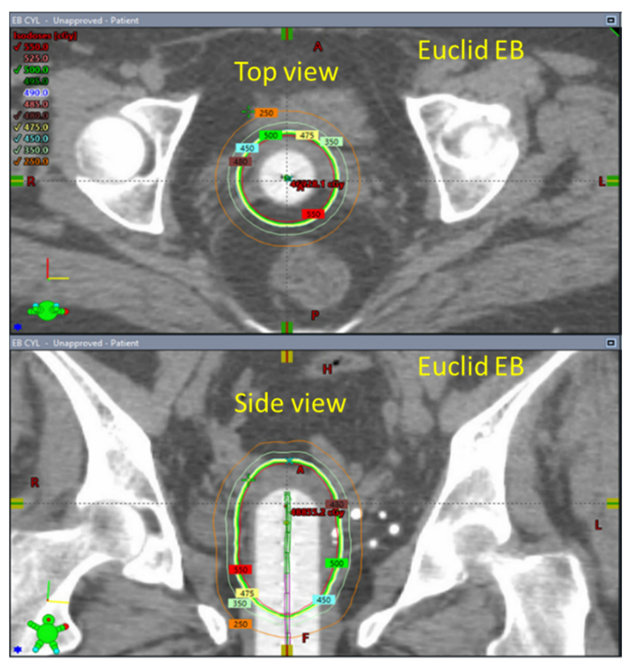



Figure 5: Percentage of total dose versus depth [cm] for Euclid's EB machine (simulation) and Ir-192.

## A MOCKUP MEDICAL TREATMENT

Several mock-up treatment plans have been studied using the simulated radiation production of our developed EB system. As an example, Fig. 6 shows the treatments plans developed for vaginal cancer for the Euclid's EB Machine and Ir-192. Isodose contours are drawn from 250 to 550 cGy, which are used to determine the total dose received by both the tumor and healthy tissue. There is very little difference in the delivered dose between the EB Machine and Ir-192, indicating the EB Machine would be suitable as a direct replacement of Ir-192.




(a)

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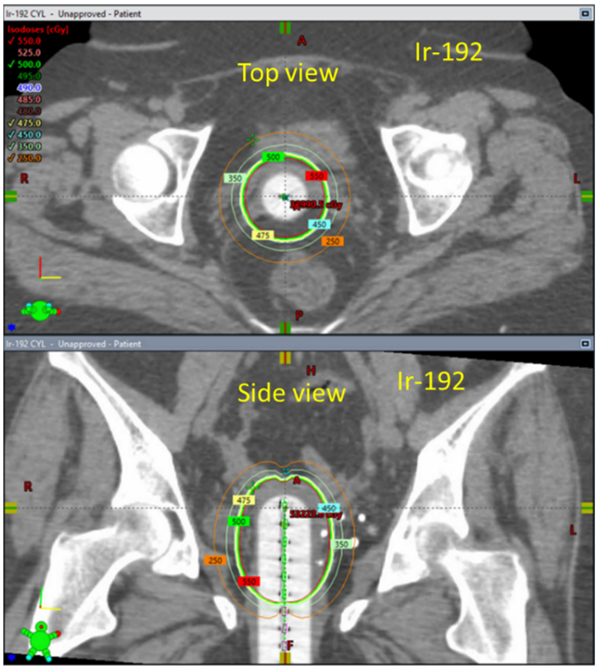


(b)

Figure 6: Mock treatment plans for vaginal cancer developed based on Euclid's EB Machine (a) and Ir-192 (b).

## STATUS

Development of the linac based EB system has been carried out with joint efforts from multiple parties. Most individual subsystems, including linac, MDT with radiation target, robotic maneuverer system, vision system, etc, have been developed. Tests of subsystems are ongoing. The first prototype machine is expected to be integrated by the end of 2022.

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