Japanese Journal of Applied Physics **59**, SHHB06 (2020) **REGULAR PAPER**
https://doi.org/10.35848/1347-4065/ab7c10

Potential use of plasma focus radiation sources in superficial cancer therapy

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Received October 31, 2019; revised February 18, 2020; accepted March 3, 2020; published online April 1, 2020

The new multidisciplinary field of plasma medicine combines plasma physics, electrical engineering, life sciences and clinical medicine. Bekeschus et al. [Plasma Processes Polym. **16**, 1800033 (2019)]. Here we explore potential uses in medicine, most particularly cancer therapy, the plasma source being brought out of the field of industrial applications into the life sciences, the focus being on superficial cancer radiotherapy strategies. Existing radiotherapy practices for such cancers rely on the use of rather large facilities, most popularly the electron linear accelerator and X-ray tube-based devices. Conversely, a compact plasma radiation source can be housed in a relatively small space, there being considerable promise for such devices to produce the fluence requirements of radiotherapy for treatment of skin cancers. The present study of feasibility investigates the plasma focus device, with the emission produced by a single discharge shown to generate an X-ray dose of few tens of mGy. The X-ray dose is the integration of emission in the discharge durations of less than a μs, it is therefore possible using these devices to build up fractional irradiation dose through repetitive operation of the discharge system.

1. Introduction

Radiation oncology together with surgery and chemotherapy, represents the three most prominent approaches in the treatment of cancer, with as an instance nearly two-thirds of cancer patients in the United States receiving radiotherapy. It is also the most effective form of palliation when a cure is no longer possible. In treating cancer, it is important for optimum outcome to effectively provide a near homogenous dose to the target volume while also seeking to mitigate dose to the surrounding normal tissue. Although in most cases the efficacy of radiation is not sensitive to cell type, nevertheless the greatest impact is to cells that are in the process of replication during irradiation as well as those that are more richly oxygenated. In these several respects, radiotherapy needs to be planned carefully with respect to dose in order to ensure optimal efficiency for tumourcidal outcome with minimal side effects.

Dose delivery and its control is multidisciplinary, involving complex radiation sources, engineered movement, location and collimation and dosimetry, involving X- and gamma-rays, charged particles and neutrons. It now represents a sophisticated endeavor that first began with the tentative steps of an American physician who used X-rays in an effort to treat cancer.[1)] Three main groups of X-ray sources have been developed: (i) tube X-ray machines with solid target sources;[2–4)] (ii) linear accelerators (hereafter referred to as the LINAC)[5)] and; (iii) synchrotron radiation sources,[6)] albeit with the latter firmly remaining a research tool.

In radiation medicine the demand for radiation facilities has continued to increase, with as an instance the number of new cancer patients in the United States reaching some 1.6 million in 2014.[7)] Indeed, cancer remains the second most common cause of death in the US, accounting for nearly 1 of every 4 deaths. A report summarizing the X-ray facilities used in medicine showed that in 2008 there were a total of 3300 facilities in developing countries whereas at the time the demand was for 5000 facilities.[8)] An innovative plasma radiation source could lessen the burden of providing for at least some of the cancer treatments through radiotherapy, finding a particular niche in treatment of superficial tumors.[9)]

Both laser-produced plasma sources and discharge-produced plasma sources can be operated to obtain X-ray production. Laser-produced plasma typically requires a high intensity laser beam to focus and heat a solid target and turn the material into plasma,[10)] while discharge-produced plasma uses high voltage to produce plasma via the pinch mechanism. The advantage of pinch type plasma devices such as the plasma focus over the laser-produced plasma is the greater conversion efficiency of input electrical energy into X-ray photo-energy. The efficiency of the plasma radiation source is also greater compared to the tube X-ray machine based on use of a solid target, with a wall-plug efficiency of as high as 25% having been reported in use of the plasma focus to produce X-rays.[11)] This can be compared to conventional electron impact sources with efficiency of only 0.1%.[12)] Furthermore, the plasma focus is a very compact, cost effective and easy to maintain technique. The purpose of investigating the feasibility of the plasma focus device as a potential X-ray source for applications in radiation medicine is based on the following specific characteristics: the X-ray is produced in a pulse which contains simultaneously the soft and hard X-ray component. The hard X-ray component with energy of 0.01–1 MeV has a very fine temporal structure with a typical duration of about 10^{-13} s. Conversely, for the small and medium plasma focus devices, the soft X-ray pulse lasts for 1–10 ns. An X-ray yield of between 0.1 J/shot up to 30 kJ/shot has been reported depending on the energy stored in the capacitor bank.[13)] Moreover, the size of the X-ray source can be down to 3 μm and as such could offer a high spatial resolution.[14)] Due to the pulsed nature of the emission and high power, imaging with lower dose could also be made possible.[14)] Gribkov et al.[13)] has reported that the multiple pulsed radiation emission from the plasma focus has successfully decreased the required dose for the production of radiation effects by four orders of magnitude, leading to important medical applications. In this work, we investigated

