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EuCARD-2

Enhanced European Coordination for Accelerator Research & Development

Press article

Towards societal applications

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Victor Malka, of Le Laboratoire d'Optique Appliquée, discusses the increasing potential of lasers in health, including cancer treatment, proton therapy and tumour imaging

Towards societal applications

Laser plasma accelerators have made significant progress in delivering compact, reliable, high quality and energetic particle beams. Their applications in high-energy physics are extremely challenging and will require several decades of intensive R&D. Near term applications such as X-FEL appear increasingly realistic in the future. Besides these two major goals, near/very near term applications have already been identified.

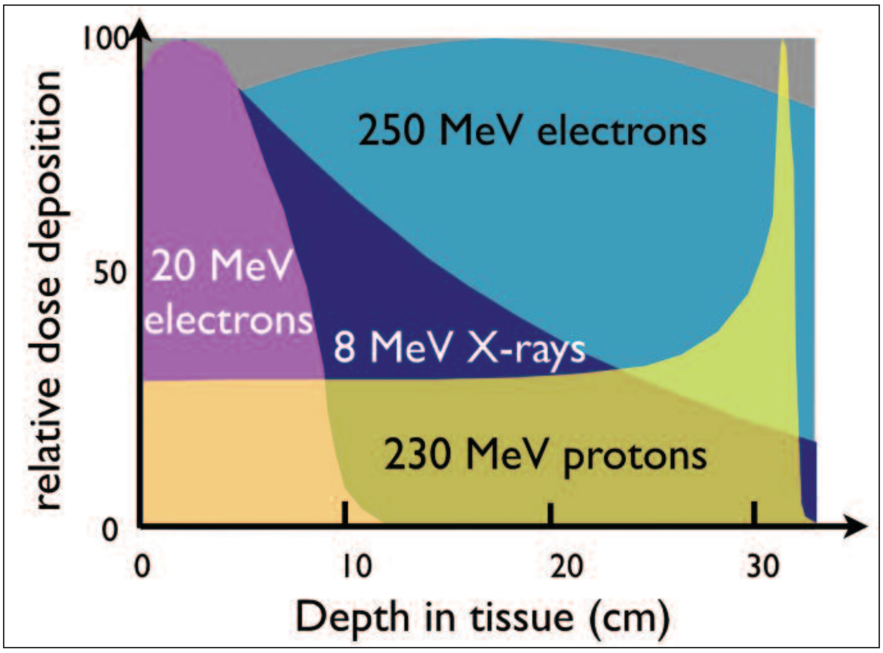
Victor Malka

Medical applications

X-rays in the few MeV energy range represent the majority of ionising radiations used for cancer radiotherapy, which is conducted in many hospitals using flexible, compact and affordable machines. In the future, very high-energy electron (VHEE) beams, such as those produced by laser plasma accelerators, would be of interest for radiotherapy, considering the dose deposition profiles and high dose rate delivery.

Fig. 1 represents the dose deposition for different ionising radiations and particles. The difference between VHE electron beams and few MeV X-rays or electrons indicates that the dose deposited by VHE electrons in the tissue depth is higher and remains efficient after a few tens of centimetres. Reducing the dose deposition before the tumour would limit some deleterious radiation effects on health tissue, while the presence of a significant dose deposition after tens of centimetres could be beneficial to cure deep cancer tumours of obese patients.

Fig. 1 Dose deposition with different ionising radiation and particles



The optimisation of a tuneable electron beam adapted for pulsed radiotherapy, considering specific aspects such as a high dose rate delivery or a short-time control of fractionating protocol, could also contribute to improvement of the treatment.

In Fig. 2, VHE electrons (left) show the same target coverage as photons (centre). Yet the dose sparing of sensitive structures (except for the femurs) is improved, which can be observed more clearly in the difference of the two dose distributions (right).

In the framework of approved treatment planning of prostate cancer with six MV photons, detailed comparisons between an X-ray beam and a 250MeV electron beam have recently been performed. The simulations indicate, as reported in Fig. 2, that the target coverage is better with VHE electrons than with X-ray photons. A difference of the two dose distributions shows this more clearly on the right part of the figure.

Such an irradiation condition contributes to a significant improvement of a clinically approved prostate treatment plan. However, compared to classical dose delivery protocols in conventional radiotherapy (~2Gy per session for a cumulated dose of about 10Gy per week during a period of two to eight weeks), the clinical consequence of very high dose delivery obtained with laser plasma accelerators (~10^{13}Gy s^{-1}) remains to be clearly established and validated.

Some fundamental questions now need to be considered, in particular concerning the adaptive responses of cells and tissues to clustered DNA damages-repairs processes. The quality factors influence short-pulsed electron beams in the MeV domain on the time-dependent relative biological efficiency. This

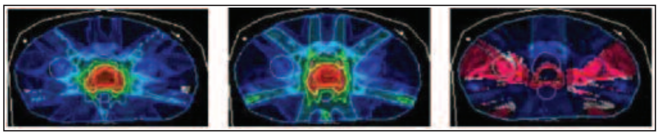


Fig. 2 A typical transversal dose distribution for prostate treatment with seven fields of irradiation

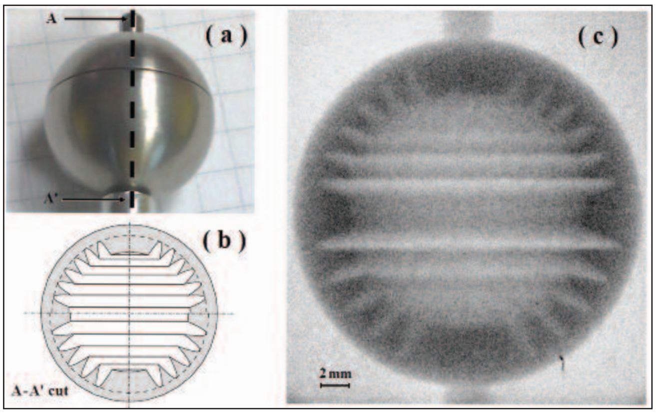
needs to be evaluated in connection with dose fractionating protocols at 10Hz repetition rate to deliver the required cumulated physical dose in a few minutes or less.

Proton therapy

With about 100,000 patients worldwide with successful clinical results, proton and hadron therapies are still emerging. They represent promising methods for the specific treatment of deep tumours and radio-resistant cancers. As seen in Fig. 1, the maximum deposition of proton energy is near the end of its range (resulting in the well-known Bragg peak phenomenon), which can coincide with tumour depth with an appropriate choice of the proton beam energy.

Healthy tissues located before and after the tumour are less affected by the irradiation. This localisation defines the strength and effectiveness of the applied irradiation procedure. However, although this treatment is expanding rapidly (more than 20 new projects are under consideration worldwide), its use is still strongly limited due to the size and cost of the infrastructure, which exceeds €100m. The infrastructure requirements, which include accelerator, beam lines, gigantic gantries of more than 100 tonnes and building, are not accessible to the majority of radiotherapy centres. With the fast development of high-power laser systems, several laser-based projects have emerged with the goal of reducing the cost of proton therapy treatment.

Fig. 3 (a) Photo of the 20mm diameter tungsten object, (b) a schematic A-A' cut and (c) the resulting radiograph with the optimised gamma-ray source



Several severe conditions have to be met before considering such an approach for medical applications. It is necessary to: increase the proton energy up to 200MeV, for which petawatt class lasers will probably be required; have enough protons at this energy to treat patients in sessions of a few minutes, for which high repetition rates (10Hz) could be needed; and have a reliable and stable laser-plasma accelerator. This promising application is very challenging as it requires the development of high-contrast, petawatt lasers operating at about 10Hz, as well as dedicated research activities in target design and high-intensity interaction. The 60MeV protons obtained recently in South Korea with a PW-30fs class laser are a promising result towards this objective.

Tumour imaging

Among the many methods to generate an X-ray beam with laser plasma accelerators, the betatron and the Compton sources appear as very promising tools for advanced X-ray contrast imaging for revealing cancer tumour at a very early stage. The recent demonstration at Le Laboratoire d'Optique Appliquée of an all-optical Compton source indicates the direction towards a compact, quasi-monoenergetic X-ray beam in the few tens of keV for this purpose. Here the advantage of laser plasma accelerators will be to deliver enough X-rays for contrast imaging in the shortest delivering time. Thanks to the very small source size, very high peak brightness and natural spatial coherence, images of very small objects with low absorption such as breast tumours would be revealed with a spatial resolution in the few microns level.

Security

Electron beams produced in laser plasma accelerators can be used to generate more energetic secondary radiation sources. The electron-beam energy is efficiently converted into multi-MeV Bremsstrahlung photons when it interacts with a solid target of high atomic number, providing a submillimetre pulsed γ-ray source that is significantly smaller (50μm) and of shorter duration (in the ps range) than other sources available today. Ultrashort γ-ray sources are interesting for several applications, including imaging material compression to high density.

A train of short laser pulses may enable the possibility to take movies of dense objects under fragmentation or of the damage evolution of structures with a spatial resolution of less than 50μm. Light and flexible devices for non-destructive material inspection would also be interesting, with potential applications in motor engineering, aircraft inspection, nuclear plant inspection and security.

HORIZON **2020**

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