

## CALCULATION OF RADIATION SHIELDING FOR LASER-DRIVEN HADRON BEAMS THERAPEUTIC INSTRUMENT

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### Abstract

The concept of a compact ion particle accelerator has become attractive in view of recent progress in laser-driven hadrons acceleration. The Photo Medical Research Centre (PMRC) of JAEA was established to address the challenge of laser-driven ion accelerator development for hadrons therapeutic. In the development of the instrument, it is necessary to do the bench-mark of the amount of the different types of radiation by the simulation code for shielding. The Monte Carlo Particle and Heavy Ion Transport code (PHITS) was used for bench-mark the dose on laser-shot radiations of short duration. The code predicts reasonably well the observed total dose as measured with a glass dosimeter in the laser-driven radiations.

### INTRODUCTION

The cancer treatment with hadron beams continues as cancer treatment facilities are being developed around the globe with state-of-the-art accelerator technology. The generation of energetic protons and ions from laser-plasma interactions, has made laser-driven hadron radiotherapy a subject of strong interest. Proton bunches with high peak current and ultralow emittance is typical yields from ultrafast laser-foil interactions.

Up to now, simple concepts of laser-driven accelerators for cancer therapy are shown in some laboratories [1, 2]. However, a realistic laser-driven medical treatment system for hadron beam therapy (HBT) has not been designed. Our main mission at PMRC is to develop integrated, laser-driven ion accelerator systems (ILDIAS) that demonstrate desired beam characteristics for such therapy. The laser-driven ion therapy will be advanced by PMRC.

We proposed a conceptual beam line design for a laser-driven HBT system with a gantry using PARMILA [3]. According to this data, the beam reaches the patient only 1.21% of total beam. The broad energy ion beam is controlled with the beam transport system, and the beam that is appropriate for the diseased part is generated. In a word, if the part where ion beam is most lost does not efficiently shield, an extra dose is given to the patient. In addition, more than 40% of the laser energy is converted to relativistic electrons, causing hard-x-ray bremsstrahlung and neutrons. It is also necessary for the ion therapy system to shield these radiations [4]. The shield structure becomes huge if it is not thought about the shield of different types of radiation from the source

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point to the beam transport system. And, it is concerned about the size that doesn't suit the concept of miniaturization therapeutic instrument. To produce a small therapeutic instrument, we should solve the problem from the viewpoint of radiation shielding.

In this paper, the bench-mark of the Monte Carlo Particle and Heavy Ion Transport code (PHITS) is described as a technique for evaluating the radiation dose on actual laser-driven accelerator.

### EXPERIMENT SETUP

The J-KAREN laser system [5] at the Kansai Photon Science Institute (KPSI) of JAEA provided P-polarized laser irradiation at a zero degree incident angle with pulses of central wavelength 800 nm, duration of 45 femtoseconds (FWHM), and energy of  $\sim 1.8$  J at a 1 Hz repetition rate. The laser target (tape target) was a polyimide tape of 12  $\mu\text{m}$  thickness. Peak irradiances up to  $10^{19}$   $\text{W}/\text{cm}^2$  were achieved on target and the intensity contrast ratio was set to  $10^{-10}$  level. For our laser-accelerated ions studies, mostly protons to date, the use of a scintillator-based time-of-flight (TOF) spectrometer to measure energy spectra is used. To reduce electrons event noise in the TOF spectrometer, electrons removes with two dipole-magnets that change the polarity to improve the accuracy of proton spectrum.

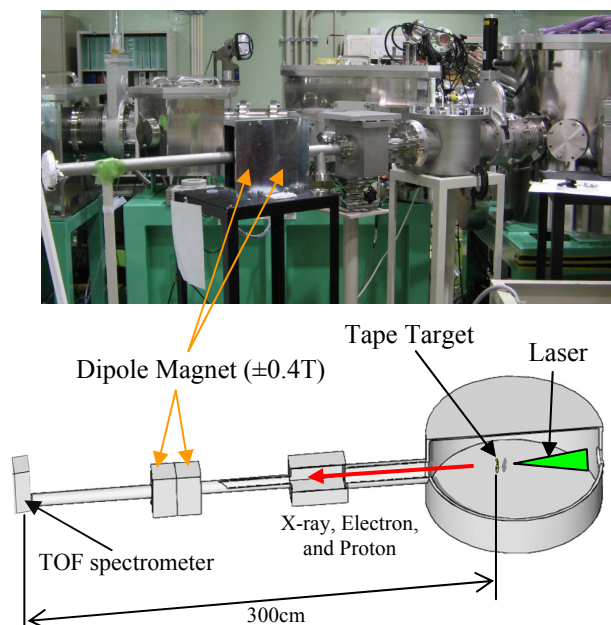


Figure 1: Setup for the diagnostic system of dose. Photograph and the geometry for PHITS initial file.

Figure 1 shows the setup of this experiment. The photograph is an actual vacuum chamber, and 3D-figure is an inputting geometry of the experimental system to PHITS code; this figure is output from PHITS code.

Total dose is measured with the glass dosimeter. Eight dosimeters are set up in outer of the main vacuum chamber and two dosimeters are set up on the proton beam line.

### PHITS CODE

We analyze the different types of radiation dose using the general-purpose Monte Carlo PHITS code [6], which can deal with transport of many hadrons and heavy ions. This is a one of five major codes; MCNPX, GEANT4, FLUKA, MARS, and PHITS, for the particle transport.

With PHITS we can also consider the important effect of interactions with the atomic nucleus. PHITS is based on the high energy hadron transport code, NMTC/JAM. It incorporates the Evaluated Nuclear Data for low energy neutron transports and the JAERI quantum molecular dynamics (JQMD) model for simulating nucleus-nucleus interactions [7]. Because PHITS input includes dipole magnet elements it also considers details of the test beam shown in Fig. 1. However, space charge effects and emittance are not considered in the code.

In this time, total dose in single laser shot is analyzed by improving the PHITS routine that calculates each dose of X-rays, electrons, and protons.

#### Radiation Distribution for PHITS Initial File

Radiation distribution to PHITS input PHITS needs to input the initial distribution of particles at the start point. Therefore, the energy spectrum and angular distribution of each radiation are described in initial file. It is not easy to measure the energy spectrum and angular distribution of proton, electron, and X-rays in a single shot simultaneously. So, we assumed following distributions.

- 1) Proton spectrum:  
If the 1.8J laser shot to tape target, it becomes the spectrum of 7MeV cutoff shown in Fig.2 (a). These data is measured by TOF spectrometer [8]. Angular distribution assumes Gaussian of  $2^\circ$  ( $1\sigma$ ).
- 2) Electron spectrum:  
There is no data of distribution in 1.8J laser shot. Then, we assume the Maxell-distribution of cutoff energy 15MeV; about two times of proton's cutoff energy. Angular distribution of electron is assumed about  $10^9$ /steradian of the spheral-distribution [9].
- 3) X-ray spectrum:  
There is also no data of distribution in 1.8J laser shot. Then, we assume the Maxell distribution of cutoff 0.2MeV ( $\sim$ Hard-X-ray), and the angular distribution of X-ray is assumed same as electron.

Figure 2 (b) shows the energy spectrums which are assumed by 1-3).

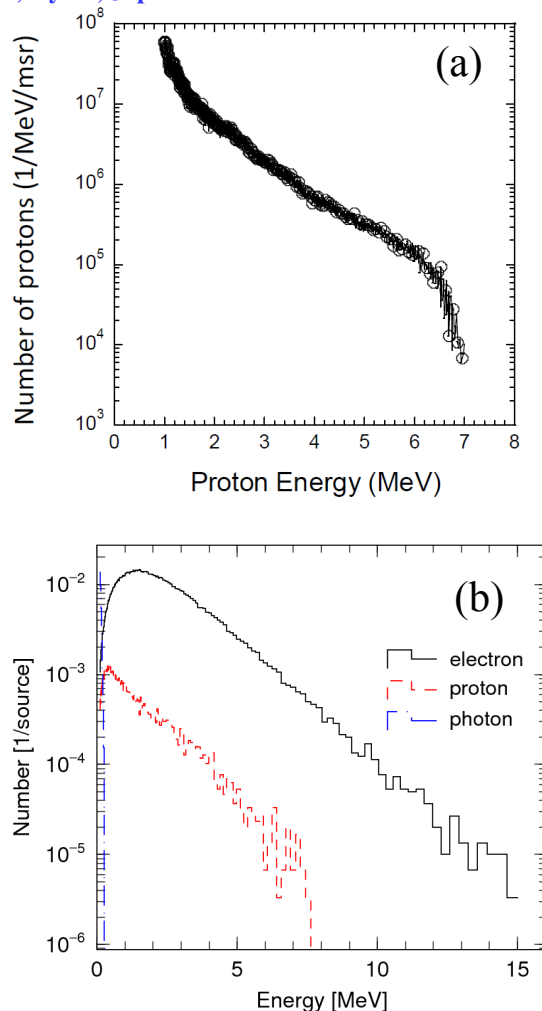


Figure 2: Typically proton spectrum obtained by 1.8J laser injection (a) [8]. Energy spectrums of the each particle for PHITS initial file (b).

#### Calculation Mesh and Number of Initial Particle

The calculation-mesh of PHITS is disposed with 2mm x 8mm in this bench-mark. Total particles, proton, electron, and X-ray, to use for calculation are 1.5 million. In addition, the elemental composition that composes the system is described in PHITS initial file. For instance, the vacuum chamber is composed of Steel, and environment that surrounds the vacuum chamber is Air.

### MEASUREMENT AND PHITS RESULTS

Figure 3 shows the measurement data (a) in the glass dosimeter and PHITS result (b). As for the measurement data, this is average value that 12 shots were integrated. The dose result by PHITS calculation is shown by contour map. A total radiation count is necessary for converting PHITS result into the absolute dose. In consideration of  $10^9$ /steradian with Ref. [10], we assume the total of proton, electron, and X-rays to be  $\sim 10^{11}$ , and are obtaining this value. In 1.8J laser-shot, the dose obtains a few  $\mu$ Sv/shot at the Glass dosimeter.

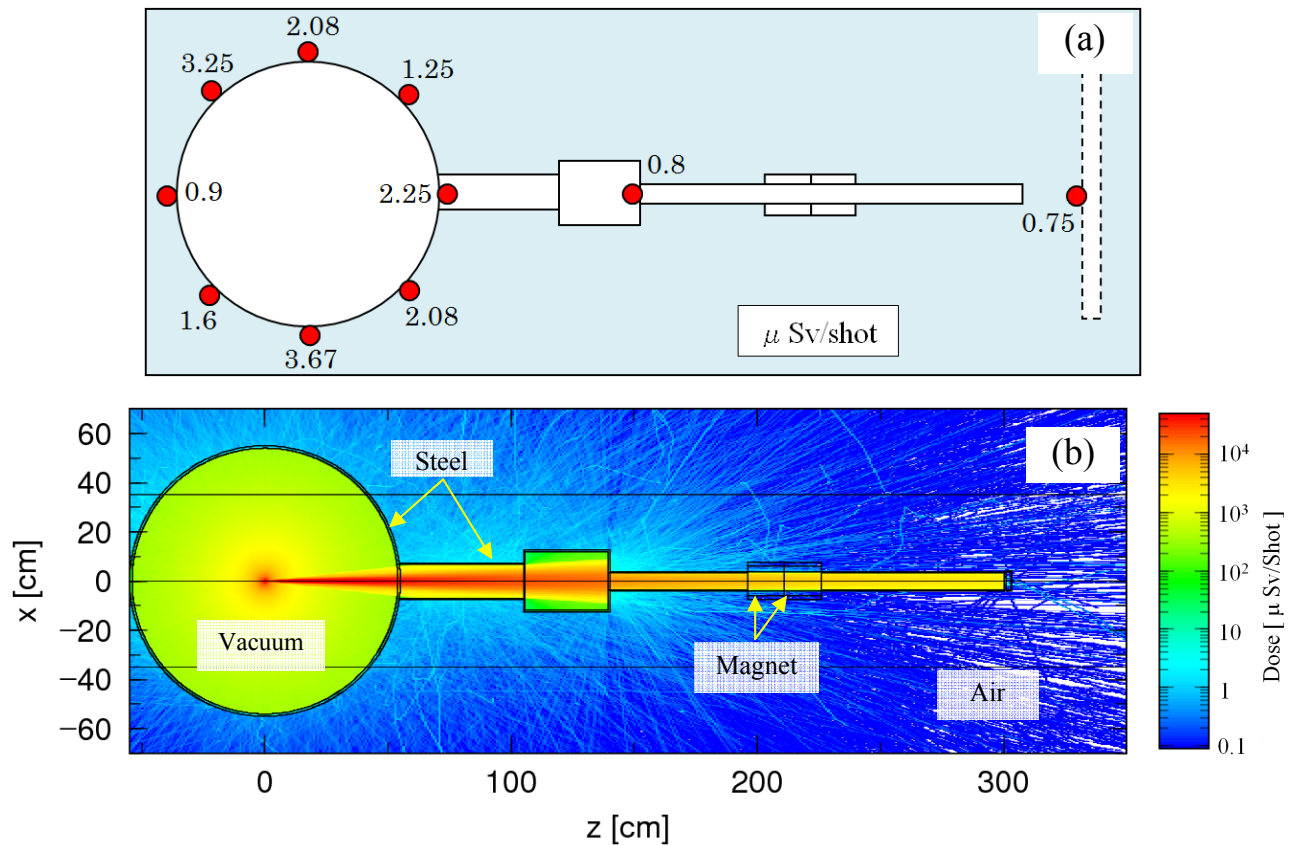


Figure 3: Measurement data (a) in the glass dosimeter and PHITS result (b). PHITS result is shown that the scattered electron beam generates the dose.

Total particle that the laser-driven accelerator generates is unstable. About 20-30% fluctuation of total particle is caused the shot by shot. It is good corresponding if this calculation result is evaluated based on this fluctuation.

## CONCLUSION

We propose a radiation dose evaluation for a laser-driven ion accelerator system using PHITS code. In this work, our simulations can be done bench-mark with lower energy evaluation beam line at  $\sim 7\text{MeV}$ . Moreover, discussing with the laser-driven ion source developer about the characteristics of ion sources, we will design the beam line shielding with characteristics of various source types.

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