In field and Out of Field Dose Profile from Therapeutic Hadron Therapy Beams at HIMAC Facility

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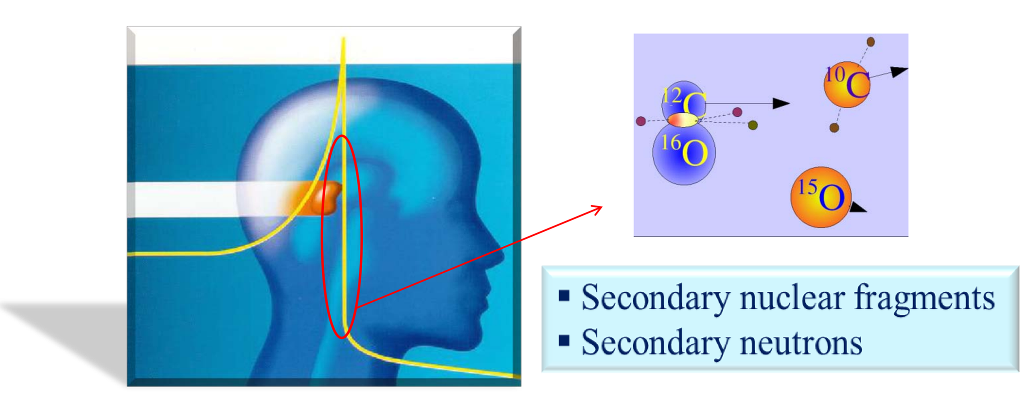
Abstract

- Carbon ion therapy has been successfully applied for cancer treatment in Heavy Ion Medical Accelerator in Chiba, Japan since 1994. The Relative Biological Effectiveness (RBE) of ^{12}C is much higher than lower Z particle beams, such as protons (2.5 for ^{12}C and 1.1 for protons). Therefore it is important to know the RBE distribution additionally to an absorbed dose distribution for ^{12}C radiotherapy, especially when the target volume is located close to a critical organ.
- The microdosimetric RBE based on a tissue equivalent proportional counter (TEPC) is currently used as conventional method for dosimetry. The drawback with this method is that the treatment beam is capable of delivering a dose approximately 1 mm wide while the TEPC can be approximately 1 cm wide. The large size of TEPC is averaging the RBE which dramatically changes close to and at the distal part of the BP.
- Silicon microdosimetry devices are offering sub-millimeter high spatial resolution of RBE derivation based on mirodosimetric spectra measurements along and downstream of the BP. The measured results obtained by the SOI Microdosimeters and the ΔE-E monolithic telescope in-field and out-of-field of a Spread Out Bragg Peak (SOBP) of a passive ^{12}C ion beam at HIMAC are presented. It was demonstrated that the microdosimetric spectra are changing dramatically within 0.5 mm depth increments close to and at the distal part of the SOBP. The response of the ΔE-E monolithic telescope to ^{12}C ion beam aiming for fragments identification was also studied theoretically and experimentally.

Introduction



- RBE determination using silicon microdosimeter and compared to TEPC
- Study of fragments contribution to the field using the ΔE-E telescope theoretically using Geant4 Monte Carlo toolkit and experimentally

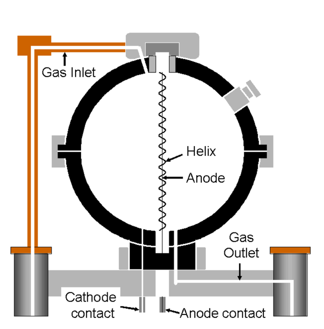


Figure 1. Schematic of TEPC

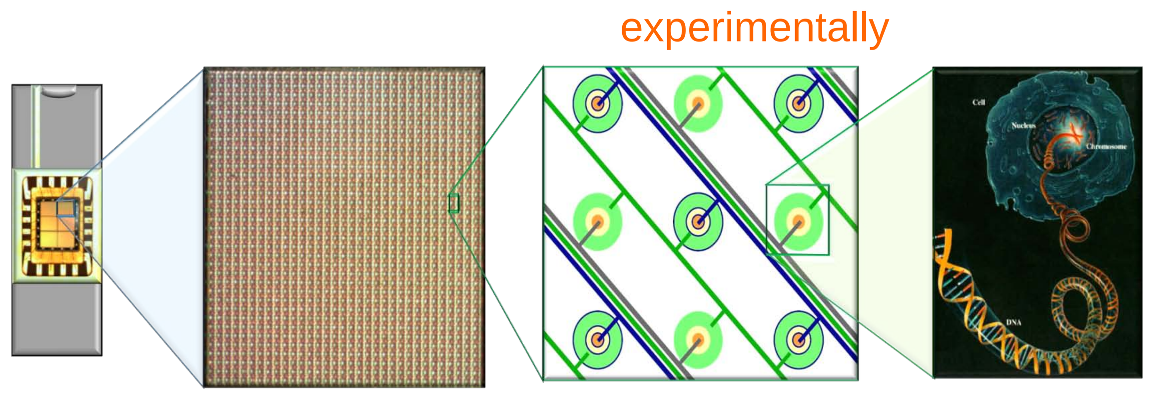


Figure 2. CMRP Silicon microdosimeter

Shortcomings of TEPC:

- High voltage
- Wall effect
- Long preparation time
- Large physical size

The solid state microdosimeter was proposed by the Centre for Medical Radiation Physics (CMRP) at the University of Wollongong as a new method of measuring energy deposition in an array of micron sized SVs [1, 2].

The concept of silicon microdosimetry aims to address the shortcomings of the TEPC. The silicon microdosimeter is based on array of micron sized silicon SVs instead of gas, to mimic an array of biological cells.

Material and Methods

Micro-dosimeter

Fig. 3a Microdosimeter connected to preamplifier and electronics

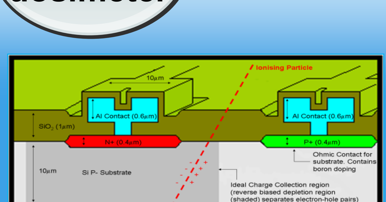


Fig. 3b 2D 30x30 μm² diode array of elongated parallelepiped diode fabricated on 5 and 10 μm thick p-SOI active layers adjacent to each other.

[P. Bradley et al 1998, I. Cornelius et al 2002]

ΔE-E Telescope

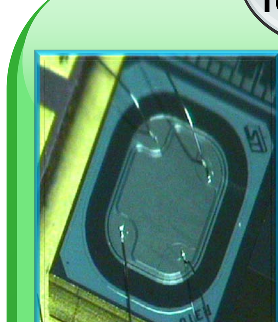


Fig. 4a ΔE-E Telescope
Area: 1x1mm²
Thickness of 2 stages:
ΔE: 1.8μm
E: 500 μm

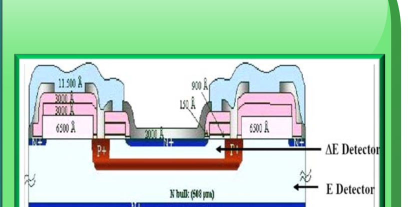


Fig. 4b Schematic cross-section of the ΔE-E Telescope

[S. Agosteo et al, 2005, Politecnico di Milano]

Experimental setup

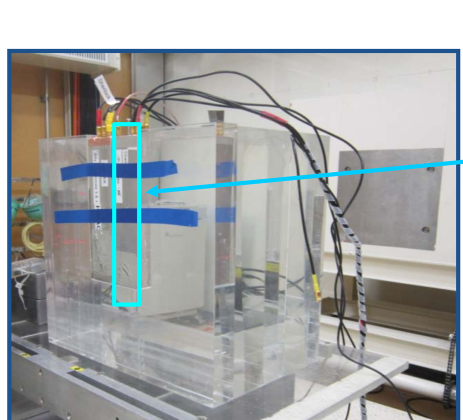
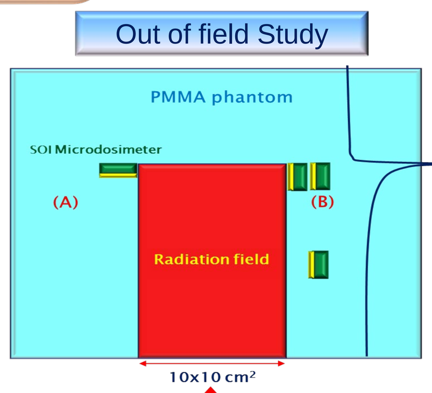


Fig. 5 Microdosimeters are placed in the PMMA phantom in front of the beam

1st-Generation SOI Microdosimeter

- The SOI Microdosimeters and the ΔE-E monolithic telescope were placed in various positions along the central axis of the SOBP therapy beam
- A modular Polymethyl Methacrylate (PMMA) phantom was used to adjust the position of the Bragg peak relative to the devices.

Out of field Study



- Detector was placed at the Brag Peak position (**128.5 mm** depth and **70mm** depth in PMMA phantom)
- Detector was placed at
- **(A) :** detector faced to the beam collimator at 0mm from the edge of the beam
- **(B) :** detector was put along to the beam with lateral distances ***0 mm and 5 mm and 10 mm*** from the edge of the beam
- Radiation field **10x10 cm²**

References:
[1] Rossi and M. Zaider, Microdosimetry and its Applications. London: Springer, 1996.
[2] P. D. Bradley, A. B. Rosenfeld, and M. Zaider, "Solid state microdosimetry," Nucl. Meth. Phys. Res. B, vol. 184, pp. 135–137, 2001.
[3] Andrew Wroe, Reinhard Schulte, Alberto Fazzi, Andrea Pola, Stefano Agosteo, Anatoly Rosenfeld, "Direct RBE estimation of radiation fields using a DE-E telescope," Medical Physics, 2009.

Results and Discussion

SOI Microdosimeter

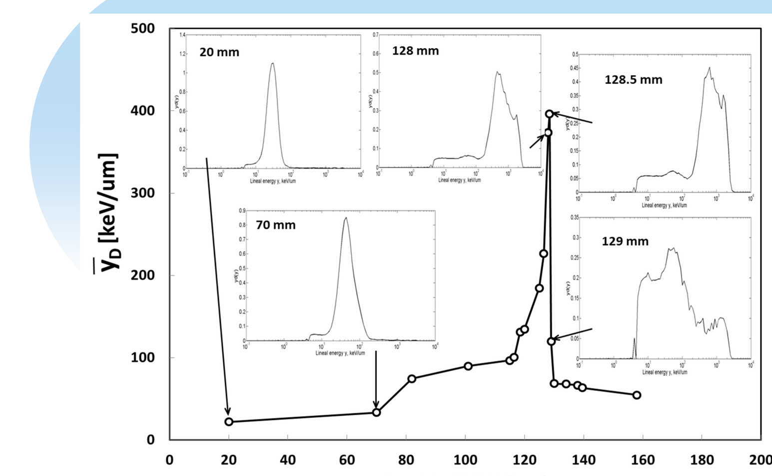


Fig. 6a Microdosimetric spectra obtained by 1st generation of microdosimeter in response to 290 MeV/u SOBP ^{12}C ions at

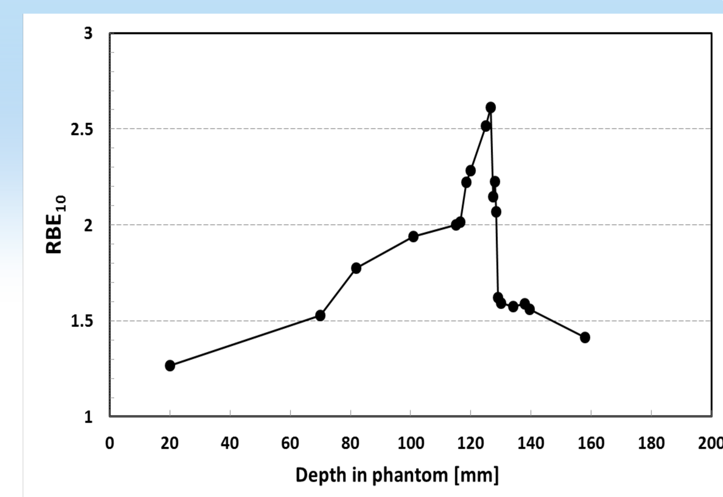


Fig. 6b RBE_{10} distribution obtained by 1st generation of microdosimeter in response to 290 MeV/u SOBP

The measurements of the dose-mean lineal energy deposition along the central axis of a 10cmx10cm radiation field of the SOBP, obtained by SOI microdosimeters are shown in Fig. 6a. The arrows indicate the spectra of the lineal energy deposition measured along the SOBP. The microdosimetric spectra were generated using conversion factor to convert silicon to tissue. Significant changes of the microdosimetric spectra were observed close to and at the distal part of the SOBP. At 128 mm depth in the PMMA phantom second peak was observed indicating the ^{12}C stopper events with their range equal to the thickness 10 um of SOI microdosimeter.

Derived RBE_{10} values based on MKM model and SOI microdosimetric spectra are matched well with derived RBE_{10} values from the TEPC measurements in a Plato and along the SOBP, however at the distal part of the SOBP, our experimental results show higher RBE_{10} values. It was due to the difference in the composition of the PMMA phantom used in our experiment while the TEPC measurements were carried out in water.

Out of field Study

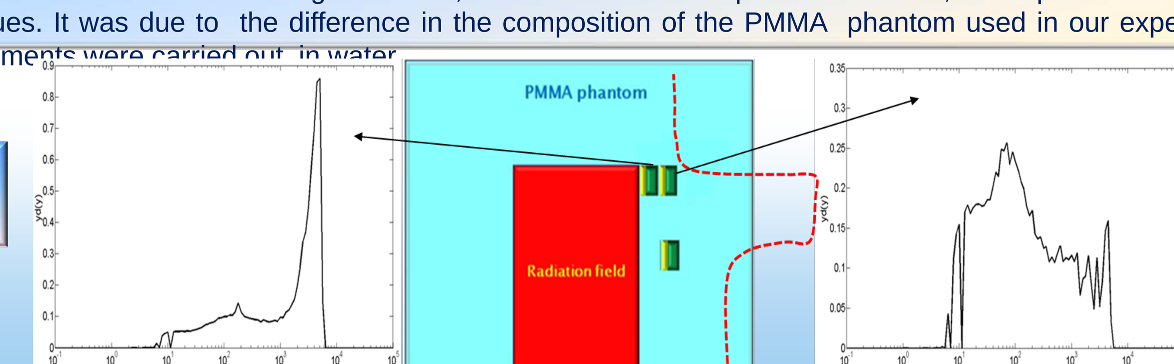


Fig. 7a Lateral out of field measurement. 0mm from the edge of the SOBP (90)

Fig. 7b Lateral out of field measurement. 5mm from the edge of the SOBP (90)

ΔE-E Telescope

Geant 4 Monte Carlo Simulation

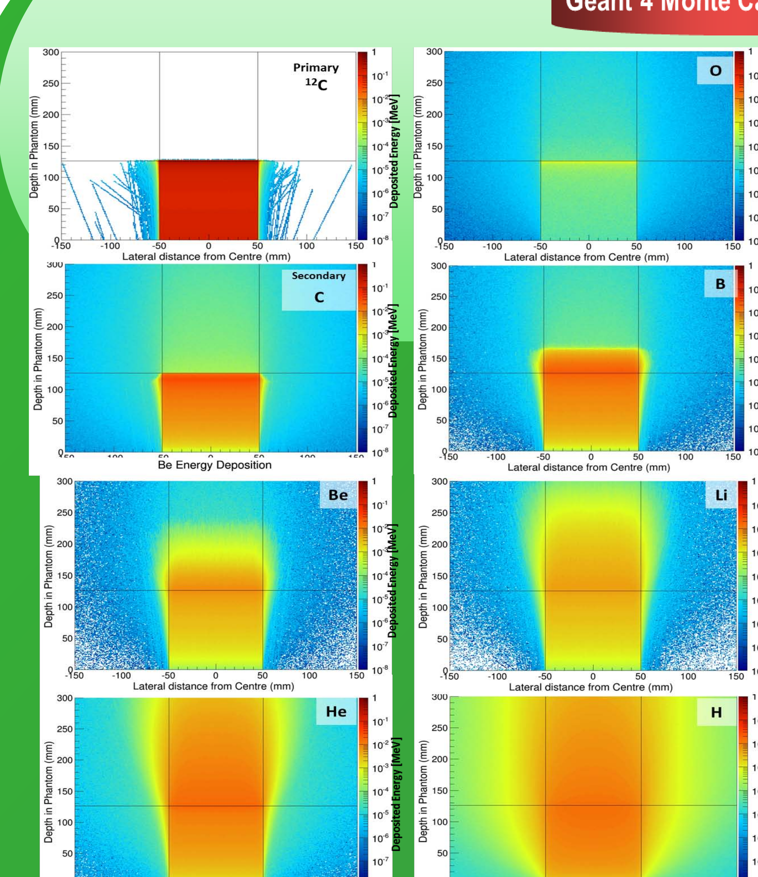


Fig. 8a 2D energy distribution of primary and secondary particles in the PMMA phantom for HIMAC experiment set up. Number of primary particles executed in the simulation was normalized to 1.

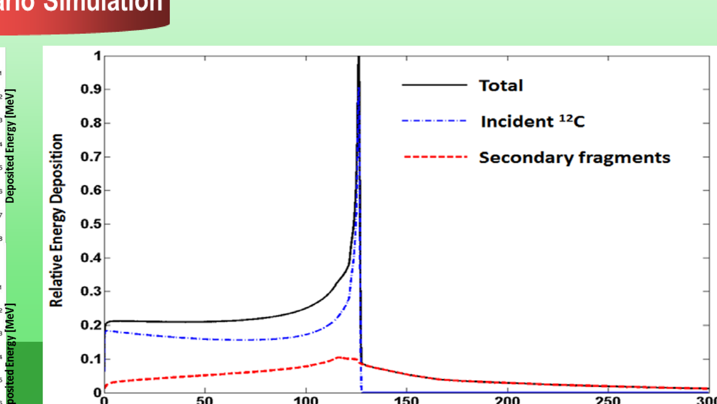


Fig. 8b Dose per incident ^{12}C ion. The energy deposition at the BP was normalised to 1.

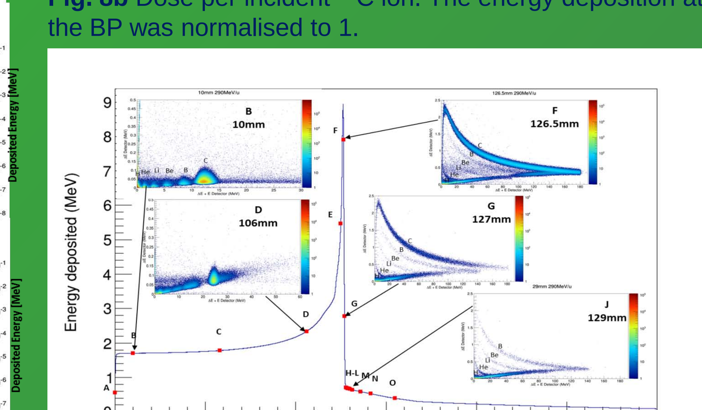


Fig. 8c Response of ΔE-E telescope to 290 MeV/u ^{12}C ion at positions A-F (two-dimensional ΔE-E plot). Number of primary particles were normalised to 1.

Experimental

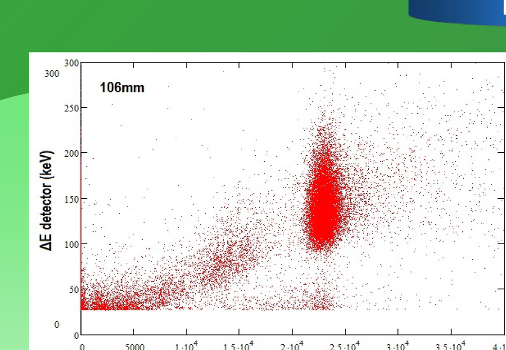


Fig. 9a Experimental result obtained by the ΔE-E telescope at 106 mm in the PMMA phantom for 290 MeV/u 12C ions at HIMAC

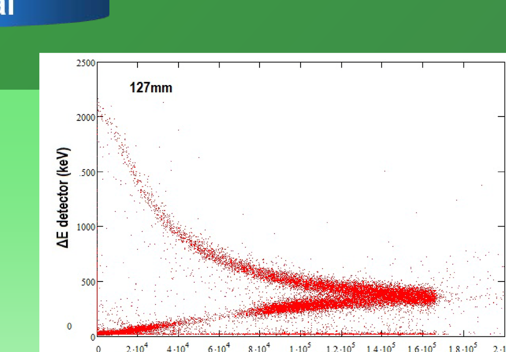


Fig. 9b Experimental result obtained by the ΔE-E telescope at 127 mm in the PMMA phantom for 290 MeV/u ^{12}C ions at HIMAC

Conclusions

- This work presented novel method of RBE derivation in ^{12}C heavy ion therapy using high spatial resolution SOI microdosimeter. It has demonstrated that the RBE_{10} value obtained by the SOI microdosimeter is close to the value obtained by TEPC at HIMAC except the distal part of SOBP due to the difference in composition of the PMMA phantom in comparison to water.
- SOI microdosimeter is easy to use and it is not required a lot of preparation time. It also provides extremely high spatial resolution of 0.1 mm along the BP and SOBP that is important for studies of RBE in a distal edge of SOBP.
- The fragments identification tool – monolithic silicon ΔE-E telescope provides not only particles types but also microdosimetric spectra using 1.8 um thick ΔE stage. The experimental results of the ΔE-E telescope are in good agreement with Geant4 simulation results. It is a comprehensive work contributing to better understanding of RBE of ^{12}C ion beam in heavy ion therapy.

Acknowledgements

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