(Form4-2)

JOINT RESEARCH PROJECT

FINAL REPORT
For Japan-Korea Joint Research Project

AREA	1. Mathematics & Physics 2. Chemistry & Material Science 3. Biology 4. Informatics & Mechatronics 5. Geo-Science & Space Science ⑥ Medical Science 7. Humanities & Social Sciences

1. **Research Title:**

Development of a gamma-ray camera to monitor the therapeutic proton dose distribution in real time

2. **Term of Research:** From July 1, 2010 To June 30, 2012

3. **Total Budget**

a. Financial Support by JSPS: Total amount: 2,000 thousand yen

1st Year 900 thousand yen 2nd Year 900 thousand yen

3rd Year 200 thousand yen

b. Other Financial Support : Total amount: 0 thousand yen

4. **Project Organization**

a. Japanese Principal Researcher	
Name	**Hidetoshi Kubo**
Institution / Department Position	**Kyoto University / Department of Science** **Assistant Professor**
b. Korean Principal Researcher	
Name	**Jongwon Kim**
Institution / Department Position	**National Cancer Center, Korea** **Principal Researcher**

c. List of Japanese-side Participants (Except for Principal Researcher)

Name	Institution/Department	Position
Toru Tanimori	Kyoto University / Department of Science	Professor
Shinya Sonoda	Kyoto University / Department of Engineering	Researcher
Shigeto Kabuki	Tokai University /Department of Medical	Researcher
Shunsuke Kurosawa	Tohoku University / Institute for Materials Research	Assistant Professor
Tatsuya Sawano	Kyoto University / Department of Science	Graduate Student
Yoshihiro Matsuoka	Kyoto University / Department of Science	Graduate Student
Shotaro Komura	Kyoto University /Department of Science	Graduate Student
Yasushi Sato	Kyoto University /Department of Science	Graduate Student
Takeji Sakae	University of Tsukuba / Proton Medical Research Center	Professor
Kiyoshi Yasuoka	University of Tsukuba / Proton Medical Research Center	Lecturer
Toshiyuki Terunuma	University of Tsukuba / Proton Medical Research Center	Research Associate

d. List of Korean-side Participants (Except for Principal Researcher)

Name	Institution/Department	Position
Chong-Chul Yun	Chung-Ang University	Research Professor
Jae Sung Lee	Seoul National University	Associate Professor
Dokyun Kim	Seoul National University	Graduate Student

5. Number of Exchanges during the Final Fiscal Year*

a. from Japan to Korea *Japanese fiscal year begins April 1.

Name	Home Institution	Duration	Host Institution
Shunsuke Kurosawa	Tohoku University	3 days	Particle Therapy Co-Operative Group
For Final Fiscal Year(FY2012) Total: 1 persons		For Final Fiscal Year(FY2012) Total: 3 ~~man~~-days	
Numbers of Exchanges during the Past Fiscal Years			
FY2010: Total 3 persons FY2011: Total 2 persons			

b. from Korea to Japan

Name	Home Institution	Duration	Host Institution
For Final Fiscal Year(FY2012) Total: 0 persons		For Final Fiscal Year(FY2012) Total: 0 man-days	
Numbers of Exchanges during the Past Fiscal Years			
FY2010: Total 0 persons FY2011: Total 0 persons			

6. Objective of Research

Proton radiation therapy has been better established lately and the patient throughput is increasing. However, no practical instrument to monitor the therapeutic proton dose distribution in real time has been realized. The Korean team in this project had found, by both simulations and experiments, that the peak position of the dose distribution (Bragg peak) can be measured in real time by measuring high-energy (a few MeV) prompt gamma rays generated secondarily in the body. Conventional gamma-ray cameras for medical imaging such as SPECT (a few hundreds keV) or PET (511 keV) cannot measure MeV gamma rays. Other conventional gamma-ray cameras capable of measuring MeV gamma rays need a collimator so that they cannot have a wide field of view and thus cannot image the dose distribution in real time.

The Japanese team in this project has developed a gamma-ray imaging camera that can measure high-energy (MeV) gamma rays with a wide field of view using Compton scattering technique. Such Compton gamma-ray cameras have been being developed by several groups in Europe and USA for application for astronomical observations. The Compton gamma-ray camera developed by the Japanese team has an outstanding ability to reject background neutrons.

The Japanese team in collaboration with the Korean team conducted experiments with our developed gamma-ray camera and a water phantom at proton-beam facilities in 2008 and 2009. We demonstrated the potential of our gamma-ray camera as a real-time monitor for the therapeutic proton dose distribution. However, further development is necessary for practical use. Objectives of this research are 1) detailed comparison of the experimental reconstructed image with simulation for prompt gamma rays by using the detector response. 2) improvement of imaging resolution of our gamma-ray camera to measure the dose distribution more precisely.

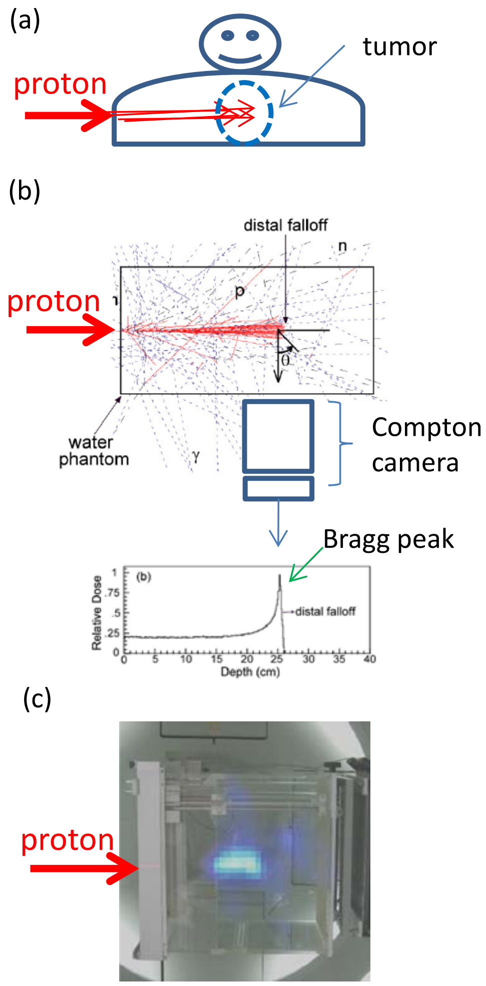

Figure 1. (a) Schematic view of radiation therapy. (b) Real time monitor for dose distribution in radiation therapy by using a Compton gamma-ray camera. (c) Prompt gamma-ray distribution in a water phantom irradiated with proton beams.

7. Methodology

・Evaluation of the reconstructed image

Before this project, we obtained the gamma-ray image with our Compton Gamma-ray camera using a water phantom, which was irradiated with a 140-MeV proton beam at the Research Center for Nuclear Physics (RCNP) of the Osaka University using our Compton gamma-ray camera (Figs.1(b), 2). We obtained simulated gamma-ray images in the following method, and compared it with gamma-ray images obtained in the experiment.

1) We simulated using the GEANT4 code to obtain an ideal gamma-ray distribution generated with a 140-MeV proton beam.

2) We measured the position and energy dependence of detection efficiency of the Compton gamma-ray camera using radioisotopes to convert the ideal (simulated) images to real images.

・Development of a novel scintillator-array camera

Angular resolution of a Compton camera depends on the energy resolution of scintillator in the Compton camera. Generally, as the light output increases, the energy resolution is higher. Thus, we measured the energy resolution of a single pixel of Ce:GAGG (Ce-doped $Gd_3Al_2Ga_3O_{12}$) scintillator crystal developed recently as a bright scintillator, and compared it with Ce:GSO (Ce:Gd_2SiO_5) which is a conventional scintillator for our Compton camera. Both scintillators had a size of 6 mm × 6 mm × 13 mm. Then, we assembled a GAGG scintillator array with 8 × 8 pixels, and measured the energy resolution of this array using a multi-anode photo-multiplier tube with 8 × 8 anodes.

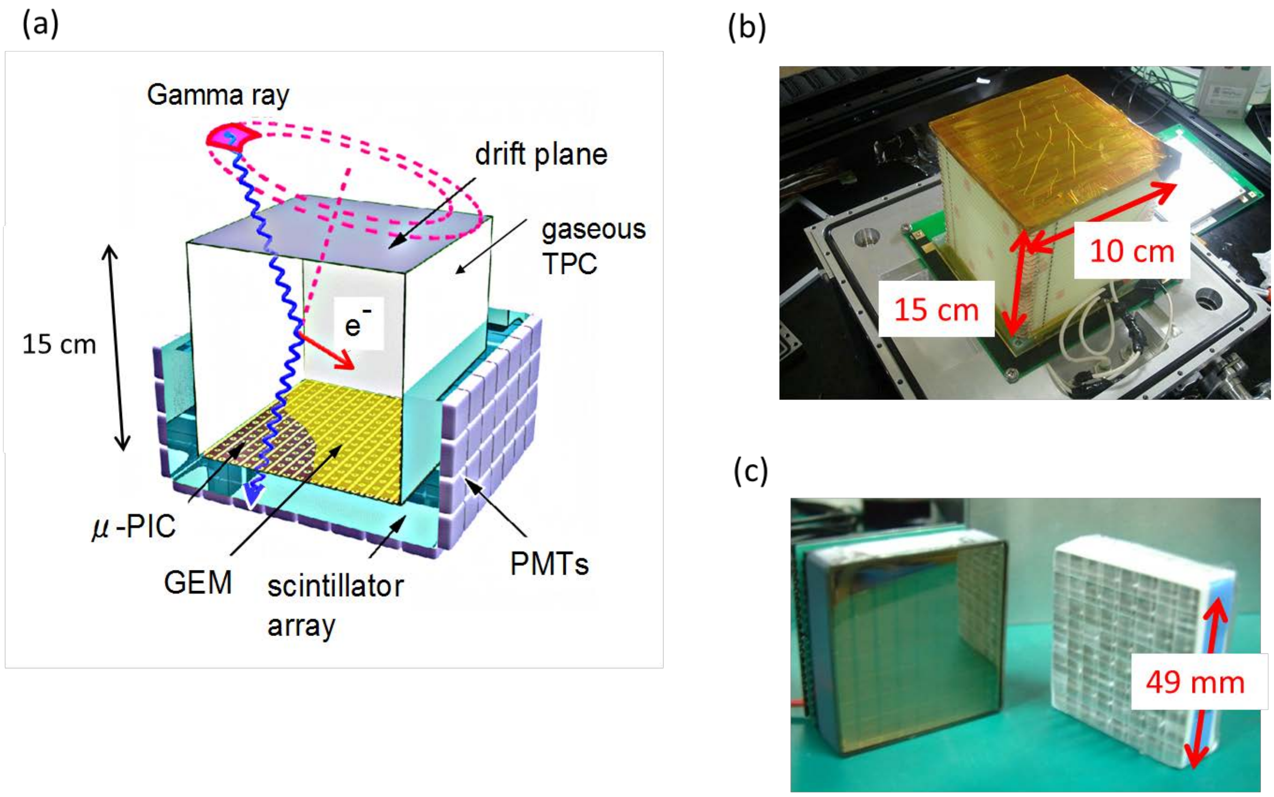

Figure 2. (a) Schematic view of our Compton gamma-ray imaging camera. Photograph of (b) the gaseous detector (TPC) and (c) the scintillator array coupled to a photo-multiplier tube (PMT).