PHYSICS
1. Count Rate Analysis of GSO-DOI PET Scanners

Keishi Kitamura and Hideo Murayama

Keywords: count rate, Monte Carlo simulation, positron emission tomography (PET), nuclear medicine

A detector made of thick crystals with a depth-of-interaction (DOI) capability can maintain high spatial resolution while increasing system sensitivity in 3D PET scanners with high geometrical efficiency, that is small detector ring diameter and large axial field of view (FOV). Along with sensitivity and coincidence resolution, count rate performance is an important factor to affect the image signal-to-noise ratio in clinical PET studies. High light yield and fast decay time properties of Gd$_2$SiO$_5$:Ce (GSO) are suitable for improving energy and time resolution, which result in the decrease in scatter and random coincidences. However, these contributions may be canceled by the dead time losses at detector modules using a large area PS-PMT placed close to the patient. We therefore investigated the count rate properties of GSO-DOI PET scanners with the large PS-PMT using a Monte Carlo simulation and event loss model.

In this work, Monte Carlo simulation programs based upon EGS4 were used to calculate photon interactions in scintillation crystals and phantoms. Photons which have escaped from the phantom were tracked within the scintillator, and their position and energy were recorded if interactions occurred. A pair of photons having the same annihilation tag was counted as a coincidence event, and single events were used to generate random events. Dead-time factors at each stage of the data acquisition system were estimated using a conventional count rate model with the product of paralyzable and non-paralyzable dead time losses for the front-end circuit and non-paralyzable dead time losses for the other circuits. Noise equivalent count rates $\text{NECR} = \frac{T}{T+S+R}$ were then calculated as a function of activity concentrations, where $T$, $S$ and $R$ are the total true, scatter and random coincidence rates, respectively, and $f$ is the ratio of the lines of response passing through the object.

The proposed detector unit consisted of four stages of 16 x 16 GSO crystal arrays with a total depth of 30 mm coupled to a 52 mm square PS-PMT having 16 x 16 multi-anodes. The scanner consisted of 5 ring detector blocks with 24 detectors per ring with a ring diameter of 38.2 cm and an axial FOV of 25.8 cm. All detector elements were assumed to have the same energy resolution of 20% with a pulse integration time of 250 ns. The outputs of the front-end circuits with an energy window of 400-600 keV were grouped into buckets and presented to the coincidence processors with a time-window of 6 ns. The relative gains of count rates by processing subset signals of the PS-PMT anodes in parallel with additional front-end electronics were also calculated. The results shown in Fig. 1 predict that the scanner will have higher sensitivity compared to current PET scanners mainly due to the high geometrical efficiency, and higher NECR despite the large size of the detector block. Using the 2x2 subdivision can increase the maximum NECR approximately 20% with a slight loss of sensitivity. However, using the 4x4 subdivision reduces sensitivity substantially because there are many escaping incident gamma rays from one segment to adjacent segments by Compton scattering in the scintillator.

![NECR for the GSO-DOI PET scanner with parallel processing of PS-PMT signals divided by 1 x 1 (without subdivision), 2 x 2, and 4 x 4.](image)

Fig 1. NECR for the GSO-DOI PET scanner with parallel processing of PS-PMT signals divided by 1 x 1 (without subdivision), 2 x 2, and 4 x 4.

Publications:

2. Algebraic 2D PET Image Reconstruction Using Depth-of-Interaction Information

Taiga Yamaya, Takashi Obi*, Masahiro Yamaguchi*, Nagaaki Ohyama* and Hideo Murayama (* Tokyo Institute of Technology)

Keywords: image reconstruction, depth-of-interaction (DOI), positron emission tomography (PET), nuclear medicine

Development of a new generation positron emission
tomography (PET) system with depth-of-interaction (DOI) capable detectors is in progress at the National Institute of Radiological Sciences. In current 3-dimensional (3D) PET scanners, the length of the detector crystals is about ten times as long as their width in order to improve detection efficiency. Therefore the PET measurement system exhibits shift-variant characteristics, such as broadened sensitivity functions of each detector pair from center to edge of field-of-view (FOV) and/or from small to large ring differences. However, using DOI information can narrow the broadened sensitivity functions while maintaining system sensitivity.

In this paper, we applied an algebraic image reconstruction method, such as natural pixel decomposition (NPD), to a 2-dimensional (2D) DOI-PET scanner, in order to evaluate the effects of using DOI information on PET image quality. Algebraic reconstruction methods have been successfully used to improve quality of PET images by accurate modeling of the measurement system, while the conventional filtered backprojection (FBP) method is based on an inaccurate system model. The measurement system model for the DOI-PET scanner was defined in consideration of geometrical arrangement and penetration of crystals. At this stage, we supposed that scatter coincidences, random coincidences and attenuation were corrected completely.

We applied NPD to simulated data for a small animal DOI-PET scanner. The scanner had a ring of 144 BGO crystals of 3.8 x 3.8 x 10 mm³ arranged in 2 DOI layers. For comparison, a non.DOI PET scanner, which had a ring of 144 BGO crystals of 3.8 x 3.8 x 20 mm³, was also simulated. The detector ring had a diameter of 187 mm, and the FOV had a diameter of 140 mm. Reconstructed images were obtained using NPD and FBP. Two figures of merit (FOMs), background noise and spatial resolution, were used to evaluate the image quality. The spatial resolution was measured as the average of radial and tangential full widths at half maximum (FWHM) of the point spread function at the center, and 20, 40 and 60 mm off center. A warm phantom of 100 mm diameter was used to measure the background noise as the normalized standard deviation (NSD). First the trade-off between the background noise and the spatial resolution was investigated, using NPD with different values of the regularization parameter and FBP with ramp filters of different cut-off frequencies. Plots of radial and tangential resolution at the same background noise levels (NSD=0.09) are shown in Fig. 2. Comparison between NPD and FBP shows the improvement of image quality by using the accurate system model. Also comparison between DOI-PET and non.DOI PET shows the improvement of resolution uniformity by using DOI information.

In summary, the numerical simulation results show that accurate system modeling improves spatial resolution without noise emphasis, and that DOI information improves uniformity of spatial resolution.

![Graph showing FWHM resolution of point source image with and without DOI information.](image)

Fig. 2. FWHM resolution of the point source image using NPD and FBP at the same background noise levels (NSD = 0.09).

Publication:

3. A Depth-of-Interaction Detector for PET with GSO Crystals Doped with Different Amounts of Ce

Naoko Inadam, Hideo Murayama and Hideyuki Kawai

**Keywords:** depth-of-interaction detector (DOI), positron emission tomography (PET), pulse shape discrimination, GSO crystal

As one way to obtain high resolution and high sensitivity in 3D mode acquisition on PET, the concept for a depth-of-interaction (DOI) detector was proposed. In this paper, the new 4-stage DOI detector which was developed from the 3-stage DOI detector reported previously is introduced. Like the previous one, it is composed of one 16-channel (4-by-4 matrix anodes) position-sensitive photomultiplier tube (PS-PMT) and four scintillator blocks. The PS-PMT is optically coupled to the blocks by silicone oil. One block is four stage deep and one stage consists of a 2-by-2 array of rectangular Gd,SiO₂ (GSO) crystal elements sized 2.9mm by 2.9mm by 7.5mm. Except for the fourth stage, there is a reflector between elements in the same stage; the fourth stage has an air gap instead. Each block is also wrapped in a reflector and optically isolated. Therefore scintillation light is spread over the block from the site
Fig. 3. 2-dimensional positioning image histograms obtained in the uniform irradiation experiment of the 4-stage DOI detector with one block. The upper histogram, (a), represents all crystal data before the selection by pulse shape and height. The lower histograms express data from (b) 0.5mol% GSO crystals and (c) 1.5mol% GSO crystals.

of the interaction through the fourth stage crystals, and it enters the photo cathode of the PS-PMT. Because incident photons have a distribution corresponding to the interaction site, outputs of the four PS-PMT anode signals under the block indicate the crystal of interaction. It is identified on a 2-dimensional positioning image histogram mapped by an Anger-type position arithmetic calculation using the signals.

The 4-stage DOI detector is achieved by using two kinds of GSO crystals doped with different amounts of Ce, 0.5mol% and 1.5mol%. The scintillation decay time constant of 1.5mol% GSO crystal is 35ns and 0.5mol% GSO is 60ns. From pulse shape discrimination, it can be recognized in which kind of crystals the interaction takes place. The Anger-type position arithmetic calculation is applied to anode signals of each event data after classifying them according to the pulse shape discrimination, and two positioning contour image histograms are obtained. Setting these GSO crystal stages alternately as a 4-stage block, the performance of the detector is evaluated by irradiating a gamma ray uniformly from a 0.1mCi $^{137}$Cs point source.

Fig. 3 (a) is the positioning image histogram of the measurement for 750k events before pulse shape discrimination and pulse height selection. Conducting pulse shape discrimination and setting windows on the energy spectra of each crystal, we obtain two 2-dimensional histograms as a result (Figs. 3 (b), (c)). The crystal of interaction can be easily identified in both histograms compared to the histogram without selecting by pulse shape and height. The accuracy of crystal identification with this 4-stage block detector is checked by scanning collimated gamma rays along the detector face. The results show that there is no significant problem for crystal identification by this method.

We conclude that the performance tests verify the 4-stage DOI detector is reliable enough for crystal identification. The detector will be investigated further while changing detector parameters such as crystal surface and size, reflector arrangement, and arrangement of two kinds of crystals in order to realize a large number of reliable detectors for the next generation PET.

Publication:

4. Improvement of the HIMAC Treatment System with the Layer-Stacking Conformal Irradiation Method

Nobuyuki Kanematsu, Tatsuaki Kanai, Yasuyuki Futami, Ken Yusa and Masahiro Endo

Keywords: heavy ion radiotherapy, 3D conformal radiotherapy, dynamic multi-leaf collimation, spread-out Bragg peak

Even though charged particles have ideal characteristics for radiotherapy, the actual particle treatments may not always be perfect in terms of dose distribution. One of the major limitations in the conventional particle therapy, where used is a range-modulation device such as a ridge filter, is that a fixed width of the spread-out Bragg peak (SOBP) has to cover the 3D target volume. Therefore, it is usually inevitable for the fixed SOBP to extend to healthy tissues. The layer-stacking method was proposed to resolve this problem by producing a variable SOBP without requiring a drastic modification of the conventional beam delivery system.

In the layer-stacking method, a target volume is virtually divided into thin layers in the depth direction and those individual layers are treated sequentially with irradiations with a common small SOBP, different beam ranges, and conformal fields. In order to deliver the sequence of irradiations automatically as a dynamic beam for daily clinical practice, the beam-monitor/device-control system was modified and an independent device-monitor/beam-interlock system was added to shut off the beam during the transition times in a sequence and in case of any control failures for safety.
In addition to the range shifter and the multi-leaf collimator, the wobblre magnets are dynamically controlled in order to keep the field uniformity during the delivery. The treatment planning system was also modified to automatically determine the control sequence of the beam. Since the conventional ridge-filter method and the layer-stacking method should flawlessly coexist on the same treatment system, great care was taken for continuity and integrity with the ongoing treatments to provide the clinical-level quality assurance.

The layer-stacking method will be routinely used at NIRS in a complementary manner with the conventional method. Furthermore, it should be a reasonable upgrade option for many other facilities with a conventional particle radiotherapy machine.

Fig. 4. Principle of the layer-stacking irradiation shown with the relevant devices and a patient. For each layer of the target, the thin ridge filter produces a small SOBP, the range shifter adjusts the beam range, and the multi-leaf collimator defines the field. The wobbling radius is always adjusted to keep the field uniformity. These devices are controlled according to the integrated output of the beam monitor to coform a variable SOBP to the target volume (red region).

Publications:

5. Quantitative Computed Tomography Using Dual-Energy Monochromatic X-rays

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Keywords: CT, electron density, synchrotron radiation, monochromatic x-rays

Monochromatic x-ray computed tomography (CT) at two different energies provides information about electron density of human tissue without ambiguity due to the beam hardening effect. This information makes the treatment planning for heavyion radiotherapy more accurate. We have started a feasibility study on the dual energy x-ray CT by using synchrotron radiation. The first goal of this study was measurement of the electron density with precision of less than one percent. A translate-rotate scanning mode CT system was developed for quantitative measurement in order to clarify what precision in the measurement was achieved in the dual energy x-ray CT.

A photon attenuation coefficient is approximately described by the following equation:

\[ \mu(k) = \rho, \sigma, Z \phi Z(\frac{M_{s}e^{2}}{k})^2 \sum J_{\phi} + \rho(z) (\frac{1}{k})^{2} \frac{Z}{Z_{\phi}} \phi(z) \]

where the first term denotes a photoelectric effect, the second term denotes a scattering effect and \( \rho_{z} \) denotes the electron density of an object. Solving simultaneous equations with respect to \( \mu(k) \) and \( \mu(k) \) with the aid of an iterative calculation gives an atomic number \( Z \) (we call it an effective atomic number) and the electron density \( \rho_{z} \).

Experiments were carried out at BL20B2 of SPring-8 by using high intensity x-rays of 40 keV and 70 keV that were obtained by monochromatizing synchrotron radiation. The translate-rotate scanning mode CT system consisted of an x-ray detector with a plastic scintillator, a rotating table and a sliding stage. An ionization chamber, upstream from the rotating table, counted the number of the incident photons. The plastic scintillator was connected with a photo-multiplier (Hamamatsu Photonics R3550). The output current of the detector was proved to be proportional to the x-ray intensity from 10 ph/s to about 10 ph/s. The rotating table on which a sample was set was moved horizontally in a step of 1 mm. Data were taken every step by being exposed to the x-rays for a few hundred ms. At the end of the stroke, the object was rotated by 0.8°. This motion was repeated until the rotation angle became 180°.
Several samples were used: phantoms equivalent to human tissue produced by Kyoto-kagaku Co. (1) soft tissue (SZ207), (2) adipose tissue (SZ49), (3) cartilage bone (SZ160) and (4) compact bone (BE-T), and aqueous solutions of dipotassium hydrophosphate K2HPO4. An ellipsoidal vessel with the dimensions of 16 cm x 12 cm filled with water that contained smaller vessels filled with the solutions was used for simulation of a human head.

In order to verify the electron densities measured with the dual energy x-ray CT, (i) we compared them with the theoretical values for the solutions of the head phantom, and (ii) we measured the electron densities of the tissue phantoms by a different method using carbon ions for a second comparison. The carbon ions entered a water column after they penetrated a sample, they have a range in water. The range was measured, both with and without the sample in front of the water column. The difference of the ranges gave information on the stopping power of the sample for carbon ions. Therefore, the electron density of the sample can be derived from the difference of the range using the Bethe-Bloch formula. The mean excitation energy for water was 75 eV quoted from ICRU 37, and it was used for the tissue phantoms except for BE-T. The mean excitation energy for BE-T was calculated from values listed in the catalogue of Kyoto-kagaku Co. and was 108 eV. In addition, aluminum samples were used to evaluate the precision of this method. Comparison of the aluminum electron density with the theoretical one suggests that the precision of this method is less than 0.5%.

The images of the head phantom reconstructed based on the electron density and the effective atomic number are shown in Figs. 5(a) and 5(b), respectively. There are noticeable differences between these images. The acrylic plastic of the vessel wall has a high electron density, but its effective atomic number is relatively small. This shows that the acrylic plastic has the highest density among materials of the head phantom, and it consists of relatively light elements. The K2HPO4 solutions have less electron density than the acrylic plastic but their effective atomic numbers are higher due to the existence of heavier elements such as potassium and phosphate. For the K2HPO4 solutions, the average ratio of the difference between the electron density and the theoretical value to the theoretical value is 0.25 %, In the case of the tissue phantoms, the ratio is 0.97 %. The results of the comparison are summarized in Fig. 6.

We conclude that:
(1) the first goal of this study has been almost achieved: electron density measurement with the precision of less than 1 %;
(2) the image of electron density and the image of effective atomic number describe different features of the material.

The information on the electron density and on the effective atomic number of a human tissue may open an avenue for new medical diagnoses.

Fig. 5(a). The image of the head phantom based on the electron density. As the color becomes lighter, the electron density becomes higher.

Fig. 5(b). The image of the head phantom based on the effective atomic number. As the color becomes lighter, the atomic number becomes larger.

Fig. 6 Comparison of the electron densities with the theoretical values for the K2HPO4 solutions and with the values measured in the method of stopping powers for the tissue phantoms.

Publication:
6. Fast Beam Cut-Off Method in RF-knockout Extraction For Spot Scanning

Taku Furukawa, Koji Noda, Shinji Shibuya, Masayuki Muramatsu, Mitsutaka Kanazawa, Eiichi Takada and Satoru Yamada

Keywords: RF-knockout slow extraction, synchrotron, heavy ion therapy, dose management, spot scanning

Beam scanning methods, such as spot and raster scanning, have been developed in order to achieve a high irradiation accuracy, even for an irregular-shaped target. Early studies indicated that to significantly reduce any unwanted dose in these irradiation methods, the time structure of an extracted beam (spill) should have a ripple of less than ±20%, and the response time to beam-off should be less than 1% of the shortest irradiation time of one spot, because the extracted particles after the cut-off signal considerably affect the dose management for irradiation.

At the HIMAC synchrotron, the RF-knockout extraction has utilized a bunched beam to reduce the beam-spill ripple. Therefore, particles near the resonance can be spilled out from the separatrixes by the synchrotron oscillation as well as by a transverse RF field. From this viewpoint, a fast beam cut-off method, turning off the transverse and longitudinal RF fields at the same time, has been proposed and verified by both simulations and experiments. The delay from the beam cut-off signal to beam-off has been improved to around 60 μs from 700 μs by turning off only the transverse RF field. Unwanted dose has been considerably reduced by around a factor of 10 compared with that by the usual method.

The delay of 700 μs corresponds to one period of the synchrotron oscillation. In the synchrotron, the delay is limited by the excursion time from the position just outside the separatrix to the extraction channel. The delay of 60 μs, obtained by the new method, is in good agreement with the analytical solution of this excursion time. Therefore, our proposal is one of the best methods to minimize the unwanted dose. The proposed method will play an important role for precise dose management in spot scanning.

Publication:

7. The Scanning Micro-Beam PIXE Analysis Facility at the Electrostatic Accelerator Building

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Keywords: PIXE, micro-beam scanning, mapping, elemental distribution

In March 1999, a HVEE Tandetron was installed in the Electrostatic Accelerator Building for PIXE (Particle Induced X-ray Emission) analysis. The specifications of the Tandetron accelerator system operating at NIRS are as follows: The accelerating voltage is 0.4 to 1.7MV, and the maximum beam current is 5 A at 3.4MeV. The accelerator facility incorporates three beam lines for conventional, in-air and microbeam PIXE analysis. The conventional beam line has two types of X-ray detecting devices, Si (Li) and CdZnTe detectors, and elements from Na (Z=11) to U (Z=92) are detectable. Fifteen samples can semi automatically be measured at one time using a proton beam of optical beam size from 0.5 to 2.0 mm at 100 nA beam current. The in-air beam line is used for irradiation of wet sample using a proton beam of optical beam size from 2 mm. The proton beam, thru out of Kapton film, is introduced into a chamber filled with helium gas of 1 atmosphere.

Fig. 7. Typical experimental results. (a) Turning off only the transverse RF field; and (b) in the fast beam cut-off method with a time scale of 200 μs/div. (c) An enlarged view using the fast beam cut-off method with a time scale of 40μs/div.
The scanning microbeam PIXE analysis line is based around an Oxford Microbeams OM2000 nuclear microscope endstage. This system provides the ability of multi-elemental mapping over sample areas up to 2 × 2 mm area with spatial resolutions routinely at 1 μm × 1 μm. The scheduled operation of this facility started in April 2000. The results of beam resolution tests carried out in 2001 are as follows: For Scanning Transmission Ion Microscopy (STIM), the estimated beam size is 100 x 200 nm, measured using a 2.6 MeV proton beam scanned over a 12.5 μm repeat distance copper grid (Fig. 8). For Particle Induced X-ray Analysis (PIXE) operation at 50 pA beam current, the estimated best spot size is 0.4 x 0.6 microns (Fig. 9). The micro-beam facility apparatus is being used for research into the elemental distribution of small biological samples such as biological cells and tissue.

The operation of this machine is controlled by the Technical Service and Development Section.

Publications:


Masayuki Kumada

Keywords: permanent magnets, magnetic circuit

The author has been developing a very strong magnet based on a new type of magnetic circuit of permanent magnet material. The strongest magnetic material was invented by Dr. Sagawa of Sumitomo Special Metal(SMMC) many years ago. It was an ingenious material. Although its patent is going to expire this year, no new material has been invented since then. Instead its performance has been improved by the continuing efforts of Dr. Sagawa’s successors at SMMC. The permanent magnet has been used to produce a relatively low field magnet in many applications as volume is less. The applications go from hard disk in computers to MRI (Magnetic Resonance Imaging). The weight of MRI magnet is more than one metric ton. The market share of MRI magnets is 1/3 where that of superconducting magnets is 2/3. Electric MRI magnets are almost unused. This is a field which requires extremely high uniformity and stability. Another high tech application is in the filed of synchrotron radiation of light by a high energy electron beam. Permanent magnet wiggler/undulator is an example of this. Main development of this kind of advanced magnet was exploited by Halbach of Laurence Berkeley laboratory(LBL). He developed the magnetic circuit of the strongest PM undulator magnet. The strongest undulator magnet was constructed by a Japanese researcher based on Halbach’s idea. It was about 3 Tesla and represented a great achievement, as it is stronger that the residual field of a material itself which is about 1.3 Tesla.

The author produced a 4.45Tesla dipole filed last year using a permanent magnet which was only possible by a superconducting magnet or pulsed field in collaboration with SSMC http://www.cerncourier.com/main/article/41/7/5/1 (CERN Courier September 2001 p9). This is shown in Figure 8. This is the world's strongest PM magnet ever manufactured. The key point was to use saturated iron as part of the pole and cool it down to -50 degree C. This world record was broken by other researchers this year at ESRF(European Synchrotron

Fig. 8. STIM tests using 2000 lines per inch Cu grid. Proton energy 2.6 MeV protons; scan sizes 50 microns; resolution estimated visually approximately 100 nm (horizontal) and 200 nm (vertical).

Fig. 9. PIXE scan of 2000 lines per inch mesh gold grid. Proton energy 3 MeV protons; scan size 50 microns; estimated beam size 0.4x0.6 microns.

The author has started to invent a variable field magnet, using PM material. It is named MiM, Magnet-in-Magnet, and is a combination of PM magnet and electro magnet. The author made a proof of principle demonstration and manufactured a 3 Tesla variable filed model magnet. There are many variations of this concept. After a successful model experiment, funding was granted from the Japan Science and Technology Corporation (JST) as a 3 years project. The author is collaborating with Prof. Iwashita of Kyoto Univ. for application of a quadrupole magnet system to get a nanosize beam. This is the application for a linear collider for high energy physics in future. Other projects for the MiM or PM cyclotron are going to be started.

9. Skin Temperature Changes in Remote Action Experiment

Weizhong Chen, Hideyuki Kokubo, Tomoko Kokado, Tong Zhang, Suzue Haraguchi, Mikio Yamamoto and Kimiko Kawano* (*Nippon Medical School, Tokyo)

*Keywords: average skin temperature change, remote action, laogong point, thermistor, hand surface

A series of remote action experiments were performed in sense shielded conditions with paired subjects. One pair has previously shown statistical significant coincidences of the time of their apparent motions.

In this study, two other subjects who had trained in many kinds of martial arts as a pair for 40 years performed a remote action in an experiment. They had mainly trained in a martial art that lets a person foresee an attack from an attacker. The experiment was performed in Rooms 201, 202 (central control room) and 203 for Various Simultaneous Measurements in the Multipurpose Facility at NIRS on March 30-31, 2000. In the experiment, the subjects were placed in separate rooms with normal communication deprivation. One of them acted as a sender (male, 58 years old) who was seated in Room 201 and the other acted as a receiver (male, 64 years old) who was seated in an electromagnetic shielding cage in Room 203.

The experiment was designed on double blinded and randomized conditions. The start and the end time of the trial was announced automatically to subjects by the multistem stimulator which was in the central control room. Before the experiment, the specific sending time was set by a pseudo random number generation program.

![Fig. 10. Photo of 4 Tesla PM dipole(left) and flux distribution(right)]()

![Fig. 11. Skin temperature changes of receiver's laogong on the left hand before and after transmission (+10.0sec) (22 trials). Error bars show standard errors.]()
and prepared in a file by someone who did not participate in the experiment. After seeing a light signal to send, the sender attempted to give "remote influence" only once to the receiver in a short time. And as soon as the sender emitted "qi" and the receiver felt it, each pushed an event marker switch.

One trial was 80 seconds and was performed with a 10-second stand-by before the next one. Three continuous trials made one run (260 seconds). A break and feedback of results of the experiment were given between runs, and subjects could talk about how to do better.

Physiological changes of the receiver were measured such as skin surface temperature of the left laogong (middle of the palm), photoplethysmogram (PPG), respiration (Resp), electrodermal activity (EDA), microvibrations (MV) and brain waves (EEG).

The receiver's skin temperature was analyzed to find if there is any change when the sender attempted to give "remote influence" to the receiver. For the period of 10 seconds before and after sending time, the average temperature was analyzed and is shown in Fig.11. It can be seen that the average temperature of 22 trials changes from increasing to constant one second before the sending time. The difference of average temperature between 2 seconds before and after that time is statistically significant and 1% or less.

In conclusion, a significant difference of average temperature change was observed 1 second before the sending time in the period of [±2.0] seconds. It was possible to consider that this was an expression of the characteristics of this martial art that trains foreseeing of a partner's attack sign.

Publications:

10. New Gamma-Ray Directional Detectors with Different Types of Scintillators
Yoshiyuki Shirakawa

Keywords: gamma ray, NaI(Tl) scintillator, BGO scintillator, photomultiplier, photopeak, coming direction, energy

The tandem detector, which positively increases directional sensitivity to incident gamma rays, mainly consists of two different types of scintillators, a photomultiplier tube and electronic devices such as a preamplifier. In the detector, a cylindrical front scintillator A, the same-sized back scintillator B and a photomultiplier tube fitted with scintillators are combined optically in this order in tandem. Since path length of gamma rays through each scintillator is dependent on incident directions, the probability of photoelectric absorption events occurring in each scintillator will also be changed. Hence the photopeak counts in a spectrum collected by the front scintillator A, and those by the back scintillator B have some relations with the incident direction $\theta$. One indicator to express these relations is proposed here. It is the ratio R which is defined as the quotient, i.e. photopeak counts by B / photopeak counts by A. They are apparently proportional to probability of photoelectric absorption:

$$R = \text{photopeak counts by B} / \text{those by A} = P_b / P_a$$

where Pb and Pf mean the probability of photoelectric absorption in the B scintillator and that in the A scintillator, respectively. We expect that R(\theta) has a value in the range between R(0) and R(90), and the value monotonously increases with $\theta$. Here requirements for both scintillators A and B should be considered. The most important characteristic is that scintillation efficiencies of both scintillators are sufficiently apart to distinguish photopeaks completely
for stable counting. Another desired feature is that each scintillator has a high density to detect gamma rays efficiently for a short counting time. From these considerations, it is reasonable to chose a NaI(Tl) scintillator as the front one of A and a BGO scintillator as the back one of B. There tandem detectors were designed and made for experiments. They have 1) the diameter of 50 mm and thickness of 25 mm for the NaI(Tl) scintillator and the BGO scintillator; 2) the diameter of 50 mm and thickness of 50 mm for the NaI(Tl) scintillator and the BGO scintillator; and 3) the diameter of 25 mm and thickness of 50 mm NaI(Tl) scintillator and the BGO scintillator. Using these detectors, we carried out experiments to confirm the measurement principle and to examine the performance. A $^{137}$Cs source of 3.7 MBq was selected as representative of gamma ray sources because of its widespread use. Experimental procedure is described with reference to Fig. 12. The source was set 100 cm in front of the detector ($\theta=0$). Gamma rays coming from the source and reaching the detector were counted for 60 seconds and the ratio R was calculated from observation of photopeaks in the spectrum. Then the source was moved in 10-degree intervals towards the side of the detector ($\theta=90$) and the same procedure was repeated. These curves were expressed by

$$R(\theta) = -4.42 \times 10^4 \theta^{-1} + 5.86 \times 10^4 \theta^{-2} - 3.53 \times 10^3 \theta^{-3} + 1.62 \text{ (2)}$$

$$R(\theta) = -4.26 \times 10^5 \theta^{-1} + 3.82 \times 10^5 \theta^{-2} + 2.31 \times 10^4 \theta^{-3} + 0.491 \text{ (3)}$$

$$R(\theta) = -2.70 \times 10^5 \theta^{-1} + 7.20 \times 10^4 \theta^{-2} + 7.20 \times 10^3 \theta^{-3} + 0.633 \text{ (4)}$$

where eq.(2), eq.(3) and eq.(4) were applied for experimental data by the detectors with the 50 mm x 25 mm scintillators, the 50 mm x 50 mm scintillators, and the 25 mm x 50 mm scintillators, respectively. These fitting curves agree well with experimental data points and the curve for the detector with the 25 mm x 50 mm scintillators is more sensitive to the change of $\theta$ than curves for the other detectors. In practical applications, $R(\theta)$ is given by calculation using photopeak count data after measurements and then the direction $\theta$, which is an objective parameter, must be solved. From this viewpoint, the third order polynomial is suitable for this application because the equation can be solved analytically and we can regularly obtain the result $\theta$. Characteristics of other parameters, i.e. energies and counts are confirmed to be the same as those by conventional NaI(Tl) and BGO scintillation detectors. Hence the simulations and experiments show that the proposed detectors have a potential for measuring three parameters simultaneously.

Publications:
1) Shirakawa, Y.: Radioisotopes, **50** [4], 117-122 (2001).

![Fig. 12. Relations between the indicator R and the incident direction $\theta$.](image-url)