

Title	Development of Energy Calibration System of CANDLES with Triggerable Gamma Ray Source for Study of $^{48}\text{Ca}$ Double Beta Decay
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Osaka University

## Abstract of Thesis

Name (VAN THI THU TRANG)	
Title	Development of Energy Calibration System of CANDLES with Triggerable Gamma Ray Source for Study of $^{48}\text{Ca}$ Double Beta Decay ( $^{48}\text{Ca}$ の二重ベータ崩壊の研究のためのトリガー可能な $\gamma$ 線源によるエネルギー較正システムの開発)
<p>Abstract of Thesis</p> <p>CANDLES experiment is a project to search for neutrinoless double beta decay (<math>0\nu\beta\beta</math>) of <math>^{48}\text{Ca}</math> by using <math>\text{CaF}_2</math> scintillators. <math>0\nu\beta\beta</math> violation of lepton number conservation which is a key principle to realize matter dominate universe. It is an extremely rare phenomenon. CANDLES detects scintillation light by which electron energy can be measured. Energy of two electrons from the <math>0\nu\beta\beta</math> corresponds its Q-value (4.3 MeV). Therefore, a precise energy calibration at the Q-value region is crucial for its identification. CANDLES has been using a radioactive source of <math>^{88}\text{Y}</math> (1.8 MeV) to calibrate 96 <math>\text{CaF}_2</math> scintillators. Although <math>^{88}\text{Y}</math> gives almost highest energy gamma ray, it is still much lower than Q-value. We, thus, have been using linear extrapolation of the calibration to the Q-value region. Later we acquired data of peak positions for several other gamma rays for the calibration. They are <math>^{40}\text{K}</math> (1.4 MeV), <math>^{208}\text{Tl}</math> (2.6 MeV), gamma energies from (n,<math>\gamma</math>) reaction at <math>^1\text{H}</math> (2.2 MeV), <math>^{28}\text{Si}</math> (3.5 MeV and 5.0 MeV), <math>^{56}\text{Fe}</math> (7.6 MeV) and <math>^{58}\text{Ni}</math> (9 MeV). The observed peak positions showed deviation from the linear extrapolation of the <math>^{88}\text{Y}</math> calibration. The deviation appeared to be 0.4% at Q-value region and has energy dependence. Since realistic estimation of region of interest (ROI) is crucial for the estimation of <math>0\nu\beta\beta</math> decay rate, we have to confirm the deviation. We know statistical error of each data, however, estimation of systematic error is vital for the confirmation of the deviation. We studied systematic errors, in particular, energy leak into liquid scintillation (LS) which acts as <math>4\pi</math> active veto in detail. Since some fraction of gamma rays energy leaks into liquid scintillation, total energy appears to be different. For this purpose, we developed a new energy calibration system by using <math>^{24}\text{Na}</math> source (1.37 MeV and 2.75 MeV). <math>^{24}\text{Na}</math> becomes <math>^{24}\text{Mg}</math> by emitting beta rays and then <math>^{24}\text{Mg}</math> emits two gamma rays. We can tag the two gamma rays by detection of beta rays by <math>\text{NaI}(\text{Tl})</math>. In order to obtain enough <math>^{24}\text{Na}</math> intensity for the calibration, size of <math>\text{NaI}(\text{Tl})</math> detector and configuration of neutron activation are optimized by Monte Carlo (MC) simulation and confirmed by the experiment. With new calibration system, we observed not only two gamma rays of <math>^{24}\text{Na}</math> but also gamma rays from backgrounds of <math>^{40}\text{K}</math> and <math>^{208}\text{Tl}</math>. This simultaneous measurement of 4 gamma rays is crucial for the evaluation of systematic errors. We confirmed the deviation from the linear extrapolation of <math>^{88}\text{Y}</math> calibration. The deviation may be attributed to genuine property of <math>\text{CaF}_2</math> scintillator. Background free spectrum obtained, by the <math>^{24}\text{Na}</math> clearly shows that the MC simulation reproduces the experimental data. We studied deviation for <math>0\nu\beta\beta</math> peak by MC simulation since electrons give less energy leak into liquid scintillation than that of gamma rays. We found the energy deviation at Q-value is <math>0.96 \pm 0.04\%</math> at maximum. Genuine property of <math>\text{CaF}_2</math> crystal may reduce the deviation which we leave for future study.</p>	

## 論文審査の結果の要旨及び担当者

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## 論文審査の結果の要旨

CANDLES is a project to search for neutrinoless double beta decay ( $0\nu\beta\beta$ ) of  $^{48}\text{Ca}$  by using  $^{96}\text{CaF}_2$  scintillators.  $0\nu\beta\beta$  demonstrates violation of lepton number conservation which is a key principle to realize matter dominate universe. It is an extremely rare phenomenon. CANDLES detects scintillation light by which electron energy can be measured. Energy of two electrons from the  $0\nu\beta\beta$  corresponds its Q-value (4.3 MeV). Therefore, a precise energy calibration at the Q-value region is crucial for its identification. CANDLES has been using a radioactive source of  $^{88}\text{Y}$  (1.8 MeV) to calibrate  $^{96}\text{CaF}_2$  scintillators. Although  $^{88}\text{Y}$  gives almost highest energy gamma ray, it is still much lower than the Q-value. We have been using linear extrapolation of the calibration to the Q-value region. Later we acquired data of peak positions for several other gamma rays for the calibration. They are  $^{40}\text{K}$  (1.4MeV),  $^{208}\text{Tl}$  (2.6 MeV), gamma energies from (n, $\gamma$ ) reaction on  $^1\text{H}$  (2.2 MeV),  $^{28}\text{Si}$  (3.5 MeV and 5.0MeV),  $^{56}\text{Fe}$  (7.6 MeV) and  $^{58}\text{Ni}$  (9 MeV). The observed peak positons showed deviation from the linear extrapolation of the  $^{88}\text{Y}$  calibration. The deviation appeared to be 0.4% at Q-value region and has energy dependence. Since realistic estimation of region of interest (ROI) is crucial for the estimation of  $0\nu\beta\beta$  decay rate, we have to confirm the deviation. We studied systematic errors, in particular, energy leak into liquid scintillation (LS) in detail. Since some fraction of gamma ray energy leaks into liquid scintillator, total energy appears to be different. For this purpose, we developed a new energy calibration system by using  $^{24}\text{Na}$  source (1.37 MeV and 2.75 MeV).  $^{24}\text{Na}$  is produced by neutron activation of  $^{23}\text{Na}$  inside  $\text{NaI(Tl)}$  scintillator.  $^{24}\text{Na}$  becomes  $^{24}\text{Mg}$  by emitting beta ray and then  $^{24}\text{Mg}$  emits two gamma rays. We can tag the two gamma rays by detection of beta rays by  $\text{NaI(Tl)}$ . Thus background free gamma ray spectrum is obtained which is new and important development of this research. In order to obtain enough  $^{24}\text{Na}$  intensity for the calibration, size of  $\text{NaI(Tl)}$  detector and configuration of neutron activation system are optimized by Monte Carlo (MC) simulation and confirmed by experiments. With new calibration system, we observed not only two gamma rays of  $^{24}\text{Na}$  but also gamma rays from backgrounds of  $^{40}\text{K}$  and  $^{208}\text{Tl}$ . This simultaneous measurement of 4 gamma rays is crucial for the evaluation of systematic errors. We confirmed the deviation from linear extrapolation of the  $^{88}\text{Y}$  calibration. The deviation may be attributed to genuine property of  $\text{CaF}_2$  scintillator. Background free spectrum obtained by the  $^{24}\text{Na}$  clearly shows that the MC simulation reproduces the experimental data. We studied deviation of  $0\nu\beta\beta$  peak by MC simulation since electrons give less energy leak into liquid scintillator than that of gamma rays. We found the energy deviation at Q value is  $0.96 \pm 0.04\%$  at maximum. Genuine property of  $\text{CaF}_2$  crystal may reduce the deviation which we leave for future study. The author plays a central role for this study, in particular, for the development of triggerable  $^{24}\text{Na}$  source.

新しいエネルギー較正法を開発し、Q値でのズレを明確にした本結果は $^{48}\text{Ca}$ の二重ベータ崩壊を研究する上で大きな一歩と言える。本論文は博士(理学)の学位論文として十分価値のあるものと認める。