Measurement of the gamma-ray strength in fresh and dried fruits using a scintillator

by

Jirapa Singhakulpitak

Submitted to the Department of Physics, Faculty of Science
in partial fulfillment of the requirements for the degree of

Bachelor of Science in Physics

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Abstract

Scintillator detector is an instument forth gamma-ray spectroscopy. The technique shows the result in the form of spectrum in a relation between counts and energy(keV). The principle of scintillator is based on the interaction between the gamma-ray photon from radioactive with the electron of scintillator detector (NaI(Tl)). The interaction include photoelectric effect, compton scattering and pair production.

This project forward on measuring the strength of gamma-ray in fresh and dried fruits using a scintillator from Potassium 40 energy. Potassium 40 is interesing because it is parity found on a component in the soil, fertilizer and a component in the form of potassium chloride (KCl) derived from citrus,fruits, honey and most vegetables are contaminate by soil or fertilizer. Moreover Potassium 40 is a radioactive and emit gamma-ray but hardly affect to human from a normal daily consumption.

Acknowledgments

First of all, I would like to thank Asst.Prof.Dr. Ratchapak Chitaree, my supervisor, for guidance, assistance and your kindness of my project.Moreover my supervisor give an opportunity for all mistake about me, pay attention and dedicated for me. Then I would like to thanks all menber of Applied Optics groups for suggestions and theaching about information of my project.

In the last year for senior have many story about me. Fist I am allergic to the mosquito bite, next I missed period around 8 months and I'm going to the doctor's, I am Polycystic Ovary Syndrome (PCOS) then I absent in many class. The last one, I so depress form senior project then I'm going to the psychiatrist and she diagnose Major depressive disorder(MDD). The symptoms are feeling sadness, tearfulness, emptiness, hopelessness,frequent or recurrent thoughts of death, suicidal thoughts, suicide attempts or suicide, then psychiatrist want to admits at hospital. When my symtoms are fared better and ready to start experiment but have a epidemic of Corona virus 2019 (COVID-19) then I can't go to department for experiment be the cause of I haven't the results. I very sadness for everything,then I give up to sadness and move on and I think the future are not out to see , this is out of control and I can't go back in the time.

From my story in the last year of senior. I think, I can't to move on if havn't my mom and my brother. I would like to thaks about support and believe to me. Moreover I would like to thanks my family, my friends, P'Beau, P'Run and other graduate senior for support and suggestion.Which cannot be missed to thanks Asst.Prof.Dr.Narumon Emarat and Miss Phetcharat Poungjad for support and beleive for me. the last one is my aunt, she have a cancer in liver,she is an inspiration for write the reports and graduate, I wanna see the picture of me and my aunt in Graduation day.

Finally, I would like to thank my self that fight for everything, many problem that I see, Thank you for patient and fight for this.

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Chapter 1

Introduction

This report is written in partial fulfilment of the requirement for the Bachelor degree of Science from the department of Physics at Mahidol University. The work was supervised by Asst.Prof.Dr. Ratchapak Chitaree.

1.1 Motivation

Potassium 40 (^{40}K) are radioactive that can be emit gamma ray. Which ^{40}K are component in the soil, fertilizer and component in form potassium chloride (KCl) derived from citrus,fruits and honey. Moreover most vegetables are contaminated by soil or fertilizer. So scintillator detector at the Department of physics can be used to prove this point.

1.2 Contributions by the Research

This project focuses on investigating the difference in the quantity of the radioactive potassium between fresh and dried fruits. there was a past research showing that dried fruits contain more radioactive potassium than fresh fruits. In this study, Figs was chosen because they have high potassium. Also, comparison between the different between dried figs and other dried fruits such as prunes and raisins were also studied. In addition, we also want to know the quantity of potassium in the potatoes which is root of vegetable.

1.3 Overview of the Report

This report is divided into five chapters. The first chapter is about the introduction and motivation of this research. Then, the second chapter is about background knowledge for this study. The methodology of this research will be presented in the chapter three. The discussion and future work will be presented in the chapter four. Finally, the conclusions of this work will be described in the chapter five.

Chapter 2

Background knowledge

This project studies about the measurement of quantity gamma-ray in fresh and dried fruits using a scintillator. In this chapter, the background knowledge of gamma spectroscopy, principle of scintillator, interaction of radiation and potassium 40 are reviewed.

2.1 Gamma Spectrocopy

Gamma ray is an electromagnetic when having high frequency and high energy. Gamma ray is radiated radiation by a radioactive of atomic neuclei. Normally gamma ray occurs after other alpha ray and beta ray decay.

Gamma spectroscopy is a technique to detect gamma ray in the form of spectrum. This project uses a scintillator to detect gamma ray which will be described in the next section.

2.1.1 Gamma Spectra from Common Commercial Sources

Normally gamma ray is emitted by the radioactive decay such as alpha ray, beta ray, positron ray or electron capture and the unit of energy is keV

2.1.2 Detector Energy Resolution

Spectrometer can detect the gamma ray energy in terms of ΔE (From spectrum of gamma ray energy). The resolution can be defined form Full Width at Half Maximum(FWHM) by FWHM devided by energy E_0 at photopeak shown in the following.

$$\%Resolution = \frac{100 \times \Delta E}{E_0}$$

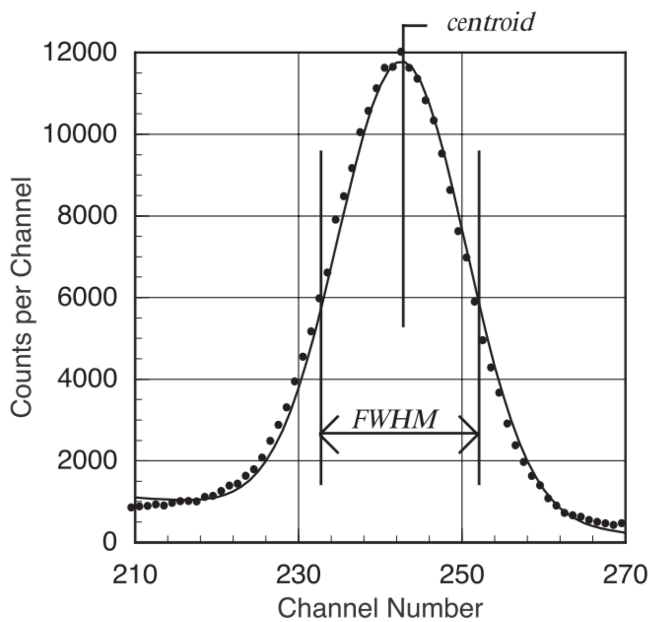

Figure 2-1: Gaussian fit to the 511 keV photopeak from a ^{22}Na spectrum

2.2 Scintillator by detector gamma radioactive

This project use a scintillator to measure the quantity of the gamma ray. Scintillator detector or fluorescent detector is composed of scintillator, light guide and photomultiplier(PMT). The component has a transparent property and has refractive index close to fluorescent.

2.2.1 Radioactive Decay

Radioactive decay is a process of element which is unstable atomic nucleus. In order to reach its stability, the radioactive decay occurs by changing proton or neutron resulting in a new chemical element. Resulting of radioactive decay for example Alpha decay occur when nucleus emit 2 protons or ${}^{4}_{2}He^{2+}$. Next is Beta decay occurs in two ways include β^- decay when nucleus emit 1 electron (e^-) and β^+ decay when nucleus emit 1 positron (e^+). Next is gamma decay when decay α and β after that nucleus will be excited to lower energy state and emitting gamma ray photon. The last one is electron capture occuring when nucleus may capture an orbiting electron,causing a proton to convert into a neutron.

2.2.2 Multichannel Scaling and Half-life

Essentially,multichannel scaling used to store the gamma data used in a different manner,selecting and starting the multichanel which result storing the total number of gammas counted in the selected time period

Half-life is the number of decay per second to decrease to half of the initial value and half-life is specific for each chemistry element and half-life($T_{\frac{1}{2}}$) value can be defined as follows,

$$\lambda = \frac{\ln 2}{T_{\frac{1}{2}}} = \frac{0.693}{T_{\frac{1}{2}}}$$

For λ is a constant for decreasing at a fixed rate.

2.2.3 Counting Statistics

From the previous section λ is the probability of decay per second, so probability rate for nondecay is 1-λ and P(x) is a binomial distribution for the probability of atoms decaying per second from a sample. If λ is small and the sample size is large, this binomial distribution can be approximated by

$$P(x) = \frac{\mu^x}{x!}e^{-u}$$

when μ is large can be approximated by normal gaussian distribution function

$$P(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-(x-\mu)^2/2\sigma^2}$$

where σ^2 is the square of the standard deviation and gives measure of the width of the distribution.

Normally in the experiment can approximate μ with our sample average $(\bar{A})$ and σ is the standard deviation. Frequency is the number of time that A is the result of measurement can defined by equation

$$Frequency = \frac{N_0}{\sqrt{2\pi\bar{A}}} e^{-(A-\bar{A}^2)/2\bar{A}}$$

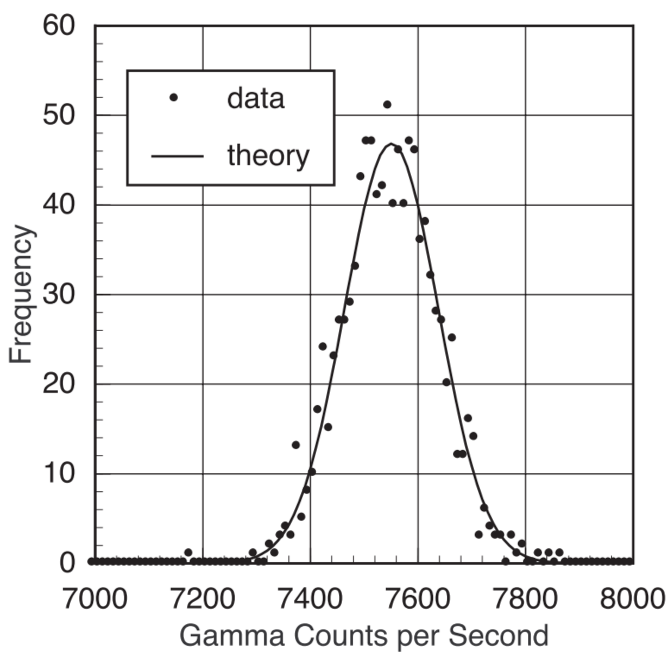

Figure 2-2: Gaussian fit to data with an average counting rate of 7,540/sec.

2.2.4 Absolute Activity of a Gamma Source

For real experiment,the result of count rate contain a noise of background for measurement some sample. So delete the noise of background and to define absolute activity of sample is given by

$$A_x = A\frac{\pi r^2}{4\pi d^2} f_\gamma \varepsilon$$

Where A_x is the observed count rate, f_r is gamma-decay fraction and ε is intrinsic probability,ε,can be determined experimental by from a measurement of count rate with known activity.For the 3.8 cm $\times$ 2.5 cm NaI(Tl) detector, the effective detector efficiency $\pi r^2\varepsilon/4\pi d^2$ as a function of gamma energy. [3]

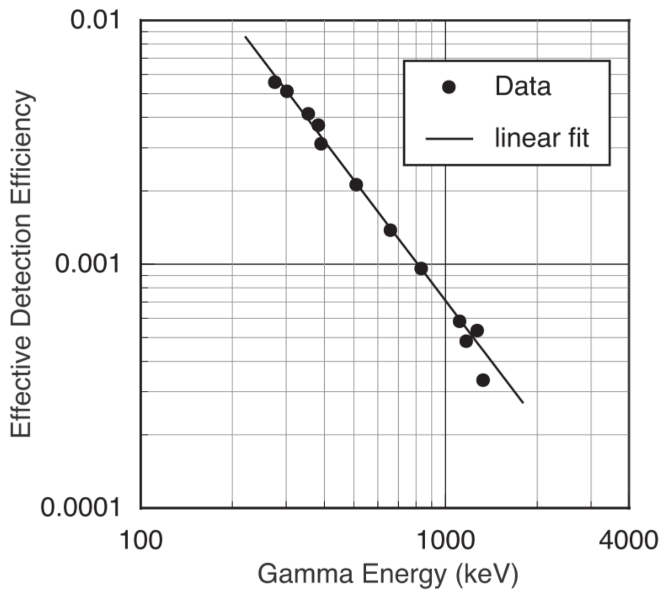

Figure 2-3: NaI(Tl) detector efficiency curve for a 3.8 cm $\times$ 2.5 cm cylindrical crystal with a source on the eighth shelf. Larger crystals will have greater detection efficiencies. The effective detector efficiency is the product $\pi r^2\varepsilon/4\pi d^2$

2.3 Interaction of Radiation with Matter

In this section, the interaction between scintillator and gamma ray from sample will be derived. Principle of scintillator,when gamma ray interaction with scintillator detector that gamma ray are emited energy due to the fact that interaction with matter such as photoelectic effect, compton scattering or pair production. When scintillator absorbs energy occur ionizaton which mention by next subsection.

2.3.1 Photoelectric effect

Photo electric process, when gamma ray photon interact with the valence electron. The effective is then released from the atom with a kinetic energy (E_e) given by

$$E_e = E_\gamma - E_{K_\alpha}$$

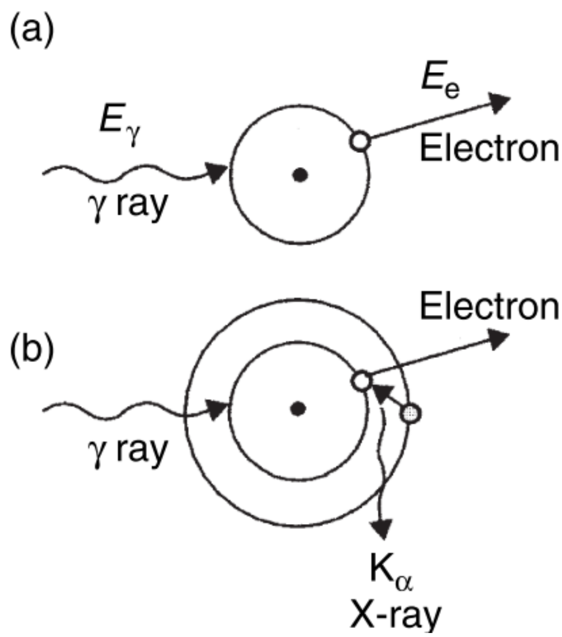

Figure 2-4: (a) The mechanism of photoelectric absorption (b) the emission of fluorescent X-rays

When E_γ is the Energy of gamma ray photon and E_{K_α} is a binding energy. The atom is in an excited state and E_{K_α} wanna be to equilibrium. The photoelectric effect given a photo peak and assume to be equal to the energy of gamma ray.

2.3.2 Compton Scattering

Compton scattering is the process when photon of gamma ray interacts with an electron. Then the photon of gamma ray is scattered.The energy imparted to the recoil electron is given by the following equation

$$E_e = E_\gamma - E'_\gamma$$

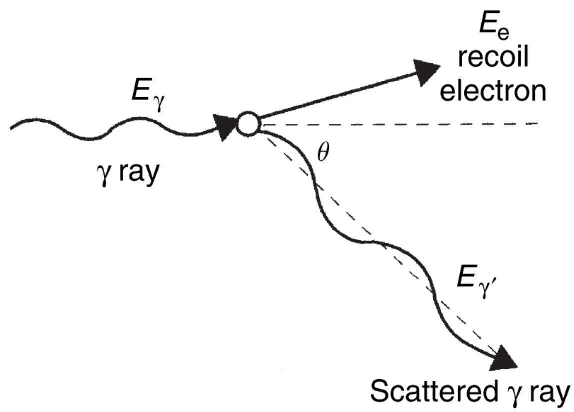

Figure 2-5: The mechanism of Compton scattering

$$E_e = E_\gamma(1 - \frac{1}{[1 + E_\gamma(1 - \cos\theta)/m_0c^2]})$$

When $\theta = 0$, the scattering is directly forward from the interaction point but when θ $= 180°$ occur, the gamma ray is backscattered and the process of compton scattering given the compton edge peak.

2.3.3 Pair Production and Annihilation

Pair producrion process takes place within the coulomb field of the nucleus,resulting in the conserversion of a gamma ray into electron-positron pair. A positron can be produce with electron by gamma ray with energy greater than 1,022 keV.

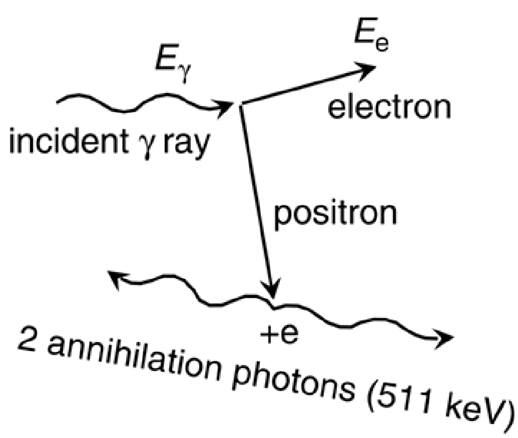

Figure 2-6: The mechanism of pair production

Annihilation process ocuur when positron will inervitably find itself near electron. The couple may exist for a short time, both positron and electron disappear and two photons produced. Normally positron and electron have energy 511 keV

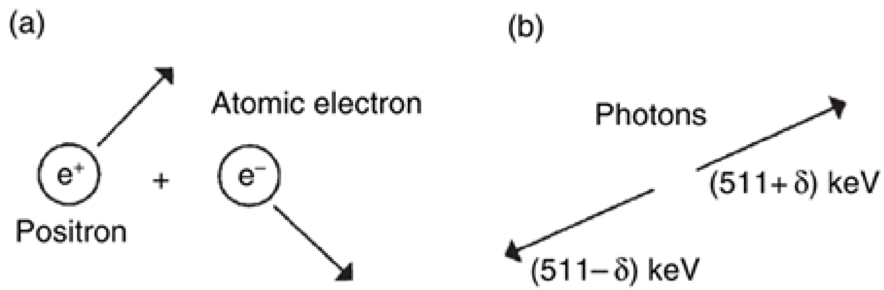

Figure 2-7: The annihilation process, showing how the resultant 511 keV photons could have a small energy shift (a) possible momenta before interaction giving (b) differing photon energies after interaction

2.4 Interaction Within The Detector

In this section all interactions are illustrated in the detector. So this is gamma ray interaction process mentioned before such as photoelectric effect, compton scattering, anihilation and pair production shown Figure2-8 . [2]

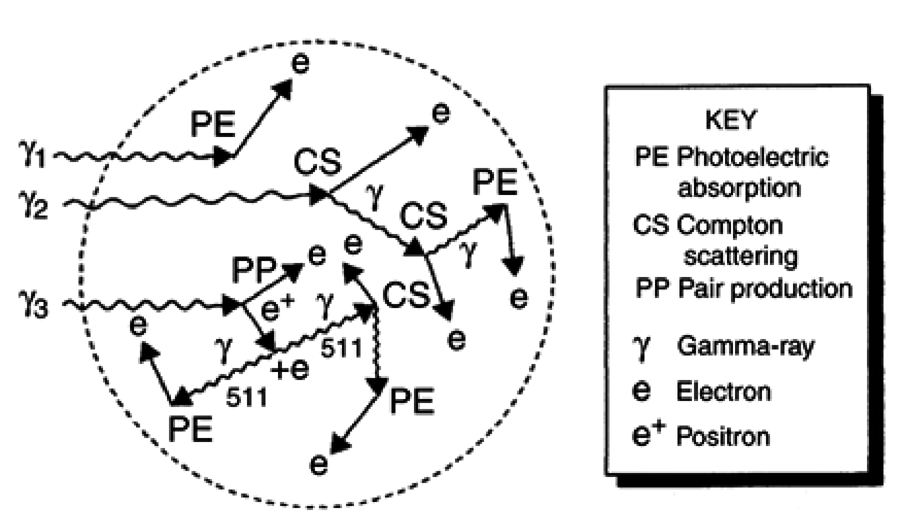

Figure 2-8: Examples of interaction histories within a detector.

2.5 Potassium 40

Potassium 40 (^{40}K) can be found in the soil, fertilizer, building materials, plants and animal. ^{40}K is radioactive and can radiate gamma ray. ^{40}K has a half-life 1.28×10^9 years. the diagram of ^{40}K decay is shown in Figer2-9.

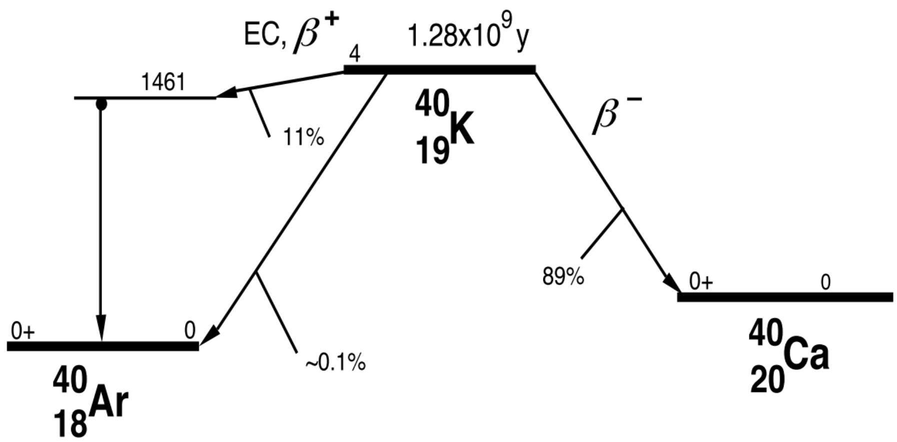

Figure 2-9: diagram of the radioactive decay of ^{40}K.

First of all ^{40}K decays β^- with an emission 89.3% of the time to the ground state to $^{40}_{20}$Ca. Then ^{40}K decays 10.5% of the time by electron capture to an excited state to ^{40}Ar.For there the emission of gamma ray gives an energy 1,460.8 keV.

Essentially, potassium is very common in nature. The potassium component in the form of the potassium chloride (KCl) is derived from citrus, fruits and honey.

Chapter 3

Methodology

This chapter is divided into 2 parts describing the Sample and Instrument. Next part describes experiment process such as sample preparation ,calibration with ^{137}Cs, measurement sample by the scintillator detector used in this experiment.

3.1 Samples and Instrument

Sample that seclected are Fresh figs, Dried figs, Prune, Raisins and Potatoes because they contain a high quantity of Potassium.

3.1.1 Objective

1. To study the working principle of the scintillator to detect gamma ray by radioactive sample.
2. To investigate the quantity of the radioactive fraction in fresh and dried fruits.
3. To determine the strength of gamma-ray in other fruits.

3.1.2 Equipment

1. Scintillator
2. container
3. Universal computer spectrometer USC-30
4. ^{137}Cs for calibration
5. Computer
6. Sample (Fresh figs, Dried figs, Prune, Raisins, Potatoes)
7. Compact scale

3.2 Experiment Process

This section describes the process of experiment, sample preparation, calibration with ^{137}Cs and measurement sample process.

3.2.1 Prepare sample

1. The potatoes were first softened in a microwave oven. They were then mashed by hand (including the skin) and tightly packed into the container.
2. The same preparation produces were conducted its other samples such as dried figs, prune and raisins with a quantity of around 3 kg. They were then mashed and tightly packed into the container.
3. Fresh figs were crushed by the blender and tightly packed into the container.

[1]

3.2.2 Measurement

1. Auto calibration by use Cs137 and exchange Channel to energy(keV).

2. Fist step of measurement by scintillator to record the background radiation in the air around 24 hours before measuring the radiation from the sample. After that measurement is made to the crushed potatoes in the container around 24 hours. Finally, the measurement of the background radiation in the air ismade again for 24 hours.

3. Follow by 2. and change sample such as dried figs, prune, raisins and fresh figs.

4. Write data count/min into the table.

Table 3.1: Counts per minute for the 1.46-MeV gamma peak. The counts/min were obtained for data taken over a 24-h period for a background (before), the sample measurement, and a background(after)

Sample	Count/min		
	Background (before)	Sample	Background (after)
Fresh figs			
Dried figs			
Prune			
Raisins			
Potatoes			

Chapter 4

Discussion and future work

4.1 Discussion

Due to the current situation of epidemic of Corona virus 2019 (COVID-19).could proceed make my as planned. So the discussion form will be based on three assumptions. First how much difference of the radiation fraction in the dried fruits and fresh fruits, dried fruits may contain high on potassium than fresh fruits does, form the experiment,Figs was chosen because they container high on potassium than other fruits. Next assumption is the in the radioactive fraction between dried figs and other dried fruits such as prunes and raisins. This is difficult to predict [4]. The last assumption is the quantity of the radioactive in potatoes especially in its root. The potato is full of soil and fertilizer which contain higher potassium.

4.2 Future work

From the mentioned reason, the measurement can't be made, So in the next step, if possible, once the measurement is made, a graph showing the relationship between counts and energy will also be presented.

Chapter 5

Conclusion

The project is about the measurement of the gamma-ray strength in fresh and dried fruits by scintillator detector. An in initial process of experiment is the measurement background radiation in the air around 24 hours, next step is the measurement of samples which divied into 2 processes such as sample preparation and measurement the sample. They are the all most important part for my project. However, this hasn't been done because, in area of Bangkok, there is an epidemic of Corona virus 2019 (COVID-19).

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