TOMSK POLYTECHNIC UNIVERSITY
ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

Министерство науки и высшего образования Российской Федерации
федеральное государственное автономное
образовательное учреждение высшего образования
«Национальный исследовательский Томский политехнический университет» (ТПУ)

Инженерная школа ядерных технологий
Направление подготовки 14.04.02 Ядерные физика и технологии
Отделение ядерно-топливного цикла

МАГИСТЕРСКАЯ ДИССЕРТАЦИЯ

Тема работы
Влияние температуры окружающей среды на результаты радиационного мониторинга

УДК 539.1.074.8:536.5

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Томск – 2021 г.

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«Национальный исследовательский Томский политехнический университет» (ТПУ)

School of Nuclear Science & Engineering
Field of training (specialty): 14.04.02 Nuclear Science and Technology
Specialization: Nuclear Power Engineering
Nuclear Fuel Cycle Division

MASTER THESIS

Topic of research work
Influence of ambient temperature on results of gamma radiation readings

UDC 539.1.074.8:536.5

Student

Group	Full name	Signature	Date
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Scientific supervisor

Position	Full name	Academic degree, academic rank	Signature	Date
Professor of NSFD	V.S. Yakovleva	PhD		

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Position	Full name	Academic degree, academic rank	Signature	Date
Associate Professor	Dan A. Verigin	PhD		

ADMITTED TO DEFENSE:

Programme Director	Full name	Academic degree, academic rank	Signature	Date
Nuclear Power Engineering	Vera V. Verkhoturova	PhD		

Tomsk – 2021

LEARNING OUTCOMES

Competence code	Competence name
Universal competences	
UC(U)-1	Ability to make critical analysis of problem-based situations using the systems analysis approach, and generate decisions and action plans.
UC(U)-2	Ability to run a project at all life-cycle stages.
UC(U)-3	Ability to organize and lead the teamwork and generate a team strategy to achieve the target goal.
UC(U)-4	Ability to use modern communication technologies to realize academic and professional interaction.
UC(U)-5	Ability to analyze and account for cultural diversity in the process of intercultural interaction.
UC(U)-6	Ability to set and pursue individual and professional activity priorities and ways to modify professional activity based on the self-esteem.
General professional competences	
GPC(U)-1	Ability to formulate goals and objectives of the research study, select assessment criteria, identify priorities for solving problems.
GPC(U)-2	Ability to apply modern research methods, evaluate and present the results of the performed research.
GPC(U)-3	Ability to present research outcomes in the form of articles, reports, scientific reports and presentations using computer layout systems and office software packages.
Professional competences	
PC(U)-1	Ability to manage personnel, taking into account the motives of behavior and ways of developing business behavior of personnel, apply methods for assessing the quality and performance of personnel, develop and implement measures aimed at preventing industrial injuries and environmental violations.
PC(U)-2	Ability to develop and ensure the implementation of measures aimed at improving, modernizing, unifying manufactured devices, facilities and their components, developing standards and certificates, improving reliability of equipment operation.
PC(U)-3	Ability to apply basic methods, techniques and means of obtaining, storing, processing information to plan and manage the life cycle of manufactured products and their quality.
PC(U)-4	Ability to create theoretical and mathematical models describing the condensed state of matter, the propagation and interaction of radiation with matter, the physics of kinetic phenomena, processes in reactors, accelerators, the effect of ionizing radiation on materials, humans and environmental objects.

PC(U)-5	Ability to use fundamental laws in the field of nuclear physics, nuclear reactors, condensed matter, ecology in a volume sufficient for independent combination and synthesis of real ideas, creative self-expression.
PC(U)-6	Ability to evaluate prospects for the development of the nuclear industry, use its modern achievements and advanced technologies in research activities related to the development of technologies for obtaining new types of fuel and materials, radioactive waste management methods and techniques.
PC(U)-7	Ability to assess risks and determine safety measures applied for new facilities and technologies, draw up and analyze scenarios of potential accidents, develop methods to reduce the risk of their occurrence.
PC(U)-8	Ability to analyze technical and computational-theoretical developments, take into account their compliance with the requirements of laws in the field of industry, ecology and safety, and other regulations.
PC(U)-9	Ability to carry out independent experimental or theoretical research to solve scientific and technical problems using modern equipment, calculation and research methods.
PC(U)-10	Ability to draw up technical assignments, use information technology, standard design automation tools and application software packages in the design and calculation of nuclear facilities, materials and devices, apply knowledge of methods of ecological efficiency and economic-value analysis in the design and implementation of projects.
PC(U)-11	Ability to develop design process documentation, execute engineering design and production projects.
PC(U)-12	Ability to conduct training sessions and develop instructional materials for the training courses within the cycle of professional training programs (bachelor degree programs).

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School of Nuclear Science & Engineering
Field of training (specialty): 14.04.02 Nuclear Science and Technology
Specialization: Nuclear Power Engineering
Nuclear Fuel Cycle Division

APPROVED BY:
Program Director
_____________ Verkhoturova V.V.
«____» ____________ 2021

ASSIGNMENT
for the Graduation Thesis completion

In the form:

Master Thesis

For a student:

Group	Full name
0AM9I	Eugenia Yeboah

Topic of research work:

Influence of temperature on the results of gamma radiation monitoring	
Approved by the order of the Director of School of Nuclear Science & Engineering (date, number):	№ 29-49/c dated January 29, 2021

Deadline for completion of Master Thesis:	05.06.2021

TERMS OF REFERENCE:

Initial date for research work: *(the name of the object of research or design; performance or load; mode of operation (continuous, periodic, cyclic, etc.); type of raw material or material of the product; requirements for the product, product or process; special requirements to the features of the operation of the object or product in terms of operational safety, environmental impact, energy costs; economic analysis, etc.)*	Influence of temperature on the results of gamma radiation monitoring. The low gamma background radiation was monitored with a scintillation detector BDKG-03, a laptop to record the experimental data and a climatic chamber to depict the environmental condition (temperature). The BDKG-03 is a NaI(Tl) inorganic scintillation detector. It is extremely delicate scintillation counter with sharpness of 350 (imp/s)/(μSv) for ^{137}Cs that is used to monitor gamma background radiation. It is mostly used for outdoor measurement of gamma radiation. The laptop has a software known as

	"Atexch" installed on it, which provides the Indication of dose and radiation measurement values, as well as writing into file and reading previously stored data, response when measured value thresholds are exceeded, error indication by instrument, message analysis and display in case of error conditions and multiple instances of program can be run in case of more than one instrument is connected to different PC ports. A climatic chamber is a confined chamber that duplicates different atmospheric conditions like temperature, humidity, and so on. It is used to examine electronic devices, industrial products and resources to see how these atmospheric conditions would influence them. The climatic chamber is close to 1000 litres in size, and its temperature ranges from about -60 - +60 ºC. It has a temperature and humidity instability precision of ±0.5% and ±1%RH respectively.
List of the issues to be investigated, designed and developed *(analytical review of literary sources with the purpose to study global scientific and technological achievements in the target field, formulation of the research purpose, design, construction, determination of the procedure for research, design, and construction, discussion of the research work results, formulation of additional sections to be developed; conclusions).*	• To review literature • To formulate the goals and objectives. • To conduct the experiment • To find the influence of temperature on detector readings of low gamma background. • To find a new temperature correction coefficient to calculate dose rate of low-level gamma radiation.
List of graphic material *(with an exact indication of mandatory drawings)*	

Advisors to the sections of the Master Thesis
(with indication of sections)

Section	Advisor
One: Literature review	Professor Valentina S. Yakovleva
Two: Materials and Methodology	Professor Valentina S. Yakovleva
Three: Results and Discussion	Professor Valentina S. Yakovleva
Four: Financial management, resource efficiency and resource saving	Assistant Professor Verigin D.A.
Five: Social Responsibility	Associate Professor E.V. Menshikova

Date of issuance of the assignment for Master Thesis completion according to the schedule	05.06.2021

Assignment issued by a scientific supervisor / advisor (if any):

Position	Full name	Academic degree, academic status	Signature	Date
Professor of NSFD	Valentina S. Yakovleva	Professor, PhD		

Assignment accepted for execution by a student:

Group	Full name	Signature	Date
0AM9I	Eugenia Yeboah		

Министерство науки и высшего образования Российской Федерации
федеральное государственное автономное
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«Национальный исследовательский Томский политехнический университет» (ТПУ)

School of Nuclear Science & Engineering
Field of training (specialty): 14.04.02 Nuclear Science and Technology
Specialization: Nuclear Power Engineering

Level of education: Master degree program
Nuclear Fuel Cycle Division
Period of completion: spring semester 2020/2021 academic year

Form of presenting the work:

Master Thesis

SCHEDULED ASSESSMENT CALENDAR
for the Master Thesis completion

Deadline for completion of Master's Graduation Thesis:	05.06.2021

Assessment date	Title of section (module) / type of work (research)	Maximum score for the section (module)
26/03/2021	Literature Review and Methodology	...
29/03/2021	Data collection	...
16/04/2021	Analysis of the experimental data	
06/05/2021	Preparation of the report and submission	
25/05/2021	Preparation of defense	

COMPILED BY:
Scientific supervisor:

Position	Full name	Academic degree, academic status	Signature	Date
Professor of NSFD	Valetina S. Yakkovleva	Professor, PhD		

APPROVED BY:

Program Director	Full name	Academic degree, academic status	Signature	Date
Nuclear Power Engineering	Vera V. Verkhoturova	PhD		

TASK FOR SECTION
«FINANCIAL MANAGEMENT, RESOURCE EFFICIENCY AND RESOURCE SAVING»

To the student:

Group	Full name
0AM9I	Eugenia Yeboah

School	Nuclear Science and Engineering	**Division**	Nuclear Fuel Cycle
Degree	Master	**Educational Program**	14.04.02 Nuclear Power Installation Operation

Input data to the section «Financial management, resource efficiency and resource saving»:	
1. *Resource cost of scientific and technical research (STR): material and technical, energetic, financial and human*	– Salary costs – 174214.63 – STR budget – 325707.14
2. *Expenditure rates and expenditure standards for resources*	– Electricity costs – 5.8 rubles per 1 kW
3. *Current tax system, tax rates, charges rates, discounting rates and interest rates*	– Labor tax – 27.1% – Overhead costs – 40%
The list of subjects to study, design and develop:	
1. *Assessment of commercial and innovative potential of STR*	– comparative analysis with other researches in this field;
2. *Development of charter for scientific-research project*	– SWOT-analysis;
3. *Scheduling of STR management process: structure and timeline, budget, risk management*	– calculation of working hours for project; – creation of the time schedule of the project; – calculation of scientific and technical research budget;
4. *Resource efficiency*	– integral indicator of resource efficiency for the developed project.
A list of graphic material *(with list of mandatory blueprints):*	
1. *Competitiveness analysis* 2. *SWOT- analysis* 3. *Gantt chart and budget of scientific research* 4. *Assessment of resource, financial and economic efficiency of STR* 5. *Potential risks*	

Date of issue of the task for the section according to the schedule	

Task issued by adviser:

Position	Full name	Scientific degree, rank	Signature	Date
Associate professor	E.V. Menshikova	PhD		

The task was accepted by the student:

Group	Full name	Signature	Date
0AM9I	Eugenia Yeboah		

Task for section
«Social responsibility»

To student:

group	Full name
0AM9I	Eugenia Yeboah

School	Nuclear Science and Engineering	Department	Nuclear fuel cycle
Degree	Master programme	**Specialization**	Nuclear Power and Engineering

Title of graduation thesis:

Influence of ambient temperature on the results of gamma radiation monitoring	
Initial data for section «Social Responsibility»:	
1. Information about object of investigation (matter, material, device, algorithm, procedure, workplace) and area of its application	Detectors of gamma radiation monitoring. Application area: radiation monitoring of low dose rates
List of items to be investigated and to be developed:	
1. Legal and organizational issues to provide safety: – Special (specific for operation of objects of investigation, designed workplace) legal rules of labor legislation; – Organizational activities for layout of workplace.	– Labour code of Russian Federation #197 from 30/12/2001 GOST 12.2.032-78 SSBT – Sanitary Rules 2.2.2/2.4.1340-03. Hygienic requirements for PC and work with it
2. Work Safety: 2.1. Analysis of identified harmful and dangerous factors 2.2. Justification of measures to reduce probability of harmful and dangerous factors	– Enhanced electromagnetic radiation level – Insufficient illumination of workplace – Excessive noise – Deviation of microclimate indicators – Electric shock – Ionizing radiation
3. Ecological safety:	– Indicate impact of natural radionuclides on hydrosphere, atmosphere and lithosphere.
4. Safety in emergency situations:	– Fire safety;

Assignment date for section according to schedule	05.06.2021

The task was issued by consultant:

Position	Full name	Scientific degree, rank	Signature	date
Associate Professor	Verigin D.A.	Cand.of Sc.		

The task was accepted by the student:

Group	Full name	Signature	date
0AM9I	Eugenia Yeboah		

Abstract

The master’s dissertation work contains 120 pages with 24 figures; 26 tables and 107 references.

Keywords: Temperature correction coefficient, scintillation detector (BDKG-03), dose rate, low gamma background radiation, count rate, an algorithm for calculating dose rate.

The main goal of the dissertation work was to find the effect of temperature of detector readings used for measurement of low gamma background radiation and to find a new temperature correction coefficient.

For some years now, students at Tomsk Polytechnic University have used a radiation detector known as the scintillation detector BDKG-03 for gamma radiation monitoring. Results of many research done using this detector for measuring low gamma background radiation have led to doubt in the correctness of the factory algorithm for converting pulse into dose. Based on this, the main objective was formulated. This research was carried out at the Institute of Monitoring of Climatic and Ecological System using a climatic chamber, which depicts the weather conditions like temperature, rainfall, and so on. Upon completion of the experiment, it was revealed that the dependence of the dose rate on temperature using the cps from the factory algorithm gave inaccurate findings for low-level doses. This is because the detectors were calibrated using high radioactive sources, therefore, affecting the temperature correction coefficient when used to measure a low-level dose. Also, it was found that the readings obtained from the detector for monitoring dose rate are dependent on temperature, therefore it must have a temperature correction coefficient. The new temperature correction coefficient that may be used to calculate low dose was found to be $\mathrm{k(T)} = (3.58 \times 10^{-13}\mathrm{T} + 2.152 \times 10^{-9})$ and validation of the results proved that it can be used to calculate dose rate of low gamma background.

Application Areas: Environmental radiation monitoring, instrumentation industry.

Cost-effectiveness: The project was not expensive.

List of Acronyms and Abbreviations

EPA – Environmental protection Agency

EMR – Electromagnetic radiation

UNSCEAR - United Nations Scientific Committee on the Effects of Atomic Radiation

USNRC – United State Nuclear Regulatory Commission.

CDC – Center for Disease Control and Prevention

ICRP - International Commission on Radiological Protection

IARC – International Agency for research cancer

ICRU – International Commission on Radiation Units and Measurement

LLNL - Lawrence Livermore National Laboratory

PMT – Photomultiplier tube

Ns – Nanosceconds

Imp – Impulse

Sv – Sievert

Z – Atomic number

eV – Electrovolt

LY – Light yield

LED – Light Emitting Diode

NaI(Tl) - Thallium – activated Sodium Iodide

cmp – Count per minute

STP – Standard temperature and pressure

Table of Contents

Introduction

Radiation monitoring has come to be of great significance in our world today. It involves the measurement of radiation in our environment. It became vital to monitor and measure background radiation especially after the Fukushima Daiichi Nuclear Power Plant accident. After the accident, radioactive substances such as caesium were released into the atmosphere, which led to the loss of life and destruction of property. This makes it very important to monitor the level of radiation in the environment (Takeyasu, 2012).

Radiation detectors are devices that are used for radiation monitoring or for the measurement of radiation dose. These detectors work based on the principle of interaction with matter. That is they interact with matter. Energy is lost by radiation when they pass through matter. Gamma-ray produces photons when it loses its energy while other particles become excited and ionize to produce free-charged carriers. These photons and free-charged carriers are what the radiation detectors detect and convert into electrical signals. There are different types of detectors. These include; the scintillation detectors, ionization chamber detectors, semiconductor detectors and so on (Kapoor & Ramamurthy, 1986).

Most of the radiation detectors are used in open environments, which mostly have different temperatures. The temperature ranges from (-40^{o}C - +40^{o}C), hence most radiation detectors have a temperature correction factor or coefficient, which are used to calibrate the dose rate read by these detectors. Over the years, the BDKG 03, which is a scintillation detector, has been used for research in Tomsk Polytechnic University to measure the dose rate for gamma background radiation. There has been doubt about the correctness of converting pulse to dose due to distortions that have been shown when we measure radiation doses that are very low. These fluctuations do not show when the radiation levels are very high.

This work was performed to investigate how ambient temperature affects the readings of low gamma background radiation and to obtain a temperature correction factor that can be used to calculate the results of low gamma background radiation obtained from the scintillation detector.

Statement Problem

Temperature is one important factor that is taken into consideration when measuring background radiation. As the weather changes every day, the temperature outside also changes and most of the detectors used to measure radiation are used at different periods of the year. Lots of research has been carried out to study the impact of temperature on scintillation detectors. A study accomplished by Casanovas et al. (2012) revealed that changes in temperature lead to a shift in peak in NaI detectors. Also, Mitra et al. (2016) conducted research, which proved that temperature differences influence NaI detectors (Yeboah et al., 2021).

Scintillation detectors are mostly designed to operate at ambient temperatures but the temperature outdoor is not always ambient. Manufacturers mostly add a built-in algorithm software, which is used to adjust the result obtained at different temperatures (Casanovas et al., 2012). Detectors used for radiation monitoring are calibrated for high sources (high dose rate) hence when used to take the measurement for low gamma background radiation (Kelsingazina, 2020), the reading produced contain error because the temperature correction factor used in the calibration of the scintillation detector turned out to be for only high-level radioactive sources.

Objectives

To investigate the effect of ambient temperature on detector readings used for measuring low gamma background radiation and to obtain a new temperature correction factor that may be used to calculate the results of low gamma background radiation obtained from the scintillation detector.

Specific Objective

To obtain a new temperature correction factor from dose rate dependence on temperature.

To compare the experimental and the built-in factory temperature correction coefficient.

To calculate and investigate the correlation with changes in meteorological parameters of low dose rate (gamma background radiation) taken in Tomsk using the experimental temperature correction coefficient.

To compare the new algorithm found with an investigation done with the factory built-in temperature correction coefficient.

Research Questions

What is the effect of temperature on inorganic scintillators (NaI (Tl))?

How to correct and stabilize the influence of temperature on inorganic scintillators (NaI (Tl))?

What is the temperature correction coefficient and does it depend on temperature?

Does the detector reading of the dose rate depend on the temperature correction coefficient?

How does temperature affect low gamma radiation readings with a scintillation detector?

Why did the results of the scintillation detector BDKG-03 give fluctuations when used to measure low radioactive gamma sources?

Chapter 1 Literature Review

1.1 Background radiation

All matter contains atoms and when these atoms are unstable they disintegrate spontaneously into radioactivity which leads to the release of ionizing energy. These ionizing radiations are also known as background radiation. Energy is absorbed when ionizing energy penetrates through matter such as tissue and this leads to ionization or excitation of the matter. (UNSCEAR, 2010).

Ionizing radiation mostly causes an electron to be taken out of its atom or orbitals when they possess sufficient forces and they always come in two ways or forms, that is they are either a particle or a wave. Radionuclides are always unstable, so for them to become stable, they undergo a process called radioactive decay. Radioactive decay is the transformation of an atom into another nucleus by emitting high-energy waves and particles such as alpha, beta, gamma, proton, neutron, etc. Alpha, beta and gamma are the three main types of radiation that are released during radioactive decay. The kinetic energy of a particle helps to determine the nuclei emitted by alpha, beta and gamma radiation (EPA, 2007).

Radiations are an 'energy package' that moves along a straight path. The highest energetic photons of the electromagnetic spectrum are represented by gamma rays with an energy ranging from 10^4 eV to 10^7 eV (Schönfelder, 2013). The electromagnetic spectrum is shown in figure 1 (Humboldt State University, 2019). Gamma radiation comes in the form of electromagnetic radiation and is emitted from excited nuclei. Photons are electromagnetic radiation, which originates from atoms and behave in a wave-like form with no mass. They have the highest energy and shortest wavelength. This makes it easier for them to penetrate through human tissues than other radiation but gamma rays find it very difficult to penetrate through thicker materials such as lead. They either stop or slow down gamma radiation, this is why lead materials are mostly used as a shield against gamma radiation (EPA, 2007; Turner, 2008).

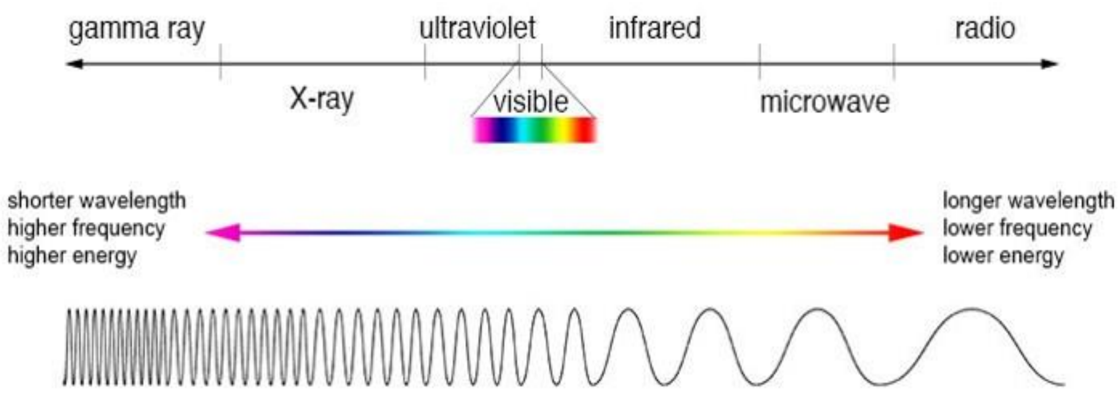

Figure 1.1 Electromagnetic Spectrum

Three main radio nuclei exist in the environment, they include potassium (^{40}K), the descendants of uranium (^{238}U) and thorium (^{232}Th). These three radionuclides are naturally occurring radionuclides. Cesium is also one of the important radionuclides in the environment, it has two isotopes ^{134}Cs and ^{137}Cs with a half-life of 2 years and 30 years respectively. It is mostly found in the soil and is transferred to plants when we plant them in the soil and animals when they eat these plants. When humans consume these plants and animals, the radionuclide is transferred through ingestion and external exposure (UNSCEAR, 2000).

Ionizing radiation, when exposed to large or low doses, can lead to health effects in humans. It can cause both biological and genetic defects. When the exposure level is high, it can cause immediate damage to the human cells while exposure to a low-level dose can cause the number of stochastic health issues with a high risk of getting cancer when the amount of exposure is increased (Prasad et al., 2004; UNSCEAR, 1986).

There are two main sources of background or ionizing radiation. The natural and artificial or man-made background or ionizing radiation (Eisenbud, 1984).

1.2 Natural background radiation

Natural background radiation is found everywhere in the world. UNSCEAR, 2010 defined three main sources of natural radiation which humans can be exposed to in the environment. They include cosmic radiation, terrestrial radiation, internal radiation (inhalation and ingestion). These sources mostly produce very small exposure and therefore do not cause much harm to the human body. However, there are some naturally occurring radionuclides that are of major concern since they cause rise in the amount of dose in the environment such as radon, which is a daughter nucleus of uranium. Approximately above 80% of the background radiation humans are exposed to come from natural background radiation (Ahmed, 2007).

1.2.1 Cosmic Radiation

Cosmic radiation consists of fast-moving particles, usually protons that are emitted from different sources such as the sun and celestial bodies. Radiations are produced when there is an interaction between charged particles from the sun or celestial bodies and the earth's atmosphere and magnetic field. These ionizing radiations at a point pass through the earth's atmosphere and are absorbed by humans from space. Even though the earth's atmosphere acts as a shield, which prevents these radiations from getting to humans, some of the radiations can penetrate through them and get to the earth. When humans are exposed too much to this radiation, it can cause skin burn and in worse cases lead to cancer. Photons are also cosmic radiation, but their energy level is that they do not cause much harm to humans. The main source of natural ionizing radiation is the earth's crust where humans live (Ahmed, 2007).

1.2.2 Terrestrial Radiation

The earth is made up of radionuclides, which decay with time into other radionuclides. Over the years, radionuclides with short half-life have become extinct from the earth while those with longer half-life remain. These radionuclides are mostly naturally occurring radionuclides such as uranium, potassium and thorium and their progeny, which are found in soil, vegetation and water. Gamma radiation is produced from these radionuclides and humans are exposed to it both externally and internally through inhalation of a radionuclide gas known as radon. Radon is an odourless, colourless noble (inert) gas, which is a decay product of radium. Radium is a decay product of uranium. Radon has a half-life of 3.8 days but because it is a daughter nucleus of uranium and thorium, which has a long half-life, it would always be in existence. Radon is an inert gas hence it emanates from the soil into the atmosphere. The nature of the soil and the geological location of a particular place causes the concentration of uranium and radium to differ (Oakley, 1972).

1.2.3 Internal radiation

Humans are exposed to internal radiation through ingestion or inhalation. The radionuclides associated with internal radiation can be found in all humans. These include lead-210, potassium-40 and carbon-14. These radionuclides are ingested or inhaled by humans when a person takes a portion of food or drink that contains radiotracers, when a person inhales a radioactive material from air and building, when a person absorbs a radioactive material through the skin and so on. These radionuclides do not cause damage to the human tissue because they are in minimal quantities (Ahmed, 2007).

1.3 Artificial or man-made background radiation

Scientists can also produce radiation in the laboratory under controlled conditions and this is termed artificial or man-made radiation. Artificial background radiation makes up about 20% of the background radiation in the environment. These man-made radiations are released into the environment from areas such as medicine, nuclear technology, geology, industries and so on. They are produced from sources such as x-ray machines that are used in medicine, x-ray scanners that are used at the airport, nuclear medicine, lasers and particle accelerators. These mostly produce only one type of radiation. Nowadays, medical imaging has become one of the advanced nuclear technologies that are being used at the hospital to cure diseases such as cancer. Medical imaging has become the main source of artificial or man-made background radiation. Nuclear radioactive waste production and nuclear accidents can also be a source of artificial background radiation. During the nuclear accident, especially the nuclear accident popularly known as the Fukushima Daiichi, which occurred in Chernobyl, the total background radiation of the area increased and this affected both the health of the people and the environment. Some products and devices made for other purposes also produce radiation. Examples of such products and devices include the television, materials used for building, phosphate fertilizer, compact fluorescent light bulbs, and detectors for smoke. Some human activities such as radiation metrology also increase the artificial or man-made background radiation. Isotopes that are sometimes produced in man-made background radiation include Iodine (^{131}I), Technetium (^{99m}Tc), Cobalt (^{60}Co), Iridium (^{192}Ir), (Caesium) ^{137}Cs and others (Thorne, 2003).

1.4 Radiation exposure

The application of background or ionization radiation leads to the release of radiation into the environment. The exposure of humans to these radiations is termed radiation exposure. Humans are exposed to radiation through both internal and external means. Diagnosis of diseases, treatment of diseases, production of electricity and nuclear weapon production are examples of how humans become prone to radiation. People working in some facilities such as the hospital, nuclear power plant and so on are sometimes exposed to radiation and this type of exposure is called occupational exposure (EPA, 2007). Humans are also exposed to radon, which is a progeny of uranium, a naturally occurring radionuclide through indoor pollution. Radon is an inert gas so it is inhaled by humans when they are exposed to it. The most common means by which people are exposed to radiation are by medical means (diagnosis and treatment) and natural sources of background radiation (CDC, 2015).

Human beings subject to ionizing radiation can cause health risks. This was first released in 1895 after the X-ray was discovered. Exposure to ionizing radiation can cause skin burn, cancer, hereditary malfunction and others. These effects of ionizing radiation can be categorized into two groups; deterministic effect and stochastic effect. The deterministic effect is the effect, which leads to complete damage of cells or death of cells. This can cause damage to the capability of an organ or tissue to function properly. The rate at which a tissue or an organ can be damaged or impaired depends on Dosimetric quantities like the quantity of dose absorbed by it (absorbed dose), dose rate and also a threshold level of dose is required or needed in order for it to become clinically observable. This means that the effect or the rate at which a cell is damaged depends greatly on the amount of dose absorbed. Some early signs or symptoms of deterministic effect on tissues include gastrointestinal symptoms (for example; haemorrhagic diarrhoea), failure of bone marrow (such as anaemia and leukocytopenia) and so on. These effects may be temporary or occur for only a short period since the organism may replace the cells lost. The second effect, which is the stochastic effect, is being pruned to ionizing radiation of a low dose. This effect does not cause damage to the cells but changes them. Thus they cause harm to the genetic cells which might lead to radiation-induced cancer some years to come or may become a hereditary malfunction or disease which may be passed on from generation to generation. This effect does not require a threshold level of dose whose probability of happening and severity is proportional or dependent and independent respectively on the dose. That is the stochastic effect increases with increasing dose and not threshold (ICRP publication 103, 2007; Kamiya et al., 2015).

1.5 Dose and dose rate

Radiation dose or dose as it is mostly termed as is defined as the amount of damage caused by radiation to a tissue, organ or body. It can be expressed as equivalent dose, absorbed dose and effective dose. Dose rate is defined as the dose per time unit. The ambient gamma equivalent dose is found by dividing the energy absorbed by matter by the mass of the tissue it is exposed to, which is mostly measured in milligrays. This energy comes from ionizing radiation of radionuclides from the atmosphere, soil surface as well as cosmic. Effective dose is mostly used as an indicator of the potential biological effects related to the amount of ionizing radiation that humans are exposed to. Effective dose is measured in millisieverts (mSv). The ambient gamma equivalent dose rate on the ground varies from time to time due to the concentration of ^{222}Rn in the air which has been influenced by changes in our weather conditions and factors such as the amount of precipitation, depth of snow cover, the temperature of soil and air. The ambient equivalent dose rate of gamma radiation can be calculated using different methods such as the scintillation and gas discharge counter (IARC, 2000). The ICRU sphere was selected as a phantom, which was close to the human body for a single dose equivalent to be used to describe the potential irradiation of an individual. The ICRU sphere that was selected was made of a diameter of 30 cm tissue-equivalent plastics with a 1 g/cm^3 density and 76.2% oxygen, 11.1% carbon, 10.1% hydrogen and 2.6% nitrogen mass composition. The "ambient dose equivalent", H*(d), sometimes in a radiation field is defined as the dose equivalent that ought to be formed by the conforming extended and allied field at a depth d in the ICRU sphere, on the radius contradicting the path of the allied field. In an extended field, the fluence and it is directional and distribution of energy have identical values all over the volume of concern as in the real field at the reference point. An extended and allied radiation field requires additionally that the fluence is unidirectional. For strongly penetrating radiations, a reference depth, d, of 10 mm was recommended (Vana et al., 2003).

1.6 Count rate

The count rate of background radiation refers to the number of counts or amount of radiation that is emitted per second or minute. It is measured in units of impulse per second (imp/sec). Count rate is measured in smaller minutes so as not to impose any risk on human health. The count rates are registered inside the detector and it depends on the kind of particle being measured. It can be measured in any direction but when we use a detector to measure, the count rate is measured in a particular direction, which is just a fraction of the original count of background radiation or source of radiation.

1.7 Influence of temperature, pressure, humidity, wind and precipitation on background radiation.

Factors such as temperature, pressure, wind, precipitation different or various influences on gamma radiation background. Mercier et al. (2009) did a study on the "increase of environmental gamma-ray dose rate during precipitation: a strong correlation with contributing air mass". From the results obtained, it was observed that there was an increase in environmental gamma-ray dose rate during precipitation intervals. It was explained that the increase was because of radon progeny in the rain droplets and snowflakes, which lead to an effect on artificial radioactivity. Another study was done by Livesay et al. (2014) on the monitoring of the increase in background radiation due to rain using Radiation Portal Monitors. It was noted from the study that there was an increase in the counting rate of gamma rays in RPMs. The increase in the background radiation was attributed to the rain, which contained two radioactive daughters of radon-222 (Pb-214 and Bi-214).

For temperature and pressure, a study was carried out by Zafrir et al. (2013) on how temperature and pressure influence radon differently within a subsurface geological media. This research was carried out in different areas in the southern part of Israel which include; a research tunnel known as Amram Mountain in Elat and at Makhtesh Ramon in Gevanim valley where there is a swallow borehole. It was found out that the site where the research takes place is also an element that can affect the temperature and pressure, if the site where measurement was taken is an enclosed place with uninterrupted environmental conditions then the radon in the environment would be even with those in the soil surface or rock. The result shows that during daytime, intra-seasonal and periodic differences in the radon concentration are due to the ambient temperature gradient in the environment and not that of the rock or soil surface. The result obtained from the shallow, open borehole showed that the radon inside the permeable media and the radon in the exposed borehole was not balanced but different. The results obtained from the gamma detectors that were used to measure the variation in the concentration of the radon in permeable rocks showed that there was a strong dependence between the concentration of the radon and the daily changes of the outer surface temperature from 1 m to 85 m. However, the alpha detectors that measure the variations in the concentrations of the radon in borehole air that was not so deep (about 1 m) showed a clear negative correlation with atmospheric pressure waves at twice a day, a day, and intra-seasonal time scales. At a height of quite a few tens of meters, external pressure waves brought about negative correlated radon changes enduring the same time, but damaged the well-arranged radon frequent day to day measurement in air space, even though virtually not disrupting the daily radon changes within the nearby permeable media.

1.8 Photon interaction with matter

A detector is a device that converts particles that enter into it into signals. It works based on the principle of some radiation particles' interaction with matter (Tsoulfanidis, 1995). For the detection of gamma rays, photons interact with matter. There are different ways by which a photon interacts with matter. These include; pair production, photoelectric effect, Compton scattering and Rayleigh scattering. When a beam of photons passes through a material, the photons go through different types of interaction. In order to know the type of photon interaction with the material that occurs most, we mostly use the cross-section of the interactions to determine the highest value at particular photon energy. The photoelectric effect occurs when a photon is completely absorbed by the atom and hence makes it unstable. In order for the atom to attain stability, it emits electrons from its bound atomic shell. The incident photon energy has to be greater than or equal to the binding energy of the loosely bound electron in the atom. Compton scattering is when a photon experiences inelastic scattering from a freely or loosely bound electron, which is at rest. This means that part of the photon is absorbed while the other part is scattered and it continues to move with a lower energy. The scattering may be due to the result of collusion since the electrons are almost free. The probability of Compton scattering occurring or happening is much higher than the photoelectric effect when the incident photon's energy is more than that of the binding energy of the innermost electron of the target atom. Pair production refers to the conversion of a photon into a positron and an electron. This process requires the conversion of energy into mass since photons have no mass but electrons and positrons do. For pair production to occur, it requires a photon energy above 1.022 MeV. Rayleigh scattering is an elastic scattering process, which requires very minimal coupling of photons to the internal structure of the target atom. The photons are deflected with very small or little energy loss and only significant at low photon energies that are less than 50 keV (Ahmed, 2007; Lewellen, 2008).

1.9 Radiation detectors

A radiation detector is an instrument or a device used to measure radiation. The most commonly used detectors use the process of either excitatory or ionization, these are processes by which energy is transferred from radiation into a stopping material. Scintillation detectors are part of the most effective and multipurpose detectors currently used in the world. It operates on the principle of a charged particle emitting fluorescent light when it passes through a stopping material. It uses the process of excitation even though the process of ionization and molecular dissociation is used when the stopping material interacts with the incident particle. There are different types of radiation detectors, most of which use the process of ionization of charged particles. These types of detectors include ionization chambers, semiconductor radiation detectors, Geiger counters and proportional counters. If charged particle such as alpha particle and electrons are the incident radiation then the ionization process occurs directly but if the incident particle were gamma-rays then the particle would have to interact with the detector first to produce a charged particle before the ionization process takes place, hence it is a secondary process (O'kelley, 1961).

Radiation detectors are applied in different fields but can be categorized or grouped into three main branches; measurement, search and protection. Detectors that are used for radiation measurement are used to monitor places where there is suspected to be a radioactive source. These detectors are used to create awareness or make known the strength of a radioactive field, boundaries of a radioactive area or the spread of radioactive contamination. They have a high range of measurement and are made in such a way that they can measure only one type of radiation. The second category of radiation detector, which is search, is used to prove that radiation is not expected at a particular area and the need to keep it that way. These types of detectors are highly sensitive in a way that they can easily detect very small or concealed radioactive sources. The last category, which is protection, is nearly comparable to that of the measurement in the way that it is used in areas where radiations are expected to be found. Nevertheless, its goal is to monitor the radioactivity itself (Mirion Technologies, n.d.).

1.9.1 Types of radiation detectors

Radiation detectors can be grouped based on their physical composition. They include Gas-filled detectors, solid-state (semiconductor) detectors, organic scintillators (liquid and plastics) and inorganic scintillators (Lewellen, 2008).

Gas-filled detectors are one of the frequently used detectors in the world. Quite a lot of detectors use the ionizing effect of radiation of gas. They all work on the same principle even though they have differences in how they operate. The gas in the detector reacts with ionization radiation when they come into contact the gas becomes ionized. This happens when the molecules that are positively charged move to the cathode and the electron (negatively charged molecule) moves rapidly to the anode when a potential difference is applied between the two electrodes in a gas-filled detector. This induces a current that may be measured using a meter or through the right means, the radiation may be converted into a pulse. There are various types of gas-filled detectors such as the ionization chamber, proportional counter and Geiger Muller counter. The ionization chamber is a gas-filled detector whose output signal is proportional to the energy of the particle dissipated in the detector. The proportional counter is a detector that has charge multiplication taking place but the output signal is still proportional energy deposited into the counter. The Geiger Muller counter is a type of detector that is very useful because they are very simple to operate, they provide a very strong signal that pre-amplification is not needed (Tsoulfanidis, 1995).

Solid-state detectors are also known as semiconductor detectors are detectors that are suitable for finding and measuring light and ionizing radiation that comes because of interaction with charged particles and photons. When a very good intrinsic (very pure) material is used for making the concept of the detector, it is easier to measure the combination of the precise time, position and energy. Examples of the semiconductor detectors include the germanium and silicon detectors that have been in use, even though they are not frequently used. These detectors are used in nuclear physics for measuring the energy of charged particles and photons but not the position (Lutz & Klanner, 2020). Semiconductor detectors work on the principle of ionization, incident radiations are made to interact with the detector material such as germanium or silicon in a solid-state (semiconductor) detector. This leads to the creation of electron-hole pairs. Charged particles then collect this electron-hole pair with the electrons and holes moving to the positive and negative electrode respectively, hence creating an electric pulse. The pulse contains information on the type, energy and time of arrival and the amount of particle arriving per unit time. They are used in gamma spectrometry because of their high-energy resolution (Rizzi et al., 2010).

1.10 Scintillation detector

Scintillation detectors are one of the oldest methods of radiation detection that have been in use. It is also the most widely used detector that is currently in use in the detection of particles in nuclear and particle physics. It makes use of the fact that flashes of light are produced when radiation falls on a material called scintillate. In the past, these lights used to be detected with the naked eye or with the help of optical instruments but nowadays information about the incident radiation is obtained by a photomultiplier which is an amplifying device that converts the flash of light into an electrical pulse. These electrical pulses are then analyzed and counted electronically (Ouseph, 2012). Scintillation detectors are mostly applied in many fields, they are used for medical diagnostics such as radiography, mammographic imaging, dosimetry, computer tomography, gamma cameras and dual-energy imaging (Globus, & Grinyov, 2006; Onoda et al., 2021).

1.10.1 General characteristics of scintillation detector

A scintillation detector generally consists of a photomultiplier, a power supply and a scintillation material. Incident radiation (photon) enters into the scintillator and causes the atoms and molecules to become excited which leads to the production of light. The light then enters the photomultiplier tube (PMT) where the photons are converted into photoelectrons, which are further amplified by an electron-multiplier system (dynodes) to cause a sizable electrical pulse that is then analyzed (Klein et al., 2018).

The PMT is a device that converts light into electric signals. It has two purposes that are to convert light or UV emission into an electric signal and for signal amplification. It is a vacuum glass tube, which contains a photocathode, 10 to12 electrode series of dynodes and an anode. The photocathode is located at the entrance of the PMT that is coated with photoemissive material that emits or ejects electrons, which are known as photoelectrons when an incident photon comes into contact with it. They are mostly made from alloy metals with extra electrons. The electric field then transfers the photoelectron to the first dynode. The first dynode is a short distance away from the photocathode, which is made of a curved metal, coated with secondary emission properties. When the photoelectrode strikes on the dynode, secondary electrons are emitted leading to electron multiplication. The amplification can be regulated by changing the applied voltage. The PMT uses a high voltage that must remain stable because of the sensitivity of the electron multiplication factor to the dynode voltage change. Electrical current is then produced. A photomultiplier coupled with a scintillation material is shown in figure 2 (Scheler & Parbandarwala, 2020).

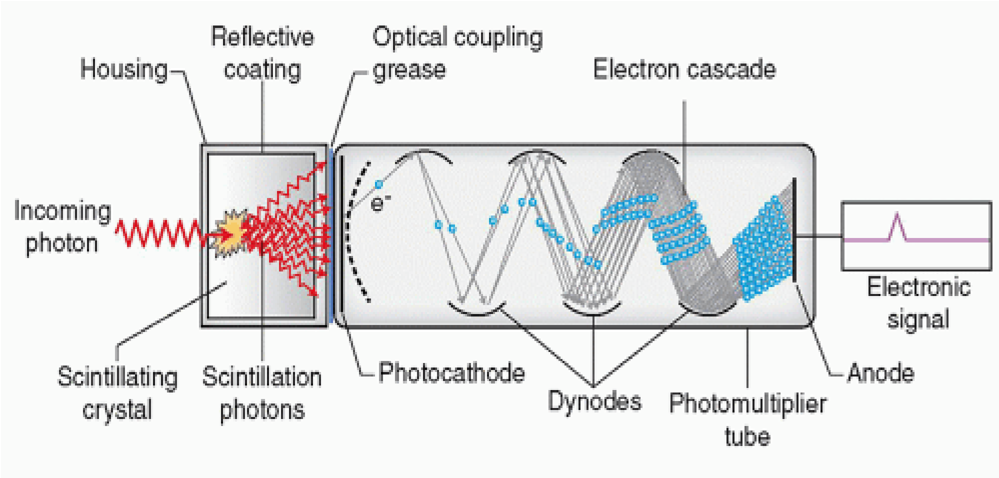

Figure 1.2 A photomultiplier coupled with a scintillation material.

Scintillation signals provide information such as sensitivity to energy, fast response to time and pulse shape discrimination.

- Sensitivity to energy. Most scintillation behaves in a nearly linear way with respect to the energy deposited. That is the output light is directly proportional to the exciting energy. When the photomultiplier is in operation accurately, the amplitude of the last electrical signal is also directly proportional to the energy, since the photomultiplier is a linear device.

- Fast time response. These detectors are fast devices because their time of response and recovery are very short, unlike the other detectors. This helps to know with greater precision the information about the time difference between two events. An example is that the fast time response allows scintillation detectors to receive greater count rates given that the time gone when waiting for the scintillator to recuperate is decreased.

- Pulse shape discrimination. The analysis of the shape of different light pulses can help identify the type of particle in some types of scintillation detectors.

This is because of the excitation of distinct fluorescence machinery by particles of distinct ionizing power. This is known as pulse shape discrimination (Leo, 2012).

A good scintillation material should have the following desirable characteristics:

- A good scintillation material should be able to convert the kinetic energy of charged particles into visible light with a great scintillation efficiency.
- The alteration must be linear. That is the light yield should be relatively equal to the energy placed over a huge range as possible.
- The medium ought to be translucent to the wavelength of its discharge for better light gathering.
- It should have a short decay time for induced luminescence so that it can generate a fast signal pulse.
- It should have good optical quality and subject to a size sufficiently huge to be of consideration as a practical detector.
- Its refractive index should be near that of glass to permit efficient coupling of scintillating light to the PMT (Knoll, 2010).

1.10.2 Mechanism of scintillation detector

Wide bandgaps can be observed between the conduction and valence bands of the insulation materials that are used in making the scintillation detectors. These insulating materials are materials that do not allow the free flow of electrons because they are tightly bound, hence electric charges cannot easily flow through them. Scintillation lights are produced by luminescence centers, which are located within the wide bandgap. These luminescence centers are made of two energy levels whose difference is the same as the energy of photons in and around the electromagnetic spectrum where the visible region is located. A scintillation photon can be released (that is there is a probability of it not occurring but rather quench may occur leading to information lost) when an electron moves from a higher energy level to the lower energy level of this center. Some of the energy of radiation is deposited along the track of the particles of the medium when radiation is incident into a scintillation material. When the energy deposited along the track is greater than the bandgap of the scintillation material, the electrons would move to the conduction band from the valence band, this leads to the production of an effective positive charge in the valence band known as a hole. The holes and electrons in the valence and conduction band respectively, are then allowed to move around freely within the material. During the movement, the electrons fall to the energy level below the lower energy level of the conduction band. When this energy is the luminescence center, the electrons move further to the energy below the luminescence center and a scintillation photon is produced or the energy is scattered off by a non-radioactive means. The electrons then move back to the valence bond and combine with the holes. In some cases, the electrons in the conduction band can also move to the electron trap. Impurities and defects in crystalline scintillators cause these traps, which are metastable energy states. These electrons when they are trapped there can stay there for either a long or a short period, whiles there, these electrons receive energy by either thermal excitement or other means and when the energy they have received is enough they move back to their original state (that is they move back to the conduction band). They can then emit scintillation light by moving to the luminescence center. These delayed photons are made up of the delayed light or the phosphorescence. The mechanism of a scintillation detector is illustrated in figure 3 (Ahmed, 2007; Byun, 2016).

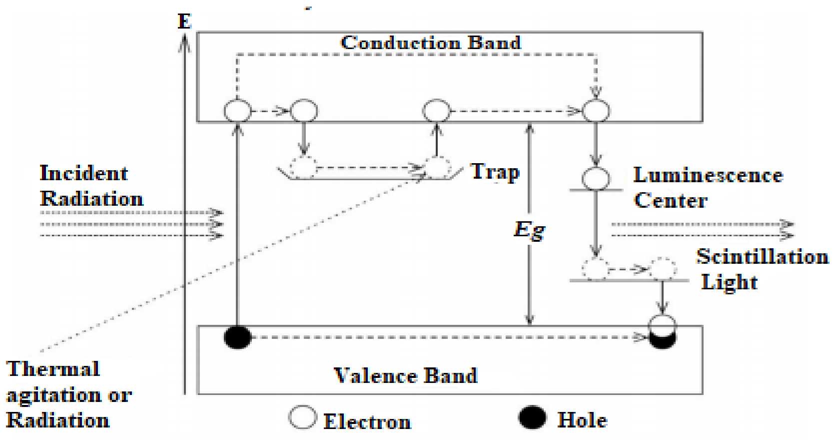

Figure 1.3 Diagram of mechanism of scintillation detector.

1.10.3 Scintillator properties

There are two main classes of scintillators. The choice of scintillator depends on the application as it is determined by the physio-chemical and optical parameters such as density, scintillation properties and radiation hardness ((Lecoq, 2020). The time resolution of the scintillation detector depends on the density of the photoelectron but at the scintillator level, it depends on the light yield and the pulse shape (the rise and decay time) of the scintillator (Lecoq et al., 2010).

Light yield (LY) is a very important parameter of a scintillator because it directly affects the energy resolution at low or medium energy via the photo statistic term proportional to (LY) $^{-1/2}$ and the timing resolution proportional to $(\tau_{sc}/LY)^{-1/2}$, where τ_{sc} is the scintillation decay time (Lecoq, 2020). The light yield estimates the production light efficiency and is defined as the number of visible photons emitted per unit of energy deposition (that is number of photons/MeV). The LY changes based on the surface, variety and condition of the crystal (Rinaldi et al., 2018). Scintillators with high LY allow them to detect radiation that has low energy or intensity with a high signal-to-noise ratio (S/N). The formula used to calculate the LY of a scintillator (LY_{Sc}) is given by:

$$\mathrm{LY_{Sc}} = \frac{\mathrm{E}}{\beta \mathrm{E_g}} \times \mathrm{S} \times \mathrm{Q} \tag{1.1}$$

Where E is the energy deposited by the ionizing radiation, β is the parameter constant, E_g is the bandgap energy, S is the migration energy efficiency from the host to the emission center and Q is the quantum efficiency (Maddalena et al., 2019).

There are two types of LY: the absolute LY (scintillation efficiency) and the technical LY. The difference between absolute LY and technical LY is that the absolute LY (η) is the ratio of the total energy (E_p) of the photons of the scintillation to the energy (E) left by ionizing radiation in the scintillator, which is given by:

$$\eta = \mathrm{E_p} \times \mathrm{E} \tag{1.2}$$

Whiles technical LY (T) is the ratio of the total energy (L_p) of scintillation photon that passes through the window of the detector to the energy (E) left by the ionizing radiation in the scintillator, which is given by:

$$T = L_p \times E \tag{1.3}$$

The relationship between the technical and absolute LY is given by:

$$T = \tau \times \eta \tag{1.4}$$

Where τ is the light collection coefficient of the scintillation detector (Sysoeva et al., 2002).

Some factors affect the LY of a scintillator. These factors include the type of scintillation material, the type of incident particles, the energy of the particles and temperature (Ahmed, 2007).

Dead time and rise time, which are directly related to the time resolution of a radiation detector, are other important properties of the scintillation detector. The decay time is directed by the speed of transmission of free electrons and holes from the ionization track to the emission center and the lifetime of the luminescence state of the activator (Yanagida, 2018). The faster the decay time the better the time resolution (Dorenbos, 2002). The light pulse of a scintillator is mostly described by the fast increase of the intensity in time, which is normally referred to as the rise time and is followed by an exponential decrease (decay time). The decay time can therefore be defined as the time it takes for the intensity of the light pulse to return to 1/e of its maximum value. For most scintillation detectors, the effective decay time is mentioned because they have more than one decay time (BNC, 2021a). The measurement for the decay time is quite easy to determine but that of the rise time is difficult because the measurement for the rise time is mostly done using very expensive devices such as the fast, pulsed X-ray sources with streak cameras (Seifert et al., 2012; Gundacker et al., 2013).

1.11 Scintillation materials

Scintillators are materials that produce light when they interact with incident radiation or particles. It can be classified into four categories – organic crystal, inorganic crystal, gases and glasses (Ouseph, 2012). The organic and inorganic crystals are the most widely used scintillators in radiation detectors.

1.11.1 Organic scintillators

The organic scintillators are made from materials that belong to the class called aromatic compounds that are planar molecules made up of benzenoid rings. Toluene and anthracene are examples of planar molecules. Suitable compounds are combined to form organic scintillators. These are categorized as unitary, binary, ternary and so on, depending on the number of compounds in the mixture. Substances, which have the highest concentration are referred to as solvent, while those that are not are referred to as solute. A binary scintillator consists of a solute and a solvent while the ternary scintillator consists of one solvent, a primary solute and a secondary solute (Tsoulfanidis, 1995). The organic scintillators have a lower atomic number (Z) with a density ranging from (1 – 2) g/cm^3. They have light yields ranging from (1 – 10) kph/Mev and fast nanoseconds (ns) decay time, which makes them have good timing resolution (Leverington, 2017).

The mechanism of production of fluorescence (light) in organic scintillators uses molecular transition. This is as a result of the transition in the energy level structure of a single molecule and hence the light can be observed from a given molecular species irrespective of its physical state. An example is an anthracene whose fluorescence can be detected as either a solid poly-crystalline material, as a vapour or as also part of a multicomponent solution. This process is quite different from the mechanism of an inorganic scintillator, which uses the energy levels of a crystal lattice. Most of the organic scintillator mechanism is based on organic molecules with certain symmetric properties that give rise to the π-electrons structure (Knoll, 2010). Saturated hydrocarbons do not have π – electron, hence there is no optimal absorption at energies less than 6 eV. Nevertheless, some molecules have non-localized π-electrons as part of their electronic structure and therefore do not require lots of energy to cause electronic excitation. Usually, three or more π-electrons absorption bands are observed and this corresponds to the change from the singlet ground state into the singlet π-electrons excited state (Horrocks, 2012). The mechanism in the organic scintillator consists of two steps. During the first step, there is a transfer of energy from the particle or incident radiation to the molecules of the scintillator, which leads to the excitation of the electrons. The second step involves the movement of the molecules of the scintillator moving back to its ground state and emitting photons. The light intensity of the photon relies on the incident radiation energy because it is proportional to the excitation energy (Kónya & Nagy, 2018).

There exist three types of organic scintillators. These are the liquid organic solution, pure organic crystal and the solid solution mostly referred to as plastic scintillator. (Dendooven, 2019).

The liquid scintillator transfers the kinetic energy of an incident particle into light when they interact with each other. They are produced by dissolving an organic scintillator in a solvent. Organic liquid scintillators are mostly made up of organic solvent or solute(s). Conjugated and aromatic properties of hydrocarbons lead to the emission of light with a characteristic spectrum when they absorb radiation. Solvent molecules, which are ionized and excited, are produced when incident radiation passes through a solution. These solvent molecules are poor scintillators because the probability of a photon being emitted is very low, the energy emitted range is between (2000 – 3000 $\mathring{A}$) where the sensitivity of the phototube is reduced and the lifetime of the solvent molecule is quite long (about 30 ns). The main purpose of the solute in an organic liquid scintillator is to trap the solvent molecules' excited energy and to efficiently release part of the energy in the form of photons. Benzene and xylene are the most commonly used solvent for liquid scintillators (Horrocks, 2012; Mirashi et al., 2000).

Two types of pure organic crystal have been exploited for radiation detection: anthracene and stilbene. Anthracene is the greatest organic scintillator with the highest light output. It is widely used because of its scintillation efficiency. The percentage of the light intensity of the anthracene is mostly quoted as the scintillation efficiency of the organic scintillator (Cieślak et al., 2019). The stilbene was not in use for many years due to issues related to the crystal growing in greater dimensions, hence making it unavailable. However, in the first 10 years in the 21st century, people have shown interest after the team at LLNL developed a new growing method (Hull et al., 2009). The anisotropic response to incident radiation of the organic crystal scintillator, which depends on the orientation of the crystal, is one of the disadvantages of using an organic crystal scintillator because it affects the performance when the orientation of the detector changes (Brubaker & Steele, 2010).

The last type of organic scintillator, which is the solid solution, is commonly referred to as the plastic scintillator. Plastic scintillators are scintillators that are produced when an organic scintillator is polymerized when dissolved in a solvent. They are used as a nuclear safeguard in portable and vehicle monitors because they are light in weight (Mukhopadhyay et al., 2004). All plastic scintillators are sensitive to x-ray, gamma rays, fast neutrons and charged particles. Plastic scintillators are used in calorimeters, nuclear gauging, time of flight detectors and large contamination detectors. The polymer matrix of a plastic scintillator includes Polyvinyltoluol, Polystyrol, Polyphenylbenylbenzol and PMMA (Krammer, n.d.). These matrices can be loaded with small quantities of certain substances such as p-Terphenyl and so on, which causes them to produce light (scintillate) when they interact with a particle or radiation (Kelly & Boyes, 2003). Plastic scintillators are more durable than liquid scintillators and can be molded nearly into any shape. It is the most widely used radiation detector in nuclear and particle physics because they are fast to rise, has high optical transmission, large available size, less expensive and easy to manufacture (Lee et al., 2017).

1.11.2 Inorganic scintillators

The inorganic scintillators are made up of mostly pure crystal or sometimes doped with impurities (small amounts of other materials). Some examples of inorganic crystals made of pure crystal include $Bi_4Ge_3O_{12}$, BaF_2, CsI. NaI(Tl), CsI(Tl), LiI(Eu) are also examples of inorganic scintillators that are doped with impurities (Leo, 2012). Some characteristic parameters of some examples of inorganic scintillators are shown in table 1.1 (Bescher et al., 2000).

The scintillation mechanism uses the energy bands in a crystal. The crystal of the inorganic scintillator is made of an insulator (alkali Halide crystals) with a valence band and a conduction band that has a wide bandgap between them. The space between the valence and conduction band ranges between 3 eV to 10 eV. The free electrons in the conduction band are very small in amount but sometimes it is empty since the scintillator has to be transparent to produce light. The valence band is mostly fully filled with electrons. Some of the energy in a charged particle or gamma radiation is transferred to the electrons in the valence band when incident into the crystal. The electrons gain enough energy that causes them to move from the valence band to the conduction band, this leads to the creation of holes in the valence band. When the electrons move to the conduction band, they move about freely and then go back to the valence band to either recombine with the holes to produce photons or create a bound state with the holes, which is known as an exciton. This exciton level has an energy level lower than the conduction band because it is located beneath the conduction band (Grupen et al., 2008). Activators, which are small amounts of impurities, are added to the pure crystal to improve the efficiency of inorganic scintillation detectors because the emission of photons in them is inefficient at room temperature. Examples of these impurities include Tl, which is added to Na and CsI to form NaI(Tl) and CsI(Tl) respectively. Iodine is mostly used for inorganic scintillation detectors because it has a high atomic number. These activators change the energy and bandgap structures by creating a special lattice site in between the pure crystal valence and conduction band. Even though the energy of the activator is added to the energy structure, the energy structure of the pure crystal does not change. The activators create energy levels in the bandgap (in between the valence and conduction band). These energy levels created turn out to be narrower than that of the pure crystal. The energy band structure to differentiate a pure crystal and an activated crystalline scintillator is illustrated in figure 4 (Byun, 2016).

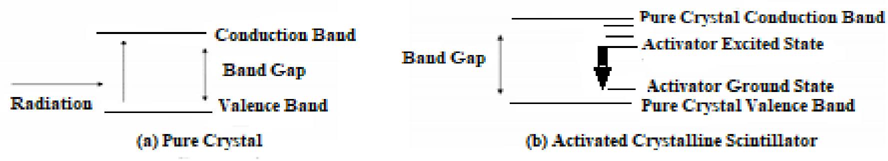

Figure 1.4 Energy band structure of a pure and activated crystalline scintillator

Table 1.1 Some characteristic parameters of inorganic scintillators.

Scintillator	Density (g/cm^3)	Wavelength of Maximum Emission λ_{max} (nm)	Index of Refraction at λ_{max}	Principle Decay constant (μs)	Total Light Yield in Photons/ MeV	Hygroscopic
NaI(Tl)	3.67	415	1.85	0.23	38,000	yes
CsI(Tl)	4.51	540	1.80	1.0	52,000	Yes
CsI(Na)	4.51	420	1.84	0.63	39,000	Yes
LiI(Eu)	4.08	470	1.96	1.4	11,000	Yes
BaF_2	4.89	310	1.49	0.62	10,000	No
CaF_2(Eu)	3.19	435	1.44	0.9	24,000	No
LSO	7.4	420	1.82	0.040	27,300	No

1.11.3 Thallium- activated Sodium Iodide (NaI (Tl)) scintillator

Thallium – activated Sodium Iodide (NaI (Tl)) scintillators have been the most widely used radiation detector since it was discovered in 1948 (Lecoq et al., 2006), even though it is hygroscopic and must be completely sealed from moisture, hence they are canned in airtight containers for use. It is widely used because it has a good fluorescence efficiency and its wavelength flash falls within the high range of the sensitivity of PMT (Sawant et al., 2020). The NaI in NaI (Tl) has a high Z (atomic number) of iodine that makes it efficiently good for the detection of gamma rays. The Na I is doped with a small amount of Tl as an activator to activate the crystal, hence designating the crystal as NaI(Tl) (MANUS, 2009). All NaI(Tl) are sensitive to shock apart from Polyscin, which is the new form of extruded NaI(TI). They are all very costly especially when large in size and their light output is mostly proportional to the energy of the absorbed photon, hence their pulse height is a measure of the incident photon energy. They can be used as a spectrometer when they are calibrated with photons of known energy. The decay lifetime of NaI (Tl) is about 230 ns, which is relatively slow for some fast timing or high counting rate application (Kelly & Boyes, 2003).

Even though new inorganic scintillators being developed in modern times have high light output, better energy resolution or fast timing capability, the NaI(Tl) is still considered and used widely in various applications due to its availability in large volume at relatively low cost. The light yield from excitation of NaI(Tl) by a fast electron or gamma-ray is about 38,000 photons per MeV of energy deposited (Knoll, 2010).

1.12 Temperature dependence on scintillation detectors

Scintillation detectors are mostly made of a crystal and a light detector has been in use for a long time. Over the years, it has been detected that scintillation detectors made of especially PMT are dependent on temperature (Pausch et al., 2005). The effect is so much that a spectrum process is required to correct the temperature effect. (Plettner et al., 2011).

The properties of inorganic scintillators are frequently affected by temperature. The dependence of the crystal performance on temperature is the most conspicuous, when the ambient temperature is considerably higher than the room temperature. The effect is very significant when there is a temperature rise. In addition, the influence of temperature on every scintillation crystal is entirely different. Some industrial applications require a small temperature effect, an example includes petroleum logging. NaI(Tl), BGO and CSI(Na) are scintillation crystals that are designed for environmental applications with high temperatures (Hou et al., 2019).

NaI(Tl) is widely used when detecting radiation outdoors for gamma spectrometry because it is very cheap and performance is high. The disadvantage of using NaI(Tl) is its gain instability over-temperature rather than its low resolution. The dependence of the light output of a scintillator on temperature is complicated because the shape and size of the light pulse change with temperature. The temperature dependence of inorganic scintillators is nonlinear for outdoor because of the complex change of LY as well as the light decay time over a temperature range. However, Ianakiev et al. (2009) experimented to investigate the behaviour of temperatures on NaI(Tl) scintillation detectors. After the experiment, they concluded that there is a linear temperature dependence of light output over a wide range of temperature including outdoor which contradicted the fact that the temperature dependence on the total light yield of a NaI(Tl) scintillator is nonlinear. Research by Moghaddam et al. (2016) on the effect of temperature and waiting time on peak shifted properties of low background NaI(Tl) detectors. They suggested that the channel shift depends on the environmental temperature and waiting (acquisition) time.

According to Moszyński et al. (2006), thermal instability in NaI(Tl) scintillators is mostly due to short peaking time and thus at low temperatures, better stability is observed at a long peaking time. They also suggested that at different temperatures, the NaI(Tl) scintillator shows a complex behaviour for the decay of light pulse. Swiderski et al. (2006), did research to study the non-proportionality of light yield and energy resolution at wide temperature (-40 °C to -23 °C) of NaI(Tl). After the completion of the research, they concluded that there was a strong variation of light yield and energy resolution as the temperature reduced to -40 °C with respect to different peaking times. This shows that the light yield and energy resolution of NaI(Tl) are dependent on temperature. The light output depends on temperature because at low temperature, it increases while at room temperature the probability of photon emission is low (Grupen et al., 2008). The dependence of the relative light output of scintillators on temperature is shown in figure 5 (BNC, 2021b).

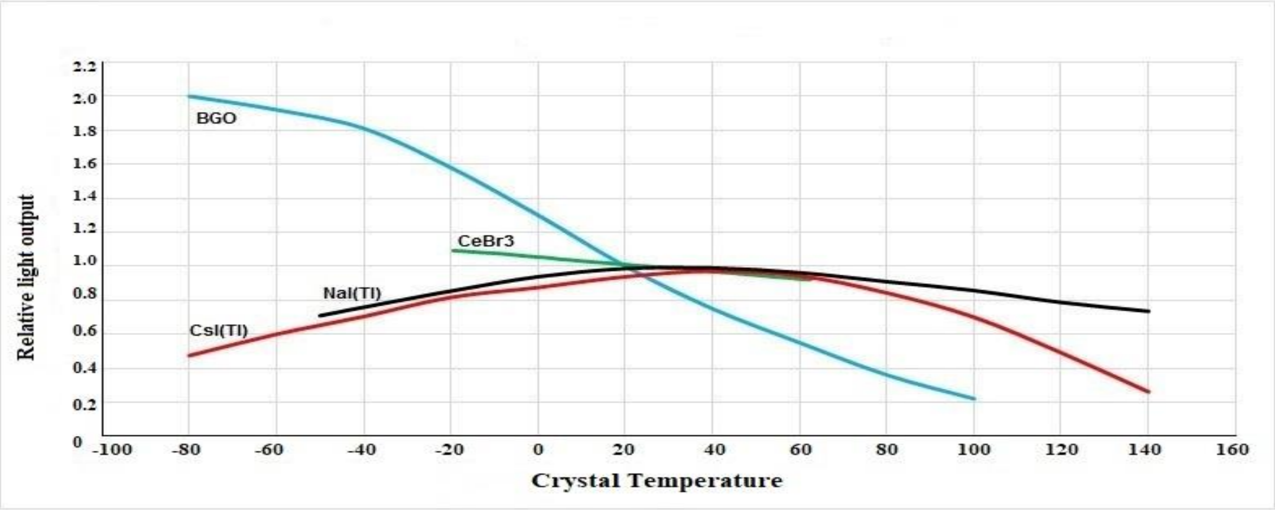

Figure 1.5 Temperature dependence of the scintillation yield.

1.13 Temperature correction factor

Change in temperature leads to a gain shift in the detectors and so most detectors have been embedded with an active system gain stabilization. This active system gain stabilization helps to keep the energy resolution and energy calibration for changing ambient temperature. Effective stabilization of detectors that are designed for outdoor application is of great importance since the temperature outdoor changes a lot with time due to strong and rapid changes in the ambient temperature (environmental climatic change). Every detector must be able to tolerate a wide range of temperatures between -30 to +55 °C (IAEA, 2006; Pausch et al., 2005). The test for determining the temperature stabilization is done by measuring the count rate induced by ambient background and that of the radioactive source. The test is normally carried out in the environmental climatic chamber (ANSI, 2004).

Due to the significant influence of temperature on scintillators, a spectrum process is used to correct them. The methods used are required to restore spectrums that have been shifted and recorded under different temperatures back to their reference spectrum (Qin et al., 2012). This helps to remove the effect of temperature change when taking measurements. The most important condition when performing this process is the linearity of the overall system that allows performing linear operations (Bu et al., 2018).

Every detector has a temperature sensor embedded in the light-emitting diode (LED). The temperature sensors work very well in closed environments like the laboratory where the ambient temperature change is very slow and weak. When working in an area where there is a change in the ambient temperature, one must consider the influence of temperature on the LED. The light output depends on the LED junction temperature. This may lead to a peak shift but it is not corrected using the stabilization process because it is not a gain shift (Saucke et al., 2005).

Cassanova et al. (2012), did an experiment using two methods to correct the temperature peak shift in NaI(Tl) and LaBr3 (Ce) for gamma-ray spectrum. They used a software algorithm without adjusting the gain shift. These methods were established on the experimental observation of relative channel shifts because of temperature changes. The first method they used corrected the spectrum using experimental data found under controlled conditions in the laboratory, which was that it only depended on the detectors' temperature. In the second method, the spectrums of the channels were corrected by using one known peak to correct all of them. When they finished experimenting, they concluded that the two methods they used could be used to stabilize gamma-ray spectra found from unsteady temperature conditions.

Research by Mitra et al. (2016) described an easy method to assess the energy change of the differential pulse height spectra recorded under different temperatures and to enable the spectrum to be restored to its reference spectrum position. Their method helped eradicate the influence of temperature change during measurement and to allow displaced spectrum to be sorted out together with a reference spectrum. This method was used for gamma spectroscopy.

1.14 Effect of readings on low-level gamma background radiation using scintillation detectors.

Sensitive radiation detectors are mostly used to detect low background radiation, especially the NaI(Tl) scintillation detector. These sensitive detectors are usually used for dose rate spectroscopy and also for environmental monitoring for detecting the low count rate of weak radioactive sources (Young-Yong et al., 2015). The most relevant fact about these radiation detectors is the inconsistencies in their response function and sensitivity to atmospheric conditions (like temperature), time and high voltage. The discrepancies in these low background radiation detections are the change in temperature and time, which result in channel shift and displacement of the spectrum during measurement and this leads to low energy resolution. Even though the change in temperature cannot be controlled since these low background radiation detectors are used outdoors, the effect of temperature on them can only be corrected by using the stabilization procedure (Moghaddam et al., 2016).

For several years, the students of Tomsk Polytechnic University in the city of Tomsk (Russia) used the NaI (Tl) scintillation detector (BDKG-03) for monitoring of gamma background radiation. Results of researches done using this detector for measuring low background radiation have led to doubt about the correctness of the temperature correction coefficient of the factory algorithm for converting pulse to dose due to fluctuations in the results obtained. An example is the measurement of dose rate taken in the city of Tomsk in the year 2019. The results from this experiment are shown in figure 1.6. Figure 1.6 a) illustrations the comparison of the annual variation of dose rate calculated from count per minute (cpm) using the factory algorithm and the dose rate calculated using the constant coefficient. From the graph, there was a burst in the reaction of gamma dose on rain and snow. Also, there was a high deviation between them. Figure 1.6 b) shows a different trend of daily variation that can be a source of wrong conclusions when analyzing the data. Figure 1.6 c) illustrations the comparison of the dose rate calculated from the cpm using the factory algorithm and the atmospheric temperature. From the graph, it can be observed that the plots were almost close to each other and this again led to doubt in the correctness of the algorithm. Based on these we formulated our main goal.

a)

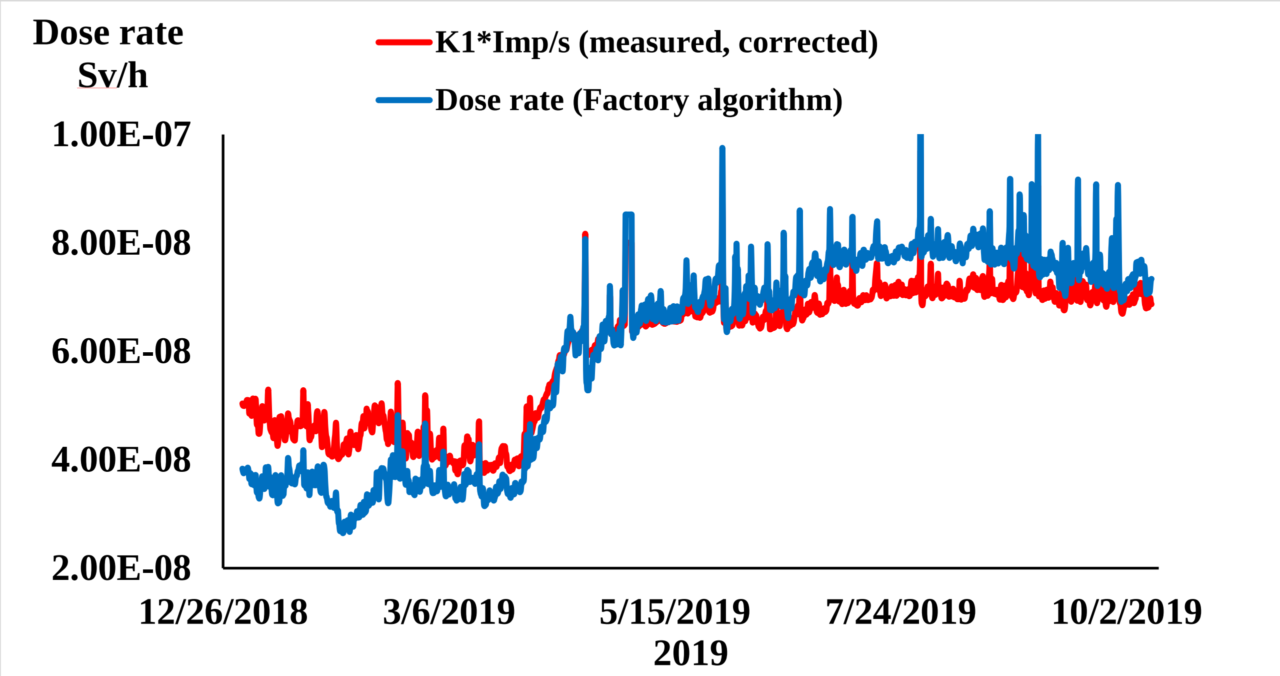

Figure 1.6 a) Comparison of the annual variation of dose rate calculated from cpm using the factory algorithm and the dose rate calculated using the constant coefficient.

b)

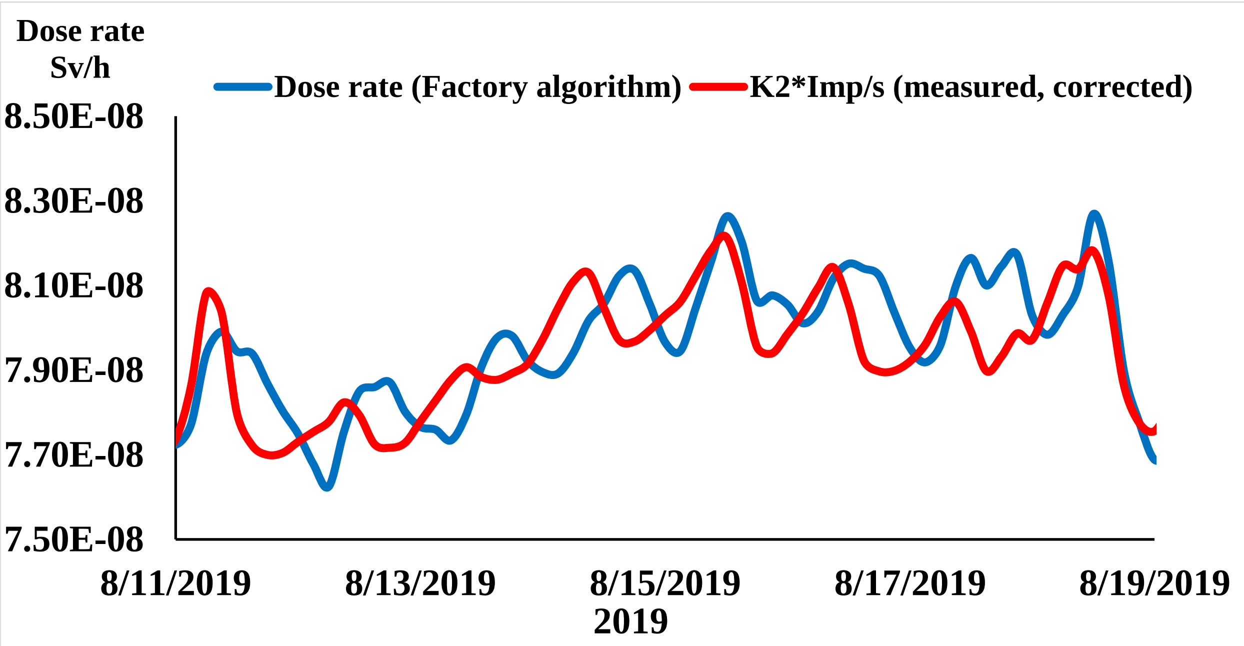

Figure 1.6 b) Comparison of the daily variation of dose rate calculated from cpm using the factory algorithm and the dose rate calculated using the constant coefficient.

c)

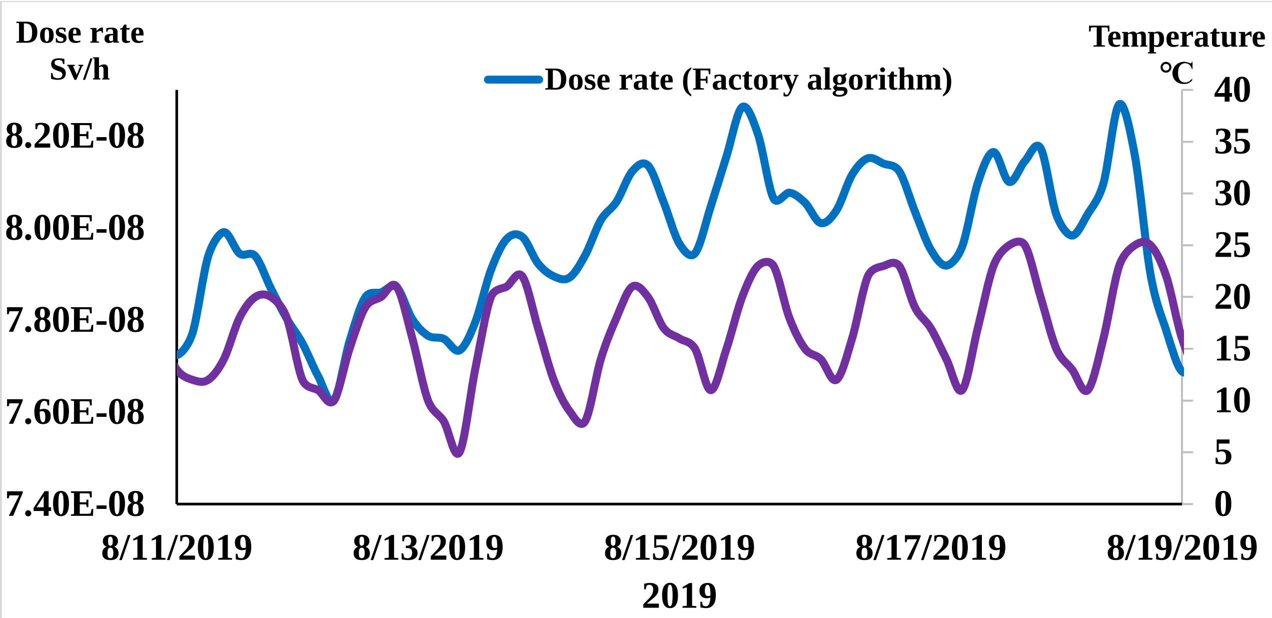

Figure 1.6 c) Comparison of the dose rate calculated from the cpm using the factory algorithm and the atmospheric temperature.

1.15 Climatic chamber

Researches have been done to show the authenticity of a climatic chamber to depict atmospheric conditions like temperature, humidity and so on. A study done by Mensah et al., (2016) on the investigation of the efficiency of the climatic chamber based on temperature and humidity. Another work was carried out by Lochlainn et al (2015) on the comparison of the hydrothermal characterization techniques of the climatic chamber as described in IEC60068. In their work, they used three common measurement systems that are used to evaluate the efficiency of the climatic chamber.

According to ANSI (2004), the test for determining the temperature stabilization of a detector is done using a climatic chamber to depict the environmental weather condition and measuring the count rate of a radioactive source or background radiation. In a study done by Csurgai et al (2020) on Temperature Dependence of NaI (Tl) Radiation Scintillation Detectors' Characteristics, they used the climatic chamber in their experiment to depict the environmental condition (temperature), when investigating the dependence of gamma spectrum measured by NaI(Tl) scintillation detector on temperature changes.

Chapter 2 Materials and Methodology

2.1 Description of instruments used

2.1.1 NaI(Tl) inorganic scintillation gamma detector (BDKG-03)

The BDKG-03 is a NaI(Tl) inorganic scintillation detector. It is an extremely sensitive scintillation counter with a sharpness of 350 (imp/s)/ (μSv) for ^{137}Cs that is devoted to monitoring gamma radiation. It is mostly used for outdoor measurement of gamma radiation. It is a portable AT1117M radiation monitor used to measure the ambient equivalent dose rate and the ambient equivalent dose of gamma radiation. It operates based on the principle of radiation monitor algorithm that provides continuous measurement, average value calculation, integrated unit that display the real-time detection unit, statistical processing of results measured, fluctuation of real-time estimation and fast accommodation of radiation level change. It stores data in the non-volatile memory of the device and transfers it to a Pc. They are applied in areas such as radioecology, research activities, nuclear industry and customs control. The detector is mostly connected to a laptop with a USB connector. The laptop has a software known as "Atexch" installed on it, which provides the following:

- Indication of dose and radiation measurement values, as well as writing into file and reading previously stored data.
- Response when measured value thresholds are exceeded.
- Error indication by instrument, message analysis and display in case of error conditions
- Multiple instances of the program can be run in case of more than one instrument connected to different PC ports (ATOMTEX, n.d.-b).

The general characteristics of the BDKG-03 are listed in table 2.1 (ATOMTEX, n.d.-a).

Figure 2.1 NaI(Tl) inorganic scintillation gamma detector (BDKG-03)

Table 2.1 Characteristics of scintillation detector BDKG-03

Specification	**Value**
Detector	Scintillator NaI(Tl) , Ø25x40 mm
Energy range	50keV – 3MeV
Measurement range of ambient gamma radiation dose rate equivalent, μSv/h	0.03 – 300 μSv/h
Measurement range of ambient gamma radiation dose equivalent	0.03 μSv – 10 mSv
Limit of intrinsic relative measurement error, %	± 20%
Typical sensitivity to ^{137}Cs gamma radiation, (imp/s)/ (μSv/h)	350 (imp/s)/ (μSv/h)

Response time for dose rate change (accuracy error ≤ ± 10%), s	≤ ≤ 2 s (for dose rate change from 0.1 to 1 μSv/h)
Operation temperature range, °C	-30 - +50 °C
Relative humidity, %	≤ 95%
Overall dimensions, mm	Ø60x299 mm
Weight, kg	0.6 kg
Energy dependence relative to 662 keV (^{137}Cs), %	± 20%
Burn-up life, Sv	≥ 100 Sv
Protection class	IP68 (Sealed container)
Interface	RS232
Immersion depth, m	Up to 30 m

2.1.2 Climatic chamber

A climatic chamber is a confined chamber that duplicates different atmospheric conditions like temperature, humidity, rain and so on. It is devoted to the testing of electrical appliances, samples, manufacturing products, organic items and materials to investigate how these atmospheric conditions would influence them. They are applied in the fields of ecology, geology and hydrology (Darehshouri et al., 2020). The climatic chamber specification is listed in Table 2.2.

Figure 2.2 Climatic Chamber

Table 2.2 Specifications of the climatic chamber

Specifications	**Values**
Volume, l	1000
Temperature range, ℃	-60 - +60
Temperature maintenance instability, ℃	0.5
Unevenness of maintain temperature by volume, ℃	± 2.0
Relative stability of humidity level, %	± 1.0
Humidity range, %	15 - 100

2.2 Built-in algorithm of NaI(Tl) detector (BDKG-03)

A correction factor is defined as the mathematical amendment of an algorithm or a computation to make up for the error that might have occurred when taking measurement. The correction factor is normally multiplied by the algorithm to make up for the systematic error that occurred during measurement. This assists us to examine and assess the outcomes obtained in the course of measurement, although most of the outcomes obtained in the course of measurement may be correct. Every single detector or device has a correction factor that helps to examine and assess the outcome during measurement. In the course of this research, the dose rate was divided using the count rate to obtain the correction factor, k.

$$\mathrm{k} = \frac{\text{Dose rate}}{\text{Count rate}} \tag{2.1}$$

2.3 Methodology

The investigation was conducted at the Institute of Monitoring of Climatic and Ecological System in Tomsk, Russia. The BDKG-03 NaI(Tl) scintillation gamma detector was positioned inside a climatic chamber and connected to a laptop using a USB connector. The climatic chambers' atmospheric condition was monitored using a reference precision temperature sensor of MIT 8. The count rate measured in imps/s and dose rate measured in Sv/h of the gamma background radiation of the detector was measured for various temperatures starting from -40 ℃ to +40 ℃ at an interval of 10 ℃. Each measurement lasted for 5 minutes. To attain precise results and reduce error, three different measurements were recorded for each temperature interval. The average of the measured count rate and dose rate were used in the calculation. The experiment lasted for a week. The experimental setup is shown in figure 2.3. A graph of dose rate and count rate against temperature was plotted and a new temperature correction coefficient and algorithm for calculating dose rate were found from the analysis of the results.

Figure 2.3 Experimental setup

Chapter 3 Results and Discussion

The results found during the investigation are presented in this section in a form of graphs of temperature dependence.

After obtaining the data, a graph of dose rate and count rate against temperature was plotted. As noticed in figure 3.1, while the dose rate was increasing from -40 °C to -20 °C that of the count rate was decreasing. Afterward, the dose rate and count rate began decreasing and increasing respectively with increasing temperature. The relative error obtained for the dose rate during measurement was about (5.0 – 5.4) % while that of the count rate about (2.2 – 2.3) %.

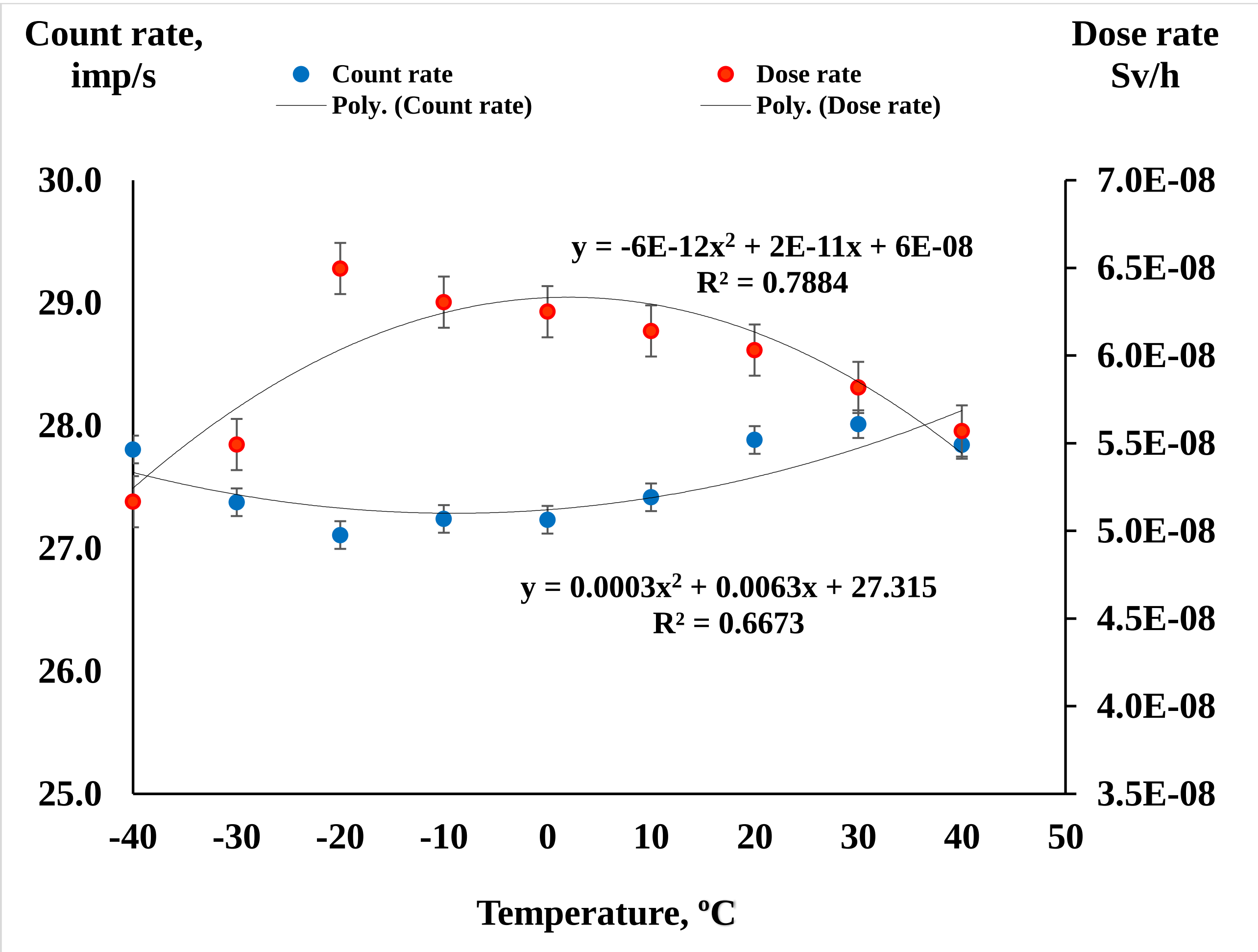

Figure 3.1 Graph of dose rate and count rate against temperature

From figure 3.2, it can be noticed that the count rate was not really influenced by ambient temperature since the values of the relative count rate was close to 1, however, the dose rate was affected by the ambient temperature particularly those measured from -40 °C to -20 °C, this is because the detectors at the factory were calibrated using high radioactive sources. Hence, another approach was used to calibrate in low background conditions. The relative measurements were obtained via the division of the individual dose rate and count rate by that at standard temperature and pressure (STP).

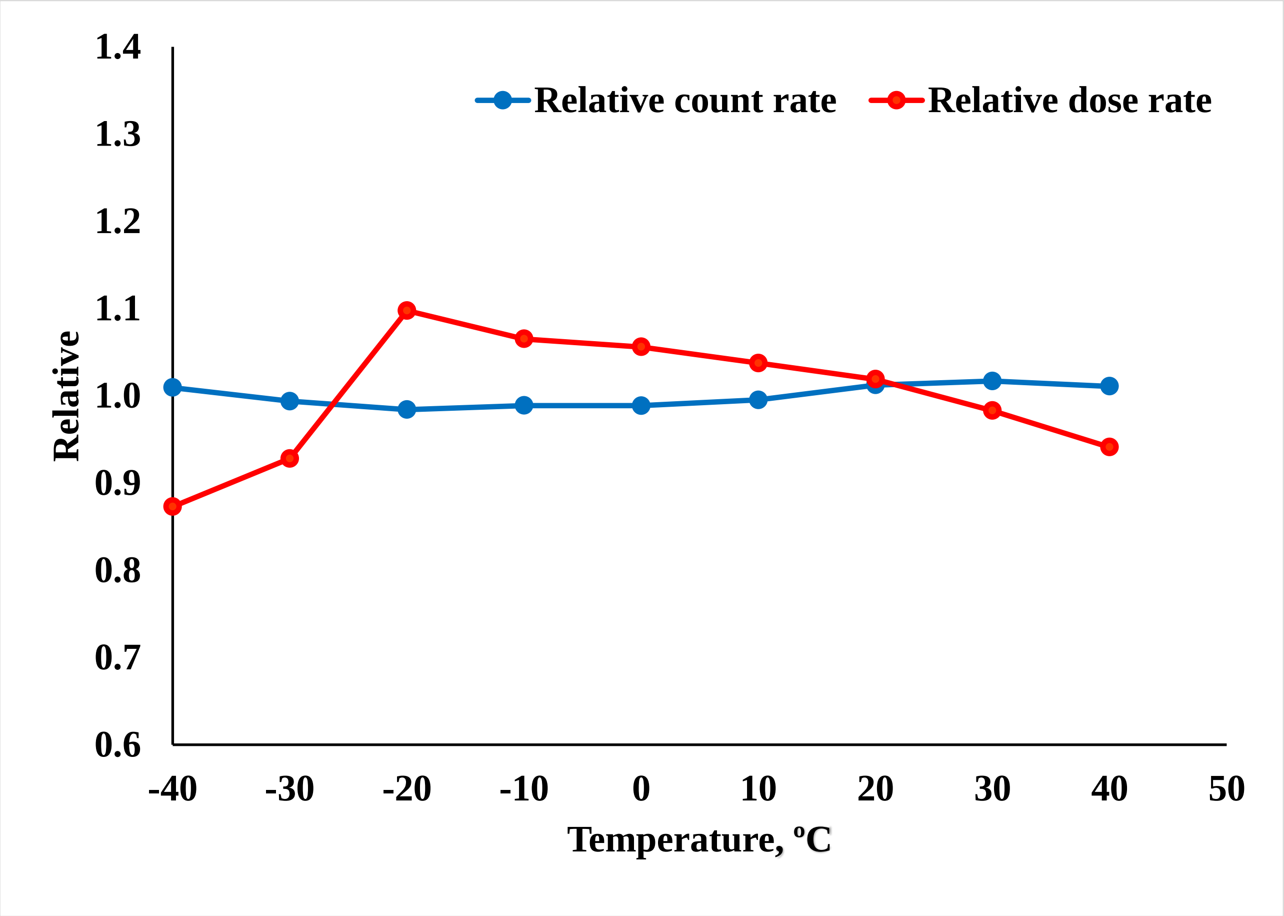

Figure 3.2 Graph of relative dose rate and count rate against temperature.

Figure 3.3 shows a graph that compares the temperature of both the climatic chamber and that of the detector to the actual temperature measurement. From the plot, it can be noticed that the climatic chambers' temperature was close to that of the detector at a lower temperature, but when the temperature started increasing from – 20 °C, there was a deviation between them. Also, the temperature of the climatic chamber was much closer to the actual value than that of the detector. This proves the need for the temperature correction factor in the detector.

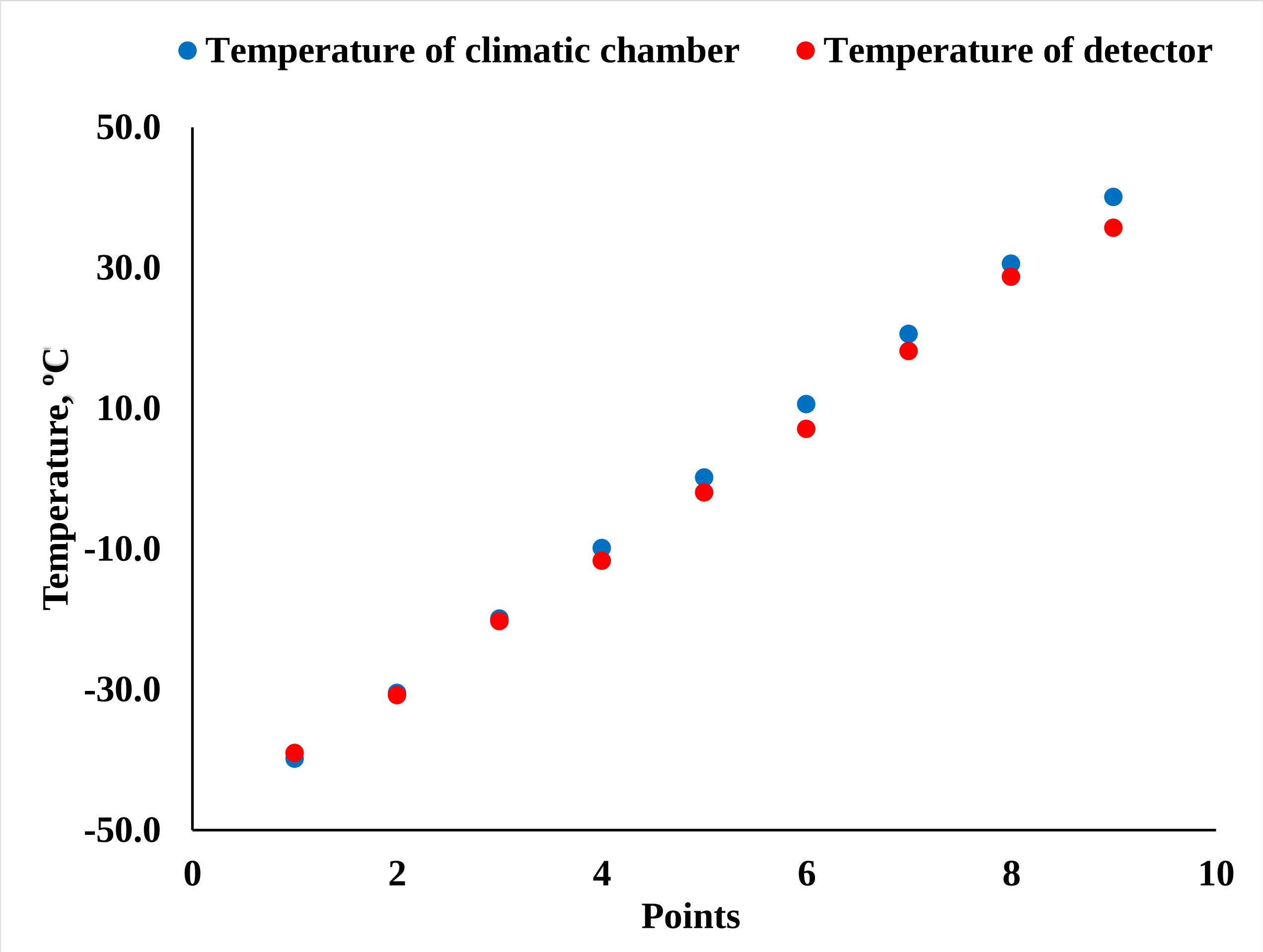

Figure 3.3 Graph of the variation of the temperature of the climatic chamber and the detector.

To find the reason for the fluctuation in the results of the readings obtained from the detector for the low gamma background radiation, a graph of the temperature correction coefficient enclosed in the detector temperature protection was plotted against temperature as illustrated in figure 3.4. The graph was split into two categories, from (-40 to -20) °C and also (-10 to +40) °C, hence two equations were generated.

However, under normal circumstances, the dependence is usually expected to have only a single equation. This might have been the reason why the results of the readings of the detector fluctuated when used to measure dose rate for low-level gamma radiation dose. Hence the need to find a new temperature correction coefficient that can be adopted for calculating the dose rate of gamma radiation of low dose.

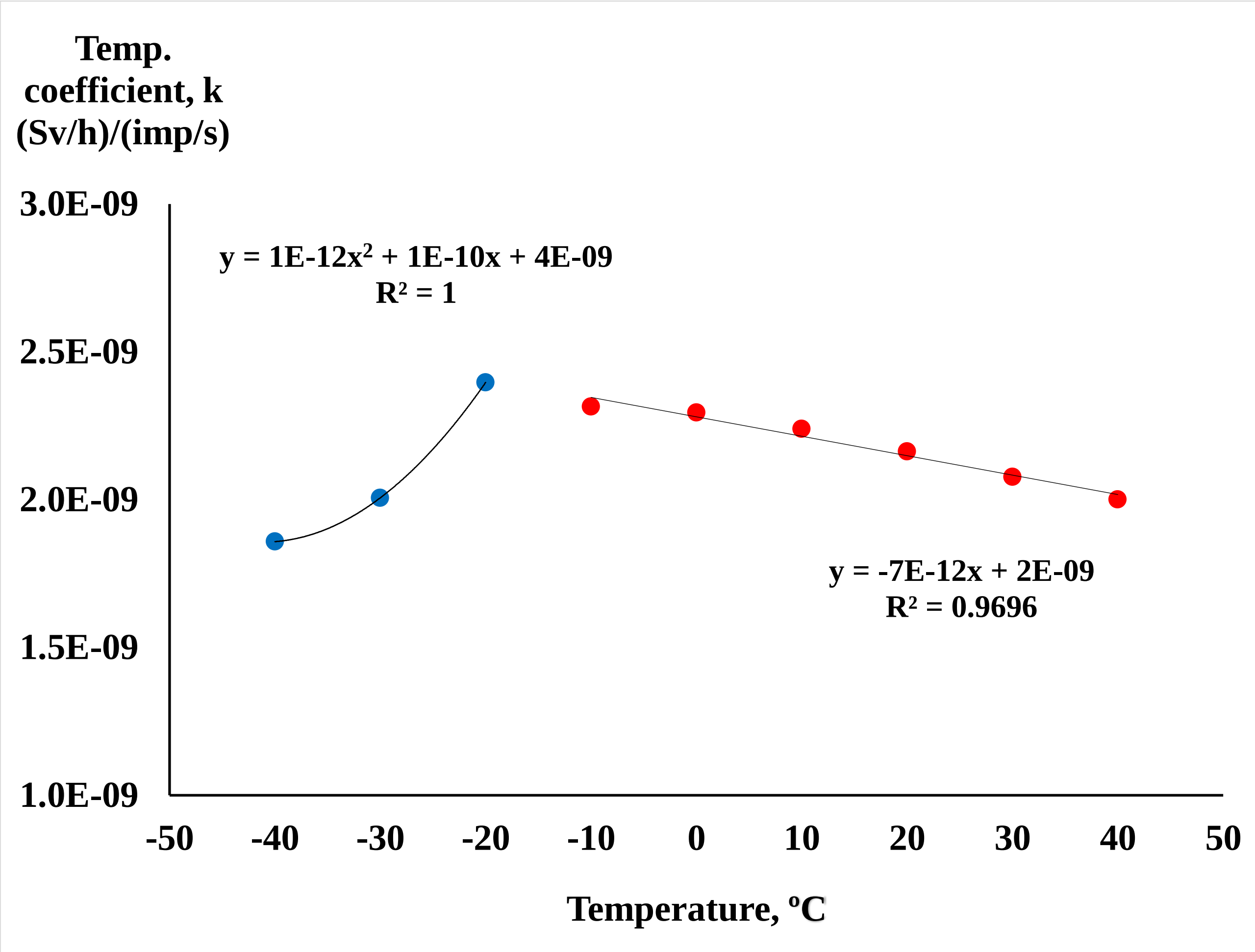

Figure 3.4 Graph of the factory's temperature correction coefficient against temperature.

To find a new temperature correction coefficient that could be used for calculating the gamma dose rate of low dose, a graph of dose rate calculated not utilizing the algorithm built inside the detector. The calculation was done by multiplying the ambient temperature correction coefficient of the factory algorithm, (which was obtained as $k = 2.163 \times 10^{-9}\left[\frac{Sv/h}{imp/s}\right]$) by the count rate measured when experimenting. The standard deviation of the ambient temperature correction coefficient of the factory algorithm was obtained as $\pm 7.317 \times 10^{-10}\left[\frac{Sv/h}{imp/s}\right]$. The equation $y = 1 \times 10^{-11}x + 6 \times 10^{-8}$ was then generated.

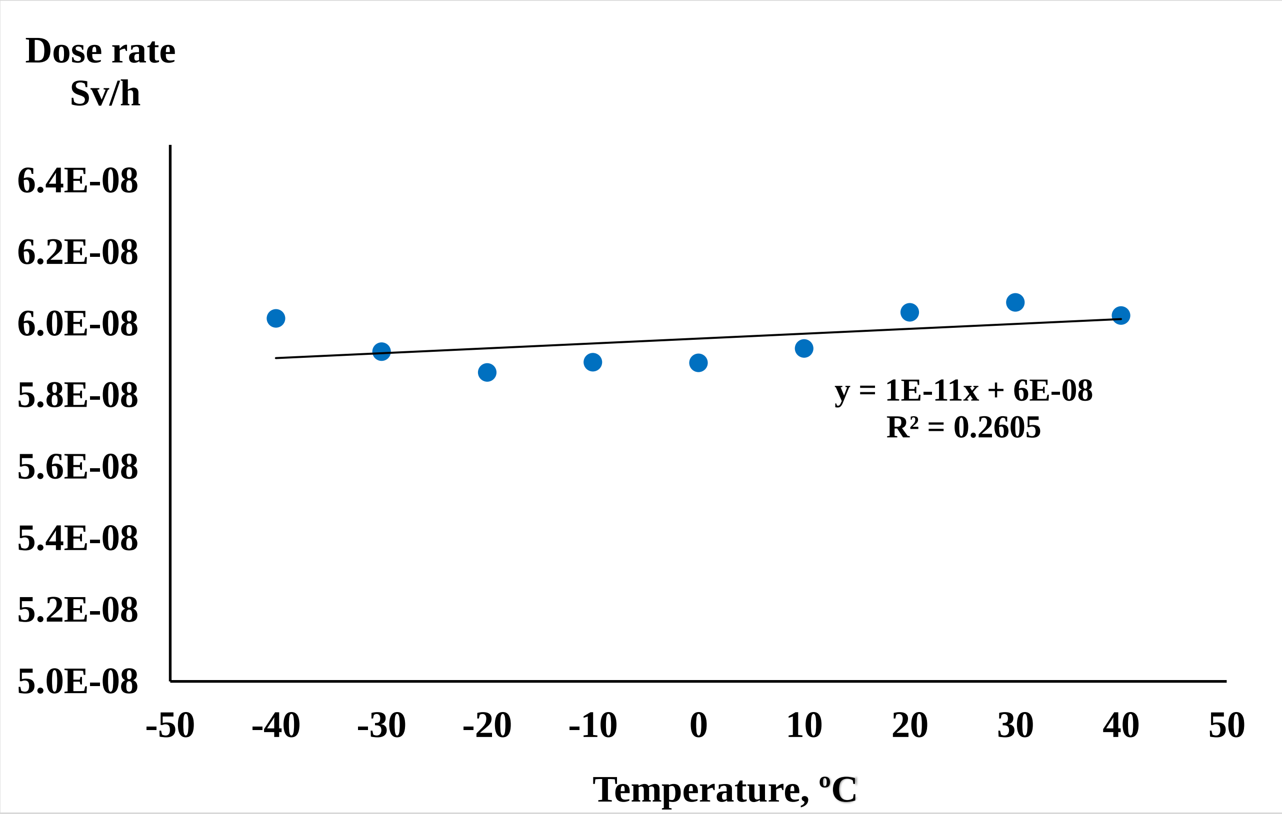

Figure 3.5 Dependence of experimental result against temperature.

Using the equation generated from figure 3.5, further calculations were to obtain an experimental algorithm for calculating the dose rate as shown in equation (3.1).

$y = 1 \times 10^{-11}x + 6 \times 10^{-8} \approx H = 1 \times 10^{-11}T + 6 \times 10^{-8}$, but, $H = Nk$

$$\Rightarrow k = \frac{H}{N}$$

$$N[k(T = 20)] = 27.88 \text{ imp/s}$$

$$k = \frac{1 \times 10^{-11}}{N} = 3.58 \times 10^{-13} \text{ (Sv/h)/(imp/s)}$$

$$k = \frac{6 \times 10^{-8}}{N} = 2.158 \times 10^{-9}\ (Sv/h)/(imp/s)$$

$$\text{Hence, } H = N \times (3.58 \times 10^{-13} T + 2.152 \times 10^{-9}). \qquad (3.1)$$

Where, N – count rate, k- Temperature coefficient, T – Temperature and H – Dose rate. A graph of dose rate calculated from the experimental algorithm against temperature was then plotted as shown in figure 3.6. From the graph, it can be observed that the values for dose rate were now close to each other independent of the temperature.

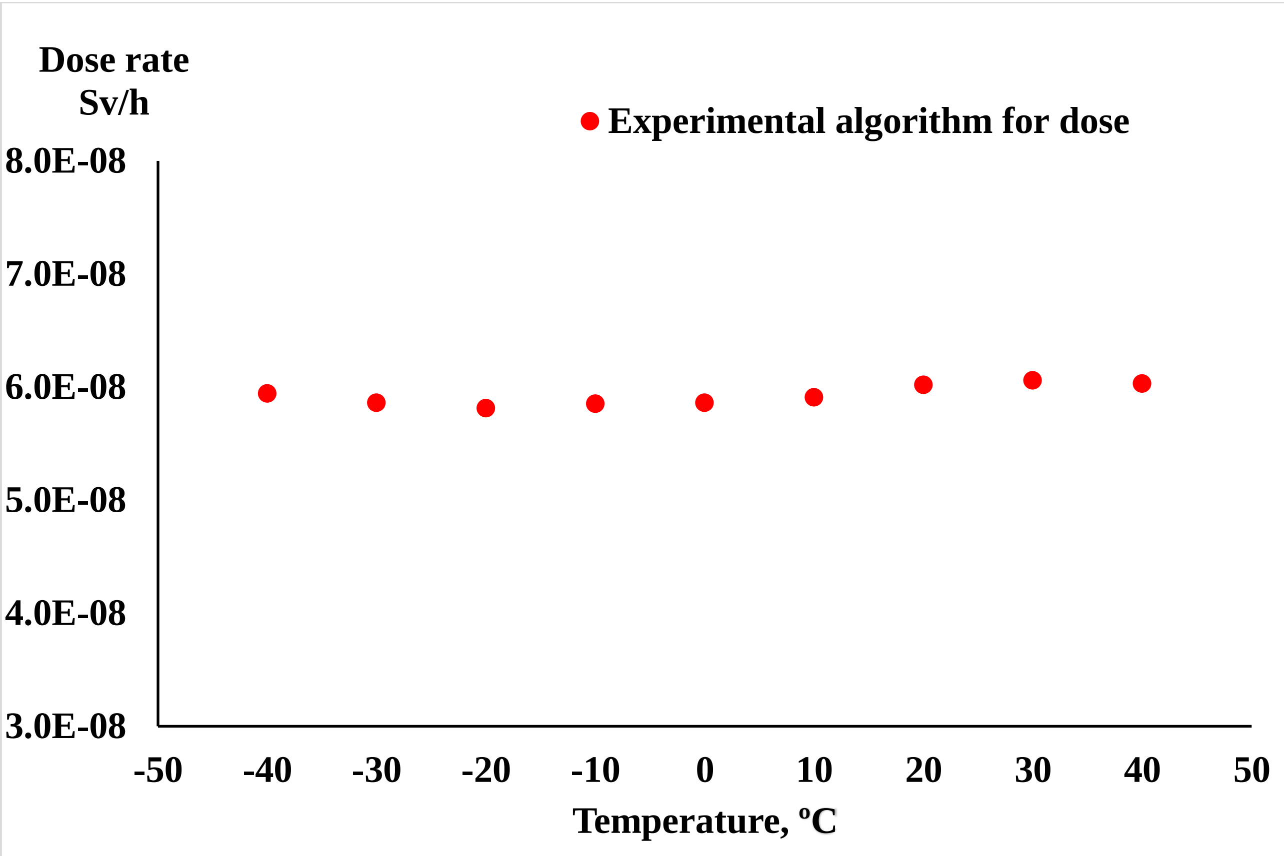

Figure 3.6 Dependence of Experimental algorithm for calculating dose rate on temperature.

The comparison of the algorithm for calculation of dose from the experimental result and the factory algorithm is presented in figure 3.7. From the graph, it can be observed that the dependence of the experimental algorithm for calculating dose rate on temperature was stronger than the dependence of the built-in algorithm for dose rate.

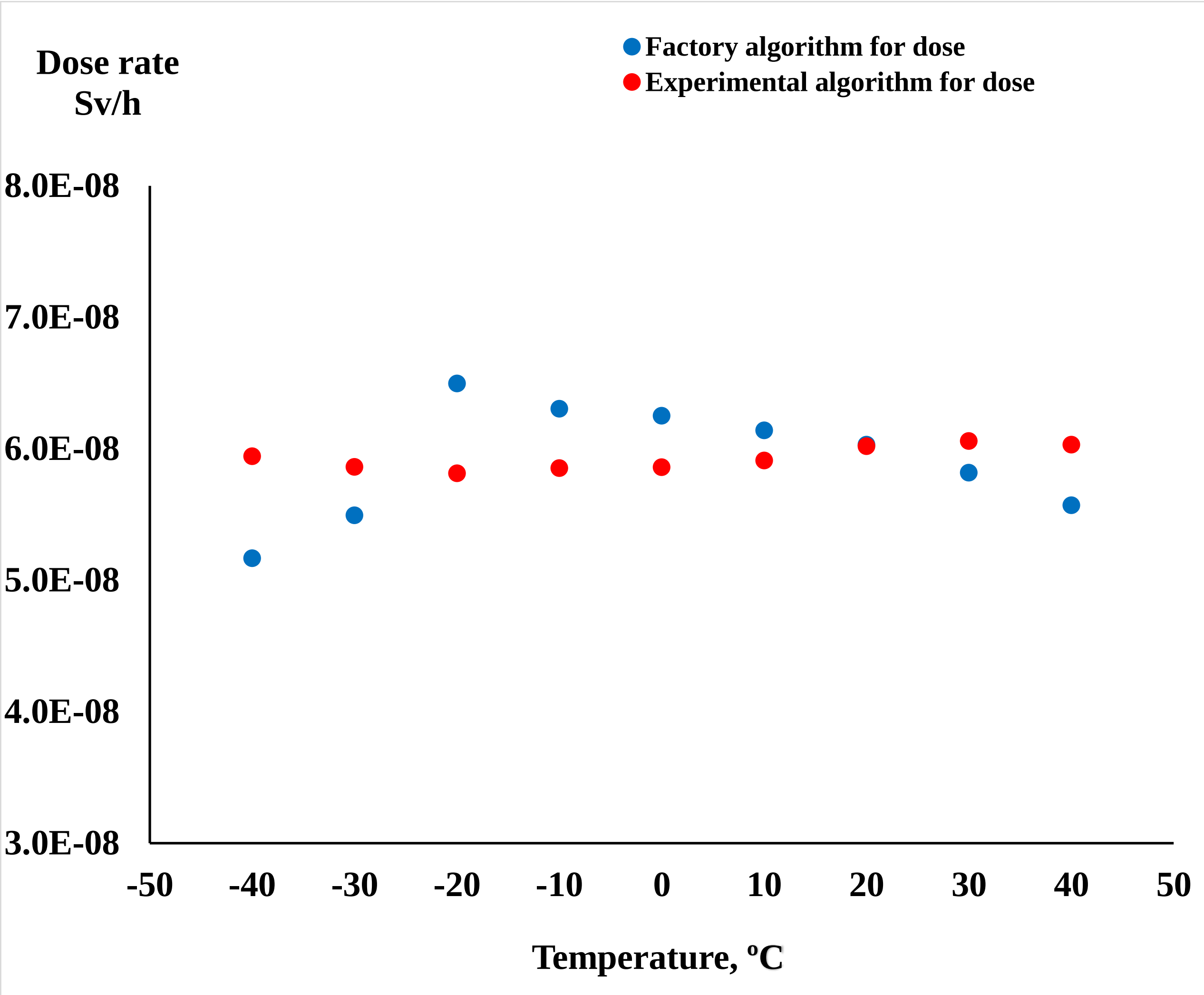

Figure 3.7 Graph of factory algorithm and experimental algorithm.

The experimental algorithm for calculating the dose rate, [$\mathrm{H} = \mathrm{N} \times (3.58 \times 10^{-13}\mathrm{T} + 2.152 \times 10^{-9})$] was compared to the formula $H = N \times k(T)$, (where H – dose rate, k(T) – temperature correction coefficient and N – count rate) to obtain an equation for calculating the temperature correction coefficient k(T). Hence, the new temperature correction coefficient was found as $\mathrm{k(T)} = \left(3.58 \times 10^{-13}\mathrm{T} + 2.152 \times 10^{-9)}\right)$. Figure 3.8 shows the experimental temperature correction coefficient. From the graph, it can be observed that the values for the temperature correction coefficient were now close to each other independent of the temperature.

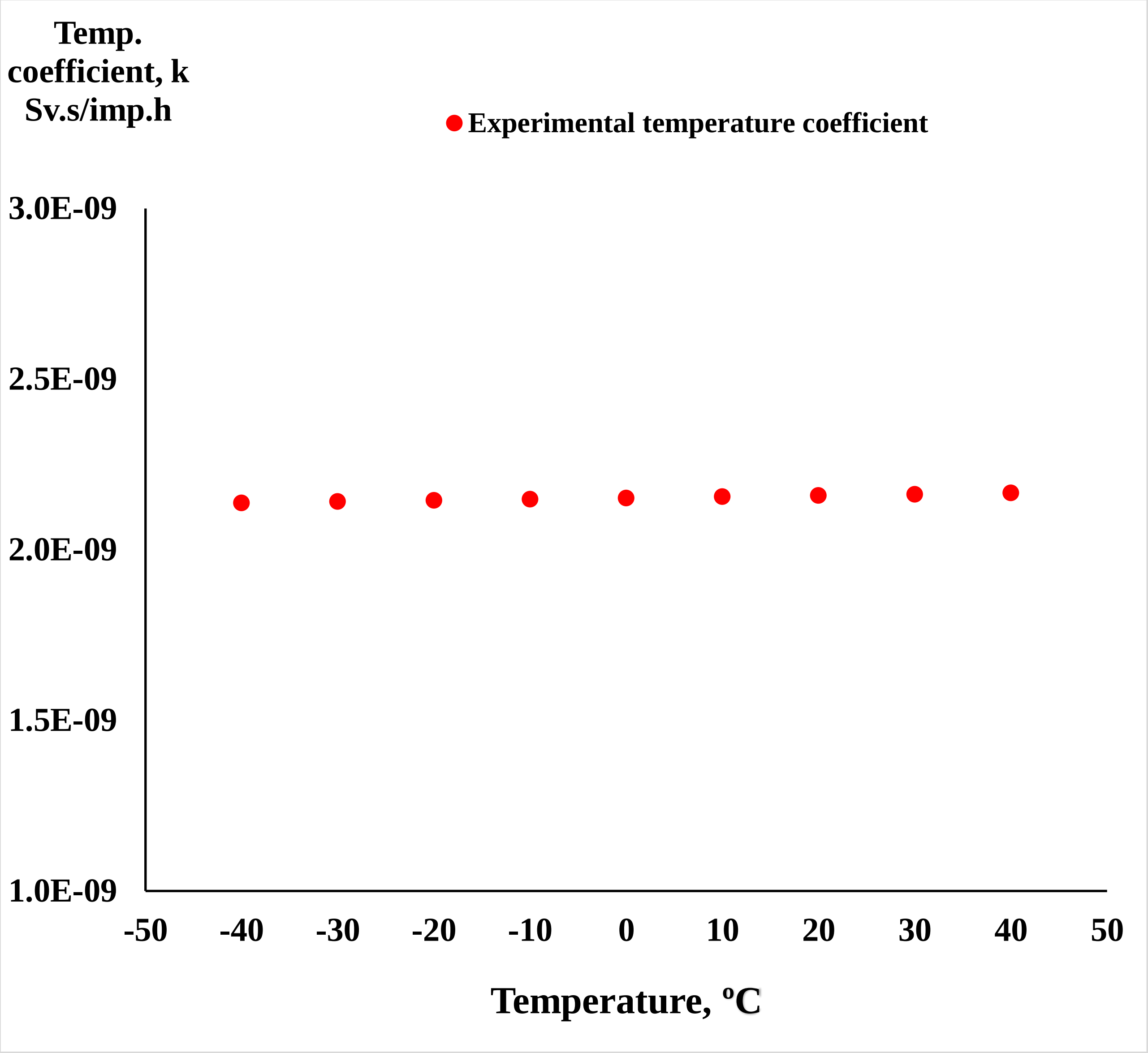

Figure 3.8 Graph of experimental correction coefficient against temperature.

The comparison of the temperature correction coefficient calculated from the experimental result and that of the factory is shown in figure 3.9. From the graph, it can be observed that the temperature correction coefficient of the experimental results showed a stronger dependence than that of the factory which showed a very weak dependence.

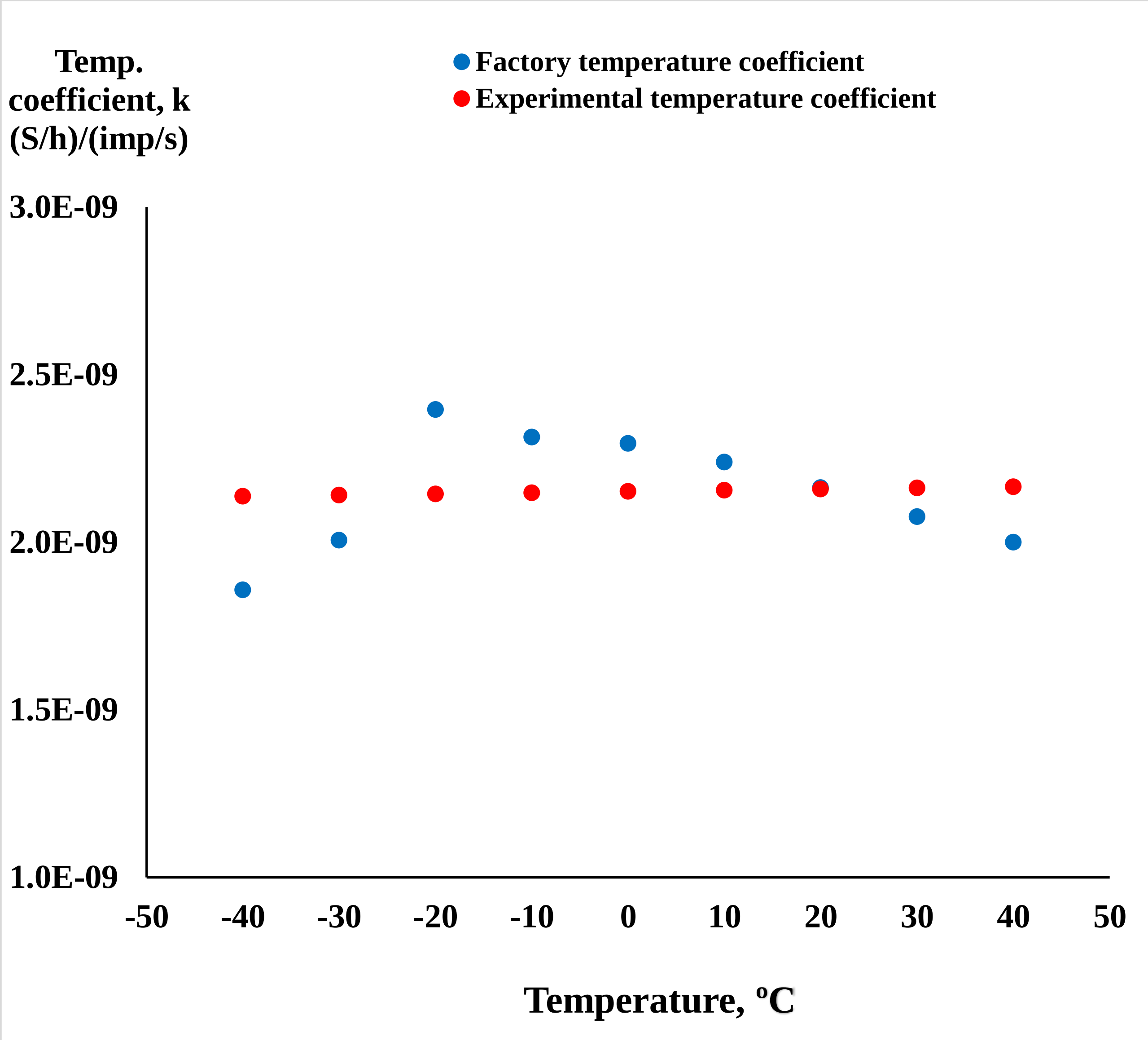

Figure 3.9 shows the comparison of the factory and the experimental correction coefficient on temperature.

Comparing the trend of figure 3.7 and figure 3.9, both graphs were similar. This shows that the accuracy of the measurement of dose rate strongly depends on the correctness of the temperature correction coefficient which intends also depends on temperature.

3.2 Validation of Results

To validate the results, the data obtained in the year 2019 in the city of Tomsk that was used to plot Figure 1.6 was recalculated using the new temperature correction coefficient and the experimental algorithm found for calculating of dose rate.

Figure 3.10 shows the comparison of the daily variation of dose rate calculated from the cpm using the factory algorithm and the dose rate calculated using the experimental algorithm. From the graph, there was a high deviation between them.

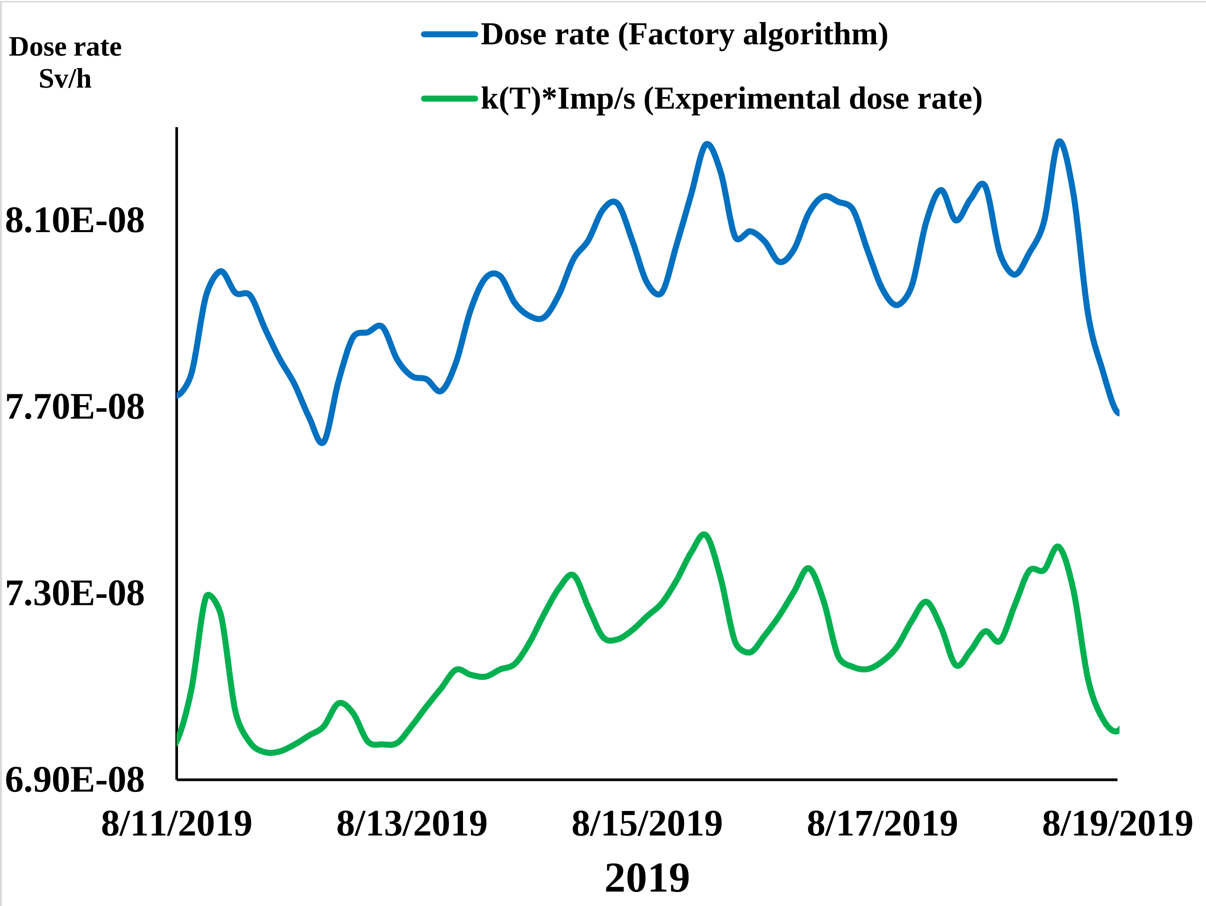

Figure 3.10 Comparison of the daily variation of dose rate calculated from the cpm using the factory algorithm and dose rate calculated using the experimental algorithm.

Figure 3.11 shows the comparison of the daily variation of dose rate calculated using the experimental algorithm and dose rate calculated using the constant temperature correction coefficient. The graph shows that they were overlapping each other.

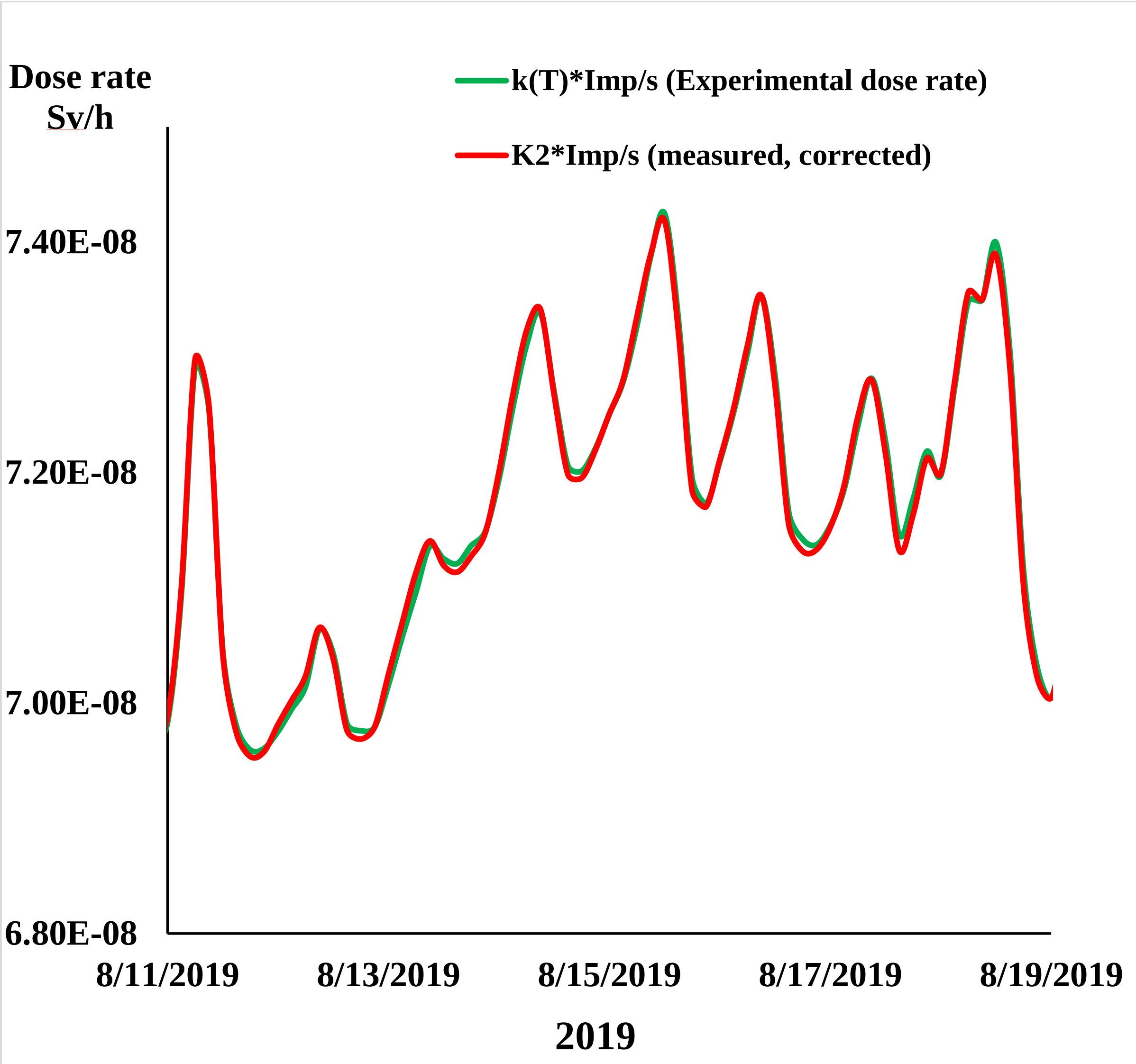

Figure 3.11 Comparison of the daily variation of dose rate calculated using the experimental algorithm and dose rate calculated using the constant temperature correction coefficient.

Figure 3.12 shows the comparison of the annual variation of dose rate calculated using the experimental algorithm and dose rate calculated using the constant temperature correction coefficient. The graph shows that again they were overlapping each other.

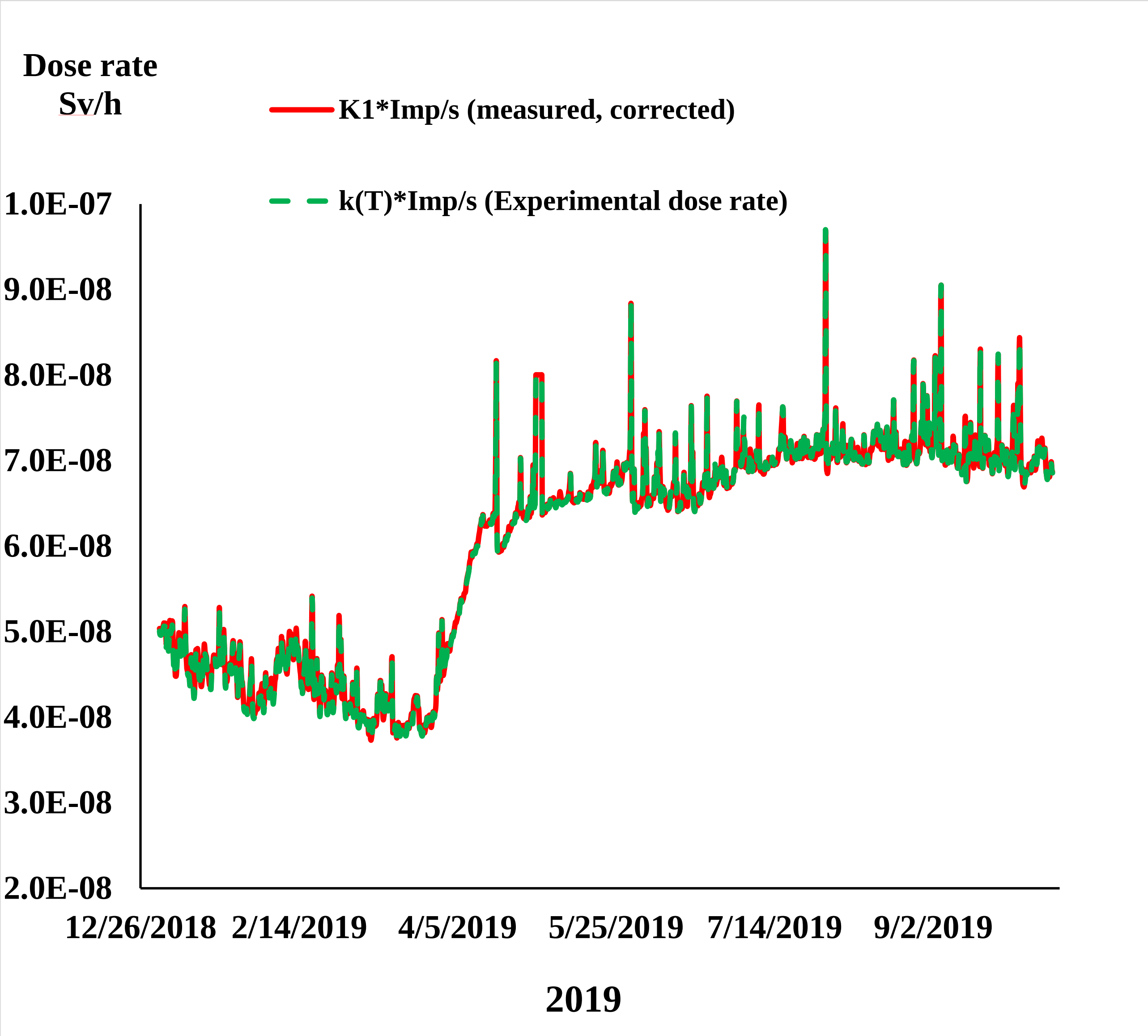

Figure 3.12 shows the comparison of the annual variation of dose rate calculated using the experimental algorithm and dose rate calculated using the constant temperature correction coefficient.

Figure 3.13 shows the comparison of the annual variation of dose rate calculated from the cpm using the factory algorithm and that of the experimental algorithm to the dose rate calculated using the constant temperature correction coefficient. The graph proofs that the experimental algorithm obtained can be used for calculating the dose rate of low gamma background radiation when using scintillation detector BDKG-03 but the factory algorithm cannot be used.

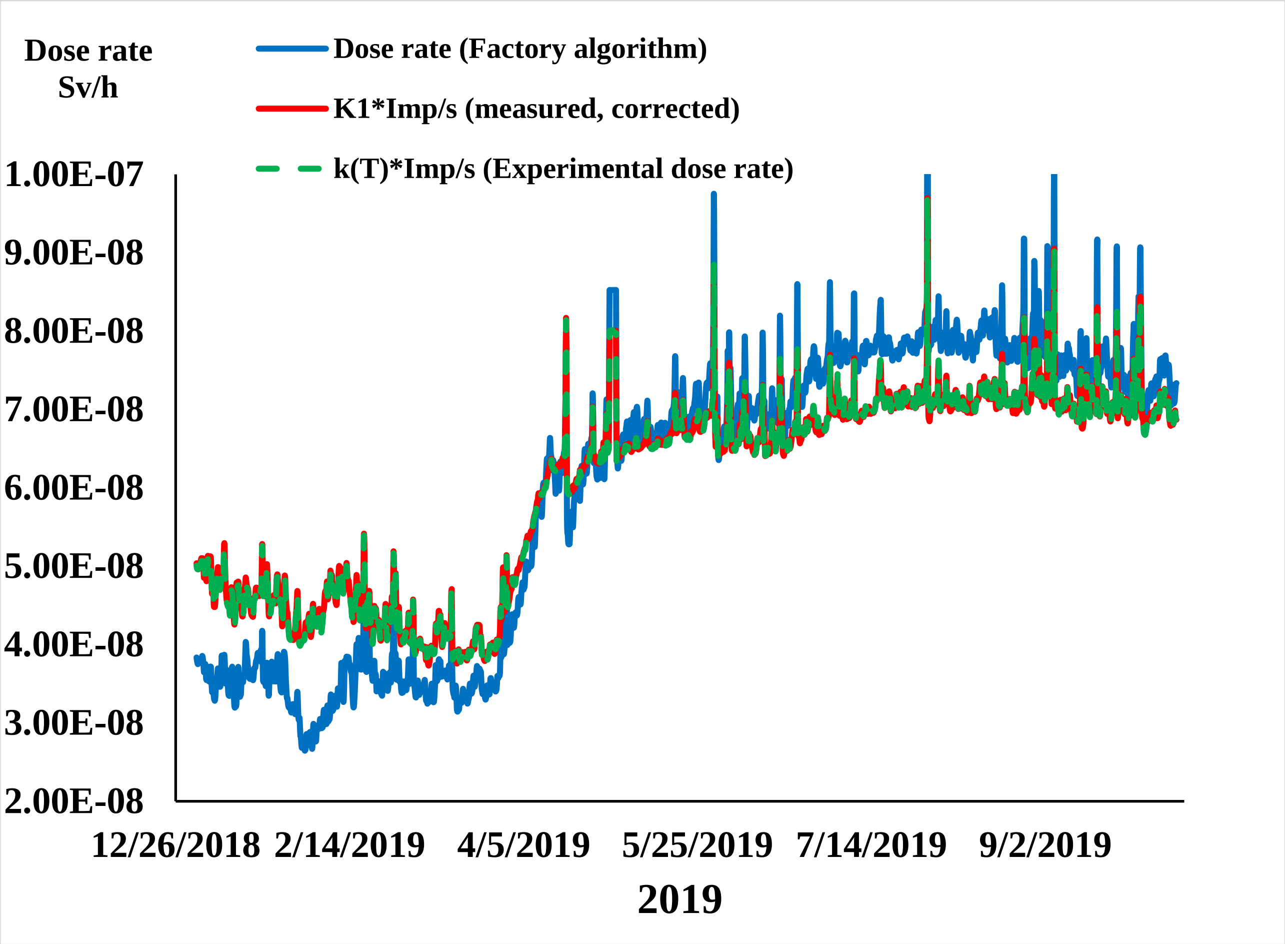

Figure 3.13 shows the comparison of the annual variation of dose rate calculated from the cpm using the factory algorithm and that of the experimental algorithm to the dose rate calculated using the constant temperature correction coefficient.

Chapter 4 Financial management, resource efficiency and resource saving

One of the most essential features in any research work is financial management. For every project or research to be started and completed successfully, one has to have a fair knowledge about financial management. Financial management can basically be defined as the process of organizing, directing, controlling, monitoring and strategic planning of financial resources of an institute or an organization, in order to achieve a set of goals and objectives. Application of management principles to financial resources of the institute or organisation plays a very vital part in financial management. Finance or money plays an essential role when it comes to the management of a business because it is needed in order to meet the requirements of the economic world and in addition, every business requires money in order to survive. No matter how small or big a business is, money needs to be put into it so as to keep it running, achieve a set of goals and gain more profit. The main aim of every businessman is to gain lots of profit, no one wants to do a business that would fail or would not generate profits hence to achieve this, one has to manage his or her finance properly.

The purpose of this section "Financial Management, Resource Efficiency and Resource Saving" discusses the issues of competitiveness, resource efficiency and resource saving, as well as financial costs regarding the object of study of Master's thesis. Competitiveness analysis is carried out for this purpose. SWOT analysis helps to identify strengths, weaknesses, opportunities and threats associated with the project, and give an idea of working with them in each particular case. For the development of the project requires funds that go to the salaries of project participants and the necessary equipment, a complete list is given in the relevant section. The calculation of the resource efficiency indicator helps to make a final assessment of the technical decision on individual criteria and in general.

In addition, it would help determine the accomplishment of the research work so as to develop a mechanism for managing and supporting specific project solutions at the implementation stage of the project lifecycle to increase productivity. The financial management solves the following objectives:

- Planning and preparation of research work.
- Budget calculation for research work.
- Development of evaluation of commercial potential.

4.1 Competitiveness analysis of technical solutions

In order to find sources of financing for the project, it is necessary, first, to determine the commercial value of the work. Analysis of competitive technical solutions in terms of resource efficiency and resource saving allows to evaluate the comparative effectiveness of scientific development. This analysis is advisable to carry out using an evaluation card.

The monitoring ad measuring of radiation level in the environment has become a very important factor in our world today and this can be achieved by using an appropriate device or equipment known as the radiation detector. Scintillation detectors are mostly used for measuring radiation outdoor and are mostly affected by environmental conditions such as temperature. Since radiation detectors are been developed most often, it is important to find the most effective and accurate method for estimating the correct algorithm for calculating dose rate under different environmental condition, especially at different temperature range, taking into consideration low cost. This algorithm must be able to calculate radiation dose rate at both low and high levels. In this work, a method with a very low cost was chosen to investigate the effect of ambient temperature on the readings of low gamma background radiation and to obtain a temperature correction factor that can be used to calculate the results of low gamma background radiation obtained from the scintillation detector. These methods include:

- The use of climatic chamber to depict the environmental conditions for different temperature range.
- The use of an inorganic scintillation detector and laptop to measure dose rate and count rate at low background gamma radiation.

- The use of excel software to analysis the results.

The scintillation detector (BDKG-03) was used because that is the radiation detector used in TPU for gamma radiation monitoring. An experiment conducted showed that the scintillation detector (BDKG-03) is the best Dosimetric method sensitive to background radiation because it had a smaller standard deviation compared to the gas discharge counter.

There are different sources of low background radiation that can be used as a source to calibrate radiation detectors that are used for monitoring in the environment. For this research, two sources can be considered:

- Gamma background radiation – P_f.
- Low radioactive source – P_i.

First of all, it is necessary to analyze possible technical solutions and choose the best one based on the considered technical and economic criteria.

Evaluation map analysis presented in Table 1. The position of your research and competitors is evaluated for each indicator by you on a five-point scale, where 1 is the weakest position and 5 is the strongest. The weights of indicators determined by you in the amount should be 1. Analysis of competitive technical solutions is determined by the formula:

$$C = \sum W_i \cdot P_i, \tag{4.1}$$

C - the competitiveness of research or a competitor;

Wi– criterion weight;

Pi – point of i-th criteria.

You can use the following criteria for the model of expert evaluation:

- noise immunity;
- set of terminals relay protection;
- reliability of relay protection;
- smart interface quality;
- energy efficiency;
- ease of operation;

- ability to connect to PC;
- estimated lifetime;
- safety;
- etc.

Table 4.1 Evaluation card for comparison of competitive technical solutions

Evaluation criteria ***Example***	**Criterion weight**	**Points**		**Competitiveness** Taking into account weight coefficients	
		P_{f1}	P_i	C_f	C_i
1	2	3	4	7	8
Technical criteria for evaluating resource efficiency					
1. Energy efficiency	0.1	4	3	0.4	0.3
2. Reliability	0.2	5	4	1	0.8
3. Safety	0.2	5	4	1	0.8
4. Functional capacity	0.1	5	5	0.5	0.5
Economic criteria for performance evaluation					
1. Development cost	0.1	5	4	0.5	0.4
2. Market penetration rate	0.1	3	4	0.3	0.4
3. Expected lifecycle	0.2	5	4	1	0.8
Total	**1**	**32**	**28**	**4.7**	**4.0**

The results of the competitiveness analysis shows that gamma background radiation have the highest value of competitiveness. This shows that they are the best option to choose when investigating the effect of ambient temperature on the readings of low gamma background radiation in order to obtain a temperature correction factor that can be used to calculate the results of low gamma background radiation.

4.2 SWOT Analysis

Complex analysis solution with the greatest competitiveness is carried out with the method of the SWOT analysis: Strengths, Weaknesses, Opportunities and Threats. The analysis has several stages. The first stage consists of describing the strengths and weaknesses of the project, identifying opportunities and threats to the project that have emerged or may appear in its external environment. The second stage consists of identifying the compatibility of the strengths and weaknesses of the project with the external environmental conditions. This compatibility or incompatibility should help to identify what strategic changes are needed.

Table 4.2 SWOT analysis

	Strengths: S1. Low cost. S2. Simplicity of method. S3. Reliability of results obtained. S4.Small relative error for both the dose rate and the count rate. S4. Very safe. S5. Very important factor for all radiation detectors.	**Weaknesses:** W1. Taking measurement and analyzing takes lots of time. W2. Difficulty in regulating the climatic chamber to get the actual temperature. W3. Need to know how to operate the detector and climatic chamber technically. W4. Software sometimes take long to open.
Opportunities: O1.Data can be used to calculate dose rate for low background radiation in BDKG -03 scintillation detector. O2. Research institute could use the method to find the influence of ambient temperature on gamma background radiation of any radiation detector used outdoor.	***Strategy which based on strengths and opportunities:*** 1. Obtained a method, which can be used to calibrate dose rate in radiation detectors.	***Strategy which based on weaknesses and opportunities:*** Regulating of climatic chamber to attain the actual temperature for measurement.

O3. Researchers can use the method can be used to estimate the algorithm for calculating dose rate under the influence of different temperature range.		
Threats: T1. Lack of financial support in purchasing of equipment. T2. Lack of demand since it is needed only after development of a radiation detector. T3. Need of a climatic chamber to depict the environmental weather conditions.	***Strategy which based on strengths and threats:*** Finding another equipment that can replace the climatic chamber to depict the environmental condition accurately.	***Strategy which based on weaknesses and threats:*** Not being able to complete project due to lack of financial support and lack of climatic chamber.

4.3 Project Initiation

The initiation process group consists of processes that are performed to define a new project or a new phase of an existing one. In the initiation processes, the initial purpose and content are determined and the initial financial resources are fixed. The internal and external stakeholders of the project who will interact and influence the overall result of the research project are determined.

4.3.1 Project Stakeholders

Table 4.3 Stakeholders of the project

Project stakeholders	**Stakeholder expectations**
Tomsk Polytechnic University (TPU)	Supervision and approval of research work came from TPU. The acquired results can be used to calculate the dose rate of low gamma background radiation in the environment when using scintillation detector (BDKG-03).

Environmental Radiation Protection Center (ERPC)	Development of a method for the stabilization of temperature in a radiation detector when there is temperature change.
Ghana Government	Utilization of the intellectual property, developing the scientific knowledge of the academic personnel of radiation monitoring.

4.3.2 Objectives and Outcomes of Project

Table 4.4 Purpose and results of the project

Purpose of project:	To investigate the effect of ambient temperature on the readings of low gamma background radiation and to obtain a temperature correction factor that can be used to calculate the results of dose rate for low gamma background radiation obtained from scintillation detector (BDKG-03).
Expected results of the project:	The factory's temperature correction coefficient inside the detector (BDKG – 03) to be incorrect for low gamma background radiation. The factory's algorithm for calculating of dose rate for low background radiation to be incorrect.
Criteria for acceptance of the project result:	Validation of results by using the obtained algorithm for calculating of dose rate to recalculate measurement obtained in Tomsk for different temperatures and getting the same values independent of the temperature range.
	Agreement between the results of project and the results of other authors on similar works.
	Industrial application. The results would help address the stabilization of temperature correction factor in scintillation detectors.
	Technical specification: To be able to measure the correct gamma dose rate at an area, effective stabilization of detectors at any environmental condition especially change in temperature is needed so as not to cause fluctuations in results. This is obtained by following laid down procedures and

	standard already established for evaluation and performance of radiation detection portal monitors.

4.3.3 Project Participants

The organizational structure of the project involves all participants or people who participated in the research work, the number of hours they spent and the roles they played in the research. In this research work, there were two participants.

- Scientific supervisor
- Engineer

Table 4.5 Structure of the project

№	**Participant**	**Role in the project**	**Functions**	**Labor time, hours (working days (from table 7) × 6 hours)**
1	Scientific Supervisor – A professor and a lecture of the Nuclear Science and Technology department at TPU.	Head of project	Formulating of research topic and giving directions of how to achieve the main aim. Ensuring that all task pertaining to the main objectives are done on time. Verification of results obtained.	48×6 = 288
2	Engineer – A student of the Nuclear Science and Technology department at TPU.	Executor	Performing of task and researching of literature review. Collecting of data and analysing of results.	82×6 = 492

4.3.4 Project limitations and Assumptions

Project limitations are all factors that can be as a restriction on the degree of freedom of the project team members.

Table 4.6 Project limitations

Factors	**Limitations / Assumptions**
3.1. Project's budget	326530.74
3.1.1. Source of financing	TPU
3.2. Project timeline:	25/05/2020 to 25/05/2021
3.2.1. Date of approval of plan of project	25/05/2021
3.2.2. Completion date	25/05/2021

4.3.5 Project Schedule

As part of planning a science project, you need to build a project timeline and a Gantt Chart.

Table 4.7. Project Schedule

Job title	**Duration, working days**	**Start date**	**Date of completion**	**Participants**
Development of the technical task	6	1/02/2021	7/02/2021	Scientific Supervisor
Drafting and approval of terms of reference	11	7/02/2021	21/02/2021	Scientific Supervisor
Choosing of a research direction	2	21/02/2021	24/02/2021	Scientific Supervisor, Engineer
Collection and study of literature	24	24/02/2021	24/03/2021	Engineer
Choosing of experimental method	2	24/03/2021	25/03/2021	Scientific Supervisor, Engineer

Choosing of a place to conduct research	2	25/03/2021	26/03/2021	Scientific supervisor
Conducting of experiment to collect data of count rate and dose rate of gamma radiation using the BDKG-03 and climatic chamber	3	26/08/2021	29/03/2021	Engineer
Analysis of results obtained	16	29/03/2021	16/04/2021	Engineer, Scientific supervisor
Summary of results	4	16/04/2021	20/04/2021	Scientific Supervisor, Engineer
Checking and assessment of results	4	20/04/2021	23/04/2021	Scientific supervisor, Engineer
Compilation of results for report	7	23/04/2021	2/04/2021	Engineer
Preparation of report	4	2/05/2021	6/05/2021	Engineer
Defence preparation	16	6/05/2021	25/05/2021	Engineer

A Gantt chart, or harmonogram, is a type of bar chart that illustrates a project schedule. This chart lists the tasks to be performed on the vertical axis, and time intervals on the horizontal axis. The width of the horizontal bars in the graph shows the duration of each activity.

Table 4.8 A Gantt chart

№	Activities	Participants	T_c, days	Duration of the project											
				February			March			April			May		
				1	2	3	1	2	3	1	2	3	1	2	3
1	Development of the technical task	Scientific Supervisor	6												
2	Drafting and approval of terms of reference	Scientific Supervisor	11												
3	Choosing of a research direction	Scientific Supervisor, Engineer	2												
4	Collection and study of literature	Engineer	24												
5	Choosing of experimental method	Scientific Supervisor, Engineer	2												
6	Choosing of a place to conduct research	Scientific supervisor	2												
7	Conducting of experiment to collect data of count rate and dose rate of gamma radiation using the BDKG-03 and climatic chamber	Engineer	3												
8	Analysis of results obtained	Engineer, Scientific supervisor	16												
9	Summary of results	Scientific Supervisor, Engineer	4												

10	Checking and assessment of results	Scientific supervisor, Engineer	4												
11	Compilation of results for report	Engineer	7												
12	Preparation of report	Engineer	4												
13	Defence preparation	Engineer	16												

Scientific Supervisor   Engineer

4.4 Scientific and technical research budget

The amount of costs associated with the implementation of this work is the basis for the formation of the project budget. This budget will be presented as the lower limit of project costs when forming a contract with the customer.

To form the final cost value, all calculated costs for individual items related to the manager and the student are summed.

In the process of budgeting, the following grouping of costs by items is used:

- Material costs of scientific and technical research;
- costs of special equipment for scientific work (Depreciation of equipment used for design);
- basic salary;
- additional salary;
- labor tax;
- overhead.

4.4.1 Calculation of material costs

The calculation of material costs is carried out according to the formula:

$$C_m = (1 + k_T) \cdot \sum_{i=1}^{m} P_i \cdot N_{consi} \qquad (4.2)$$

where

m – the number of types of material resources consumed in the performance of scientific research;

N_{consi} – the amount of material resources of the i-th species planned to be used when performing scientific research (units, kg, m, m^2, etc.);

P_i – the acquisition price of a unit of the i-th type of material resources consumed (rub./units, rub./kg, rub./m, rub./m^2, etc.);

k_T – coefficient taking into account transportation costs.

Prices for material resources can be set according to data posted on relevant websites on the Internet by manufacturers (or supplier organizations).

Table 4.9 Material costs

Name	**Unit**	**Amount**	**Price per unit, rub.**	**Material costs, rub.**
Office supplies	-	1	1000	1000.00
Transportation	Unit	8	100	800.00
Printing	Unit	200	4	800.00
Total				2600.00

4.4.2 Calculation of the depreciation.

Depreciation is not charged if an equipment cost is less than 40 thousand rubles, its cost is taken into account in full.

If you use available equipment, then you need to calculate depreciation:

$$A = \frac{С_{перв} * Н_а}{100} \quad (4.3)$$

A - annual amount of depreciation;

$C_{перв}$ - initial cost of the equipment;

$Н_а = \frac{100}{Т_{сл}}$ - rate of depreciation;

$T_{сл}$ - life expectancy.

For this research, a gamma radiation detector (BDKG-03), a climatic chamber and a laptop, which cost 118000 rubles, 400000 and 30000 respectively, were used. The gamma detector and the laptop both had a life expectancy of 5 years whiles that of the climatic chamber was 10 years. The depreciation for the gamma detector, climatic chamber and laptop can be calculated as follows:

Gamma detector:

$$\mathrm{D} = \frac{\mathrm{Cost}}{\mathrm{Time}} \quad (4.4)$$

$$\mathrm{D} = \frac{118000}{5 \times 365} = 64.66 \frac{\mathrm{rubles}}{\mathrm{day}} \quad (4.5)$$

Since the equipment was used for 3 days

$$\mathrm{A} = 64.66 \times 3 = 193.97 \text{ rubles} \quad (4.6)$$

Climatic chamber:

$$\mathrm{D} = \frac{\mathrm{Cost}}{\mathrm{Time}} \quad (4.7)$$

$$\mathrm{D} = \frac{400000}{10 \times 365} = 109.589 \frac{\mathrm{rubles}}{\mathrm{day}} \quad (4.8)$$

Since the equipment was used for 3 days

$$\mathrm{A} = 109.589 \times 3 = 328.767 \text{ rubles} \quad (4.9)$$

Table 4.10 Depreciation of special equipment (+software)

№	equipment identification	Quantity of equipment	Total cost of equipment, rub.	Life expectancy, year	Depreciation for the duration of the project, rub.
1.	Scintillation gamma radiation	1	118000	10	193.97

	detector (BDKG-03)				
2.	Climatic chamber	1	400000	10	328.77
3	Laptop	1	30000	-	30000
Total					30522.74

4.4.3 Basic salary

This point includes the basic salary of participants directly involved in the implementation of work on this research. The value of salary costs is determined based on the labor intensity of the work performed and the current salary system

The basic salary (S_b) is calculated according to the formula:

$$S_b = S_a \cdot T_w \text{,} \tag{4.10}$$

where S_b – basic salary per participant;

T_w – the duration of the work performed by the scientific and technical worker, working days;

S_d - the average daily salary of an participant, rub.

The average daily salary is calculated by the formula:

$$S_d = \frac{S_m \cdot M}{F_v} \text{,} \tag{4.11}$$

where,

S_m – monthly salary of a participant, rubles;

M – the number of months of work without leave during the year:

at holiday in 48 days, M = 11.2 months, 6 day per week;

F_v – valid annual fund of working time of scientific and technical personnel (251 days).

Table 4.11 The valid annual fund of working time

Working time indicators	
Calendar number of days	365
The number of non-working days - weekend - holidays	 52 14
Loss of working time - vacation - isolation period - sick absence	48
The valid annual fund of working time	251

Monthly salary is calculated by formula:

$$S_{month} = S_{base} \cdot (k_{premium} + k_{bonus}) \cdot k_{reg} , \qquad (4.12)$$

where, S_{base} – base salary, rubles;

$k_{premium}$ – premium rate;

k_{bonus} – bonus rate;

k_{reg} – regional rate.

Table 4.12 Calculation of the base salaries

Performers	S_{base}, **rubles**	$k_{premium}$	k_{bonus}	k_{reg}	S_{month}, **rub.**	W_d, **rub.**	T_p, **work days (from table 7)**	W_{base}, **rub.**
Scientific Supervisor	40000				52000	1784.86	48	85673.28
Engineer	19870				25831	886.63	82	72703.66
Total								158376.94

4.4.4 Additional salary

This point includes the amount of payments stipulated by the legislation on labor, for example, payment of regular and additional holidays; payment of time associated with state and public duties; payment for work experience, etc.

Additional salaries are calculated on the basis of 10-15% of the base salary of workers:

$$W_{add} = k_{extra} \cdot W_{base}, \tag{4.13}$$

where,

W_{add} – additional salary, rubles;

k_{extra} – additional salary coefficient (10%);

W_{base} – base salary, rubles.

Table 4.13. Additional Salary

Participant	**Additional Salary, rubles**
Scientific Supervisor	8567.32
Engineer	7270.37
Total	15837.69

4.4.5 Labor tax

Tax to extra-budgetary funds are compulsory according to the norms established by the legislation of the Russian Federation to the state social insurance (SIF), pension fund (PF) and medical insurance (FCMIF) from the costs of workers.

Payment to extra-budgetary funds is determined of the formula:

$$P_{social} = k_b \cdot (W_{base} + W_{add}) \tag{4.14}$$

where,

k_b – coefficient of deductions for labor tax.

In accordance with the Federal law of July 24, 2009 No. 212-FL, the amount of insurance contributions is set at 30%. Institutions conducting educational and scientific activities have rate - 27.1%.

Table 4.14 Labor tax

	Project leader	**Engineer**
Coefficient of deductions	27.1%	
Salary (basic and additional), rubles	94240.60	79974.03
Labor tax, rubles	25444.96	21672.96
Total		47117.92

4.4.6 Overhead costs

Overhead costs include other management and maintenance costs that can be allocated directly to the project. In addition, this includes expenses for the maintenance, operation and repair of equipment, production tools and equipment, buildings, structures, etc.

Overhead costs account from 30% to 90% of the amount of base and additional salary of employees.

Overhead is calculated according to the formula:

$$C_{ov} = k_{ov} \cdot (W_{base} + W_{add}) \qquad (4.15)$$

where,

k_{ov} – Overhead rate.

Table 4.15 Overhead

	Project leader	**Engineer**
Overhead rate	40%	
Salary, rubles	94240.60	79974.03
Overhead, rubles	37696.24	31989.61
Total		69685.85

4.4.7 Other direct costs

Energy costs for equipment are calculated by the formula:

$$C = P_{el} \cdot P \cdot F_{eq}, \qquad (4.16)$$

where,

P_{el} − Power rates (5.8 rubles per 1 kWh);

P − Power of equipment, kW;

F_{eq} − Equipment usage time, hours.

Table 4.16 Other direct costs

	Power rates, kWh	**Power of equipment, kW**	**Equipment usage time, hr**	**Energy cost, rubles**
Climatic chamber	5.8	0.5	24	69.60
Laptop	5.8	0.5	492	1426.80
Gamma radiation detector (BDKG-03)	5.8	0.5	24	69.60
Total				1566.00

4.4.8 Formation of budget costs

The calculated cost of research is the basis for budgeting project costs.

Determining the budget for the scientific research is given in the table 4.17.

Table 4.17 Items expenses grouping

Name	**Cost, rubles**
1. Material costs	2600.00
2. Equipment costs	30522.74
3. Basic salary	158376.94
4. Additional salary	15837.69
5. Labor tax	47117.92
6. Overhead	69685.85
Other direct costs	1566.00
Total planned costs	**325707.14**

4.5 Evaluation of the comparative effectiveness of the project

Determination of efficiency is based on the calculation of the integral indicator of the effectiveness of scientific research. Its finding is associated with the definition of two weighted average values: financial efficiency and resource efficiency.

The integral indicator of the financial efficiency of a scientific study is obtained in the course of estimating the budget for the costs of three (or more) variants of the execution of a scientific study. For this, the largest integral indicator of the implementation of the technical problem is taken as the calculation base (as the denominator), with which the financial values for all the options are correlated.

The integral financial measure of development is defined as:

$$I^d{}_f = \frac{C_i}{C_{max}} \tag{4.17}$$

where,

$I^d{}_f$ – Integral financial measure of development;

C_i – The cost of the i-th version;

$C_{\max}$ – The maximum cost of execution of a research project (including analogues).

As an analogue, the method of temperature stabilization of a radiation detector is done by placing the detector in the climatic chamber and measuring the dose rate and count rate of a gamma ray source.

The integral financial measure of development can be calculated as:

$$I^d{}_f = \frac{C_i}{C_{max}} \tag{4.18}$$

where,

C_i – The cost of the research work using gamma background radiation = 325707.14

And C_{max} – The maximum cost of execution of research project using a gamma radioactive source = 400,000.00

$$I^d{}_f = \frac{325707.14}{400000.00} \tag{4.19}$$

$$I^{d}{}_{f} = 0.814 \tag{4.20}$$

and

$$I^{a}{}_{f} = \frac{C_i}{C_{max}} \tag{4.21}$$

$$I^{a}{}_{f} = \frac{400000.00}{400000.00} \tag{4.22}$$

$$I^{a}{}_{f} = 1 \tag{4.23}$$

The obtained value of the integral financial measure of development reflects the corresponding numerical increase in the budget of development costs in times (the value is greater than one), or the corresponding numerical reduction in the cost of development in times (the value is less than one, but greater than zero).

Since the development has one performance, then I_f^d = 1.

The integral indicator of the resource efficiency of the variants of the research object can be determined as follows:

$$I_m^a = \sum_{i=1}^{n} a_i b_i^a \qquad I_m^p = \sum_{i=1}^{n} a_i b_i^p \tag{4.24}$$

where,

I_m – Integral indicator of resource efficiency for the i-th version of the development;

a_i – The weighting factor of the i-th version of the development;

b_i^a, b_i^p – Score rating of the i-th version of the development, is established by an expert on the selected rating scale;

n – Number of comparison parameters.

The calculation of the integral indicator of resource efficiency is presented in the form of table 4.18.

Table 4.18 – Evaluation of the performance of the project

Criteria	Weight criterion	Points	
		I_m^a	I_m^p
1. Energy efficiency	0.2	5	3
2. Reliability	0.1	4	4
3. Safety	0.2	5	5
4. Functional capacity	0.1	4	4
Economic criteria for performance evaluation			
1. The cost of development	0.1	4	4
2. Market penetration rate	0.1	5	5
3. Expected life	0.1	4	4
4. After-sales service	0.1	4	5
Total	**1**	**4.5**	**4.2**

$$I^a{}_m = \sum_{i=1}^{n} a_i b_i^a \quad (4.25)$$

$$I^a{}_m = (0.2 \times 5) + (0.1 \times 4) + (0.2 \times 5) + (0.1 \times 4) + (0.1 \times 4) + (0.1 \times 5) + (0.1 \times 4) + (0.1 \times 4) \quad (4.26)$$

$$I^a{}_m = 4.5 \quad (4.27)$$

$$I^p{}_m = \sum_{i=1}^{n} a_i b_i^a \quad (4.28)$$

$$I^p{}_m = (0.2 \times 3) + (0.1 \times 4) + (0.2 \times 5) + (0.1 \times 4) + (0.1 \times 4) + (0.1 \times 5) + (0.1 \times 4) + (0.1 \times 5) \quad (4.29)$$

$$I^p{}_m = 4.2 \quad (4.30)$$

The integral indicator of the development efficiency (I_e^p) is determined on the basis of the integral indicator of resource efficiency and the integral financial indicator using the formula:

$$I_e^P = \frac{I_m^P}{I_f^{d}}, I_e^a = \frac{I_m^a}{I_f^{a}} \quad (4.31)$$

$$I_{\text{исп.2}} = \frac{I_{\text{р−исп2}}}{I_{\text{финр}}^{\text{исп.2}}} \text{ и т.д.} \quad (4.32)$$

$$I^p{}_e = \frac{I^p{}_m}{I^d{}_f} = \frac{4.5}{0.877} = 5.13 \quad (4.33)$$

$$I^a{}_e = \frac{I^a{}_m}{I^a{}_f} = \frac{4.2}{1} = 4.2 \quad (4.34)$$

Comparison of the integral indicator of the current project efficiency and analogues will determine the comparative efficiency. Comparative effectiveness of the project:

$$E_c = \frac{I_e^p}{I_e^a} \quad (4.35)$$

.

$$E_c = \frac{5.13}{4.2} = 1.221 \quad (4.36)$$

Thus, the effectiveness of the development is presented in table 4.19.

Table 4.19 Efficiency of development

№	**Indicators**	**Points**	
		P	a
1	Integral financial measure of development	0.814	1
2	Integral indicator of resource efficiency of development	4.5	4.2
3	Integral indicator of the development efficiency	1.221	1

Comparison of the values of integral performance indicators allows us to understand and choose a more effective solution to the technical problem from the standpoint of financial and resource efficiency.

4.6 Conclusion

Thus, in this section was developed stages for design and create competitive development that meet the requirements in the field of resource efficiency and resource saving.

These stages include:

- Development of a common economic project idea, formation of a project concept;
- Organization of work on a research project;
- Identification of possible research alternatives;
- Research planning;
- Assessing the commercial potential and prospects of scientific research from the standpoint of resource efficiency and resource saving;
- Determination of resource (resource saving), financial, budget, social and economic efficiency of the project.

Chapter 5 Social Responsibilities

5.1 Introduction

Radiation can be found all around us and it is important to measure or monitor the amount of radiation in the environment. This is because humans are exposed to them and when the level of radiation is high, it can have a negative impact on human health. After the nuclear accidents that occurred especially after the Fukushima Daiichi Nuclear Power Plant accident, environmental radiation monitoring become very essential. Radiation monitoring is done using a device known as radiation detectors. Scintillation detector is one of the oldest radiation detectors in the world and NaI (Tl) detector is an example of a scintillation detector.

The scintillation detector (NaI(Tl)) are mostly used out door, where they are subject to change in environmental conditions such as temperature which intend affect the readings of gamma radiations using the detector. Therefore, every detector has a temperature correction algorithm that is used to correct this defect. Research done in TPU revealed doubt in the correctness of the algorithm used in the scintillation BDKG-03 and this lead to my research work. The essence of my thesis work is to investigate the effect of ambient temperature on the readings of NaI (Tl) scintillation detector, to find the correct temperature correction factor and the algorithm for calculating dose rate for low gamma background radiation.

5.2 Legal and organizational items in providing safety

Nowadays one of the main ways to radical improvement of all prophylactic work referred to reduce Total Incidents Rate and occupational morbidity is the widespread implementation of an integrated Occupational Safety and Health management system. That means combining isolated activities into a single system of targeted actions at all levels and stages of the production process.

Occupational safety is a system of legislative, socio-economic, organizational, technological, hygienic and therapeutic and prophylactic measures and tools that ensure the safety, preservation of health and human performance in the work process [Federal Law].

According to the Labor Code of the Russian Federation, every employee has the right:

- To have a workplace that meets Occupational safety requirements;
- To have a compulsory social insurance against accidents at manufacturing and occupational diseases;
- To receive reliable information from the employer, relevant government bodies and public organizations on conditions and Occupational safety at the workplace, about the existing risk of damage to health, as well as measures to protect against harmful and (or) hazardous factors;
- To refuse carrying out work in case of danger to his life and health due to violation of Occupational safety requirements;
- Be provided with personal and collective protective equipment in compliance with Occupational safety requirements at the expense of the employer;
- For training in safe work methods and techniques at the expense of the employer;
- For personal participation or participation through their representatives in consideration of issues related to ensuring safe working conditions in his workplace, and in the investigation of the accident with him at work or occupational disease;
- For extraordinary medical examination in accordance with medical recommendations with preservation of his place of work (position) and secondary earnings during the passage of the specified medical examination;
- For warranties and compensation established in accordance with this Code, collective agreement, agreement, local regulatory an act, an employment contract, if he is engaged in work with harmful and (or) hazardous working conditions.

The labor code of the Russian Federation states that normal working hours may not exceed 40 hours per week. The employer must keep track of the time worked by each employee.

Rules for labor protection and safety measures are introduced in order to prevent accidents, ensure safe working conditions for workers and are mandatory for workers, managers, engineers and technicians.

5.3 Basic ergonomic requirements for the correct location and arrangement of researcher's workplace

The workplace when working with a PC should be at least 6 square meters. The legroom should correspond to the following parameters: the legroom height is at least 600 mm, the seat distance to the lower edge of the working surface is at least 150 mm, and the seat height is 420 mm. It is worth noting that the height of the table should depend on the growth of the operator.

The following requirements are also provided for the organization of the workplace of the PC user: The design of the working chair should ensure the maintenance of a rational working posture while working on the PC and allow the posture to be changed in order to reduce the static tension of the neck and shoulder muscles and back to prevent the development of fatigue.

The type of working chair should be selected taking into account the growth of the user, the nature and duration of work with the PC. The working chair should be lifting and swivel, adjustable in height and angle of inclination of the seat and back, as well as the distance of the back from the front edge of the seat, while the adjustment of each parameter should be independent, easy to carry out and have a secure fit.

5.4 Occupational safety

A dangerous factor or industrial hazard is a factor whose impact under certain conditions leads to trauma or other sudden, severe deterioration of health of the worker [Federal Law].

A harmful factor or industrial health hazard is a factor, the effect of which on a worker under certain conditions leads to a disease or a decrease in working capacity.

5.4.1 Analysis of harmful and dangerous factors that can create object of investigation

The object of investigation is scintillation detector of ionizing radiation. The object of investigation itself create dangerous factor of high voltage. The high voltage supplies photomultiplier tube of scintillation detector.

5.4.2 Analysis of harmful and dangerous factors that can arise at workplace during investigation

The working conditions in the workplace are characterized by the presence of hazardous and harmful factors, which are classified by groups of elements: physical, chemical, biological, psychophysiological. The main elements of the production process that form dangerous and harmful factors are presented in Table 5.1.

Table 5.1 - Possible hazardous and harmful factors

Factors (GOST 12.0.003-2015)	**Work stages**			**Legal documents**
	Development	**Manufacture**	**Exploitation**	
1. Deviation of microclimate indicators	+	+	+	
2. Excessive noise		+	+	
3.Increased level of electromagnetic radiation	+	+	+	

4.Insufficient illumination of the working area		+	+	and regulations "Hygienic requirements for personal electronic computers and work organization." Sanitary rules 2.2.1 / 2.1.1.1278–03. Hygienic requirements for natural, artificial and combined lighting of residential and public buildings. Sanitary rules 2.2.4 / 2.1.8.562–

				96. Noise at workplaces, in premises of residential, public buildings and in the construction area. Sanitary rules 2.2.4.548–96. Hygienic requirements for the microclimate of industrial premises.
5. Abnormally high voltage value in the circuit, the closure which may occur	+	+	+	Sanitary rules GOST 12.1.038-82 SSBT. Electrical safety.

through the human body				Maximum permissible levels of touch voltages and currents.
6. Increased levels of ionizing radiation	+	+	+	Sanitary Rules 2.6.1. 2523 -0 9. Radiation Safety Standards (NRB-99/2009).

The following factors effect on person working on a computer:

- Physical:
  - Temperature and humidity;
  - Noise;
  - Static electricity;
  - Electromagnetic field of low purity;
  - Illumination;
  - Presence of radiation;
- Psychophysiological:
  - Psychophysiological dangerous and harmful factors are divided into:
- Physical overload (static, dynamic)
- Mental stress (mental overstrain, monotony of work, emotional overload).

5.4.2.1 Deviation of microclimate indicators

The air of the working area (microclimate) is determined by the following parameters: temperature, relative humidity, air speed. The optimum and permissible values of the microclimate characteristics are established in accordance with [SanPiN] and are given in Table 5.2.

Table 5.2 - Optimal and permissible parameters of the microclimate

Period of the year	Temperature, °C	Relative humidity,%	Speed of air movement, m/s
Cold and changing of seasons	23-25	40-60	0.1
Warm	23-25	40	0.1

5.4.2.2 Excessive noise

Noise and vibration worsen working conditions, have a harmful effect on the human body, namely, the organs of hearing and the whole body through the central nervous system. It result in weakened attention, deteriorated memory, decreased response, and increased number of errors in work. Noise can be generated by operating equipment, air conditioning units, daylight illuminating devices, as well as spread from the outside. When working on a PC, the noise level in the workplace should not exceed 50 dB.

5.4.2.3 Increased level of electromagnetic radiation

The screen and system blocks produce electromagnetic radiation. Its main part comes from the system unit and the video cable. According to [2], the intensity of the electromagnetic field at a distance of 50 cm around the screen along the electrical component should be no more than:

- In the frequency range 5 Hz - 2 kHz - 25 V / m;
- In the frequency range 2 kHz - 400 kHz - 2.5 V / m.

The magnetic flux density should be no more than:

- In the frequency range 5 Hz - 2 kHz - 250 nT;
- In the frequency range 2 kHz - 400 kHz - 25 nT.

5.4.2.4 Abnormally high voltage value in the circuit

Depending on the conditions in the room, the risk of electric shock to a person increases or decreases. Do not operate the electronic device in conditions of high humidity (relative air humidity exceeds 75% for a long time), high temperature (more than 35 ° C), the presence of conductive dust, conductive floors and the possibility of simultaneous contact with metal components connected to the ground and the metal casing of electrical equipment. The operator works with electrical devices: a computer (display, system unit, etc.) and peripheral devices. There is a risk of electric shock in the following cases:

- With direct contact with current-carrying parts during computer repair;
- When touched by non-live parts that are under voltage (in case of violation of insulation of current-carrying parts of the computer);
- When touched with the floor, walls that are under voltage;
- Short-circuited in high-voltage units: power supply and display unit.

Table 5.3 Upper limits for values of contact current and voltage

	Voltage, V	Current, mA
Alternate, 50 Hz	2	0.3
Alternate, 400 Hz	3	0.4
Direct	8	1.0

5.4.2.5 Insufficient illumination of the working area

Light sources can be both natural and artificial. The natural source of the light in the room is the sun, artificial light are lamps. With long work in low illumination conditions and in violation of other parameters of the illumination, visual perception decreases, myopia, eye disease develops, and headaches appear.

According to the standard, the illumination on the table surface in the area of the working document should be 300-500 lux. Lighting should not create glare on the surface of the monitor. Illumination of the monitor surface should not be more than 300 lux.

The brightness of the lamps of common light in the area with radiation angles from 50 to 90° should be no more than 200 cd/m, the protective angle of the lamps should be at least 40°. The safety factor for lamps of common light should be assumed to be 1.4. The ripple coefficient should not exceed 5%.

5.4.2.6 Increased levels of ionizing radiation

Ionizing radiation is radiation that could ionize molecules and atoms. This effect is widely used in energetics and industry. However, there is health hazard. In living tissue, this radiation could damage cells that result in two types of effects. Deterministic effects (harmful tissue reactions) due to exposure with high doses and stochastic effects due to DNA destruction and mutations (for example, induction of cancer).

To provide radiation safety with using sources of ionizing radiation one must use next principles:

a) Keep individual radiation doses from all radiation sources not higher than permissible exposure;

b) Forbid all activity with using radiation sources if profit is low than risk of possible hazard;

c) Keep individual radiation doses from all radiation sources as low as possible.

There are two groups of people related to work with radiation: personnel, who works with ionizing radiation, and population.

Table 5.4 Dose limit

Quantity	**Dose limits**	
	personnel	**population**
Effective dose	20 mSv per year in average during 5 years, but not higher than 50 mSv per year	1 mSv per year in average during 5 years, but not higher than 5 mSv per year
Equivalent dose per year in eye’s lens	150 mSv	15 mSv
Skin	500 mSv	50 mSv
Hands and feet	500 mSv	50 mSv

Effective dose for personnel must not exceed 1000 mSv for 50 years of working activity, and for population must not exceed 70 mSv for 70 years of life.

In addition, for women from personnel of age below 45 years there is limit of 1 mSv per month of equivalent dose on lower abdomen. During gestation and breast feeding women must not work with radiation sources.

For students older than 16, who uses radiation sources in study process or who is in rooms with increased level of ionizing radiation, dose limits are quarter part of dose limits of personnel.

5.4.3 Justification of measures to reduce the levels of exposure to hazardous and harmful factors on the researcher

5.4.3.1 Deviation of microclimate indicators

The measures for improving the air environment in the production room include: the correct organization of ventilation and air conditioning, heating of room. Ventilation can be realized naturally and mechanically. In the room, the following volumes of outside air must be delivered:

- At least 30 m^3 per hour per person for the volume of the room up to 20 m^3 per person;
- Natural ventilation is allowed for the volume of the room more than 40 m^3 per person and if there is no emission of harmful substances.

The heating system must provide sufficient, constant and uniform heating of the air. Water heating should be used in rooms with increased requirements for clean air.

The parameters of the microclimate in the laboratory regulated by the central heating system, have the following values: humidity 40%, air speed 0.1 m / s, summer temperature 20-25 ° C, in winter 13-15 ° C. Natural ventilation is provided in the laboratory. Air enters and leaves through the cracks, windows, doors. The main disadvantage of such ventilation is that the fresh air enters the room without preliminary cleaning and heating.

5.4.3.2 Excessive noise

In research audiences, there are various kinds of noises that are generated by both internal and external noise sources. The internal sources of noise are working equipment, personal computer, printer, ventilation system, as well as computer equipment of other engineers in the audience. If the maximum permissible conditions are exceeded, it is sufficient to use sound-absorbing materials in the room (sound-absorbing wall and ceiling cladding, window curtains). To reduce the noise penetrating outside the premises, install seals around the perimeter of the doors and windows.

5.4.3.3 Increased level of electromagnetic radiation

There are the following ways to protect against EMF:

- Increase the distance from the source (the screen should be at least 50 cm from the user);
- The use of pre-screen filters, special screens and other personal protective equipment.

When working with a computer, the ionizing radiation source is a display. Under the influence of ionizing radiation in the body, there may be a violation of normal blood coagulability, an increase in the fragility of blood vessels, a decrease in immunity, etc. The dose of irradiation at a distance of 20 cm to the display is 50 µrem / hr. According to the norms [SanPiN], the design of the computer should provide the power of the exposure dose of x-rays at any point at a distance of 0.05 m from the screen no more than 100 µR / h.

Fatigue of the organs of vision can be associated with both insufficient illumination and excessive illumination, as well as with the wrong direction of light.

5.4.3.4 Increased levels of ionizing radiation

In case of radiation accident, responsible personnel must take all measures to restore control of radiation sources and reduce to minimum radiation doses, number of irradiated persons, radioactive pollution of the environment, economic and social losses caused with radioactive pollution.

Radiation control is a main part of radiation safety and radiation protection. It is aimed at not exceeding the established basic dose limits and permissible levels of radiation, obtaining the necessary information to optimize protection and making decisions about interference in the case of radiation accidents, contamination of the environment and buildings with radionuclides.

The radiation control is control of:

- Radiation characteristics of radiation sources, pollution in air, liquid and solid wastes.

- Radiation factors developed with technological processes in working places and environment.
- Radiation factors of contaminated environment.
- Irradiation dose levels of personnel and population.

The main controlled parameters are:

- Annual effective and equivalent doses
- Intake and body content of radionuclides
- Volume or specific activity of radionuclides in air, water, food products, building materials and etc.
- Radioactive contamination of skin, clothes, footwear, working places and etc.
- Dose and power of external irradiation.
- Particles and photons flux density.

Radiation protection office establish control levels of all controlled parameters in according to not exceed dose limits and keep dose levels as low as possible. In case of exceeding control levels radiation protection officers start investigation of exceed causes and take actions to eliminate this exceeding.

During planning and implementation of radiation safety precautions, taking any actions about radiation safety and analysis of effectiveness of mentioned action and precautions one must value radiation safety with next factors:

- Characteristics of radioactive contamination of the environment;
- Probability of radiation accidents and scale of accidents;
- Degree of readiness to effective elimination of radiation accidents and its aftermathches;
- Number of persons irradiated with doses higher than controlled limits of doses;
- Analysis of actions for providing radiation safety, meeting requirements, rules, standards of radiation safety;

- Analysis of irradiation doses obtained by groups of population from all ionizing radiation sources.

5.4.3.5 Abnormally high voltage value in the circuit

Measures to ensure the electrical safety of electrical installations:

- Disconnection of voltage from live parts, on which or near to which work will be carried out, and taking measures to ensure the impossibility of applying voltage to the workplace;
- Posting of posters indicating the place of work;
- Electrical grounding of the housings of all installations through a neutral wire;
- Coating of metal surfaces of tools with reliable insulation;
- Inaccessibility of current-carrying parts of equipment (the conclusion in the case of electroporating elements, the conclusion in the body of current-carrying parts) [GOST].

5.4.3.6 Insufficient illumination of the working area

Desktops should be placed in such a way that the monitors are oriented sideways to the light openings, so that natural light falls mainly on the left.

Also, as a means of protection to minimize the impact of the factor, local lighting should be installed due to insufficient lighting, window openings should be equipped with adjustable devices such as blinds, curtains, external visors, etc.

5.5 Ecological safety

5.5.1 Analysis of the impact of the research object on the environment

All matters contains atoms, which are mostly unstable, hence in other to become stable they undergo spontaneous disintegration, which leads to the release of ionizing radiation into the environment. This ionizing radiation is also known as background radiation. There are two main source of background radiation; natural and man –made sources. Humans are always exposed to background radiation through inhalation or ingestion. Background radiation is all around us and when the level is high can affect the health of humans.

Radiation detectors are very important because they help measure and monitor the level of radiation in the environment. The correctness of measurement of dose rate is also essential because if the dose rate measured were incorrect or wrong, it would lead to wrong analysis of results, which is very dangerous. Incorrect reading of dose rate by the detector can also have a negative impact on the environment and also led to global environmental issue.

5.5.2 Analysis of the environmental impact of the research process

Process of investigation itself in the thesis do not have essential effect on environment. One of hazardous waste is fluorescent lamps. Mercury in fluorescent lamps is a hazardous substance and its improper disposal greatly poisons the environment.

In addition, a laptop, which is an electronic device, was used for the processing of the data. The problem with the laptop is the future disposal of it when not in use anymore. Electronic devices contain toxic substances and this makes it very important to dispose them in such a way that they might not lead to pollution of the environment.

Outdated devices goes to an enterprise that has the right to process wastes. It is possible to isolate precious metals with a purity in the range of 99.95–99.99% from computer components. A closed production cycle consists of the following stages: primary sorting of equipment; the allocation of precious, ferrous and non-ferrous metals and other materials; melting; refining and processing of metals. Thus, there is an effective disposal of computer devices.

5.5.3 Justification of environmental protection measures

Pollution reduction is possible due to the improvement of devices that produces electricity, the use of more economical and efficient technologies, the use of new methods for generating electricity and the introduction of modern methods and methods for cleaning and neutralizing industrial waste. In addition, this problem should be solved by efficient and economical use of electricity by consumers themselves. This is the use of more economical devices, as well as efficient regimes of these devices. This also includes compliance with production discipline in the framework of the proper use of electricity.

Simple conclusion is that it is necessary to strive to reduce energy consumption, to develop and implement systems with low energy consumption. In modern computers, modes with reduced power consumption during long-term idle are widely used.

5.6 Safety in emergency

5.6.1 Analysis of probable emergencies that may occur at the workplace during research

The fire is the most probable emergency in our life. Possible causes of fire:

- Malfunction of current-carrying parts of installations;
- Work with open electrical equipment;
- Short circuits in the power supply;
- Non-compliance with fire safety regulations;
- Presence of combustible components: documents, doors, tables, cable insulation, etc.

Activities on fire prevention are divided into: organizational, technical, operational and regime.

5.6.2 Substantiation of measures for the prevention of emergencies and the development of procedures in case of emergencies

Organizational measures provide for correct operation of equipment, proper maintenance of buildings and territories, fire instruction for workers and employees, training of production personnel for fire safety rules, issuing instructions, posters, and the existence of an evacuation plan.

The technical measures include compliance with fire regulations, norms for the design of buildings, the installation of electrical wires and equipment, heating, ventilation, lighting, the correct placement of equipment.

The regime measures include the establishment of rules for the organization of work, and compliance with fire-fighting measures. To prevent fire from short circuits, overloads, etc., the following fire safety rules must be observed:

- Elimination of the formation of a flammable environment (sealing equipment, control of the air, working and emergency ventilation);
- Use in the construction and decoration of buildings of non-combustible or difficultly combustible materials;
- The correct operation of the equipment (proper inclusion of equipment in the electrical supply network, monitoring of heating equipment);
- Correct maintenance of buildings and territories (exclusion of the source of ignition - prevention of spontaneous combustion of substances, restriction of fire works);
- Training of production personnel in fire safety rules;
- The publication of instructions, posters, the existence of an evacuation plan;
- Compliance with fire regulations, norms in the design of buildings, in the organization of electrical wires and equipment, heating, ventilation, lighting;
- The correct placement of equipment;
- Well-time preventive inspection, repair and testing of equipment.

In the case of an emergency, it is necessary to:

- Inform the management (duty officer);

- Call the Emergency Service or the Ministry of Emergency Situations - tel. 112;
- Take measures to eliminate the accident in accordance with the instructions.

5.7 Conclusions

In this section about social responsibility the hazardous and harmful factors were revealed. All necessary safety measures and precaution to minimize probability of accidents and traumas during investigation are given.

Possible negative effect on environment were given in compact form describing main ecological problem of using nuclear energy.

It could be stated that with respect to all regulations and standards, investigation itself and object of investigation do not pose special risks to personnel, other equipment and environment.

Chapter 6 Conclusion

Results from investigating the influence of temperature on results of gamma radiation monitoring revealed that:

The dependence of dose rate measurement on temperature using the built-in algorithm gives unreliable results for low-level radiation since the dependence of dose rate on ambient temperature for the scintillation detector was very weak.

The results also revealed that the detector readings for dose rate depend on the environmental factor (temperature), hence the need for temperature correction coefficient.

The built-in algorithm for temperature correction gave two equations instead of one for low dose hence making it impossible to use the embedded temperature correction coefficient to calculate low dose. This is because the detectors were calibrated using a high radioactive source, therefore the need to find a new temperature correction coefficient.

An expression was found for calculating the temperature correction coefficient based on the dependence of the detector reading on temperature. The new correction coefficient obtained for calculating the dose rate in the detector was found to be k(T) = $(3.58 \times 10^{-13}\mathrm{T} + 2.152 \times 10^{-9})$ and the experimental algorithm for calculating low gamma radiation was found to be $\mathrm{H} = \mathrm{N} \times (3.58 \times 10^{-13}\mathrm{T} + 2.152 \times 10^{-9})$.

Validation of the results proved that the experimental algorithm can be used to calculate the dose rate of low gamma background when using BDKG-03. From the results obtained, it can be concluded that the ambient temperature affects the readings of gamma radiation monitoring when using scintillation detector (BDKG-03).

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