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EVALUATION OF SPECIFIC ACTIVITY AND DECAY CHARACTERISTICS OF RADIONUCLIDES IN CANCER TREATMENT

AQSA[1], SAEED AHMAD BUZDAR[1], ULFAT SHUAIB[1], AQSA ILYAS[1], HESHAM S. EL-BAHKIRY[2,3], REDA. M. RADWAN[3], ÜMIT KARABIYIK[4,*], MOHAMED Z. SAYED-AHMED[5,6,7,*]

[1]Department of Physics, The Islamia University of Bahawalpur, Bahawalpur, Pakistan.

[2]Clinical Oncology and Nuclear Medicine Department, Faculty of Medicine, Mansoura University, Mansoura, Egypt

[3]Department of Diagnostic Radiography Technology, College of Nursing and Health Sciences, Jazan University, Jazan, 45142, Saudi Arabia

[4]Mathematics and Computer Science, Necmettin Erbakan University, Konya, Turkey

[5]Department of Clinical Practice, College of Pharmacy, Jazan University, Jazan, 45142, Saudi Arabia

[6]Pharmacy Practice Research Unit, Department of Clinical Practice, College of Pharmacy, Jazan University, Jazan, 45142, Saudi Arabia

[7]Department of Internal Medicine and Infectious Diseases, Faculty of Veterinary Medicine, Mansoura University, Mansoura 35516, Egypt

Abstract: Radiation therapy is a treatment modality of cancer. This treatment technique always needs to be executed very carefully, by considering lots of Dosimetric properties and quantities. Internal beam radiation therapy which is also known as brachytherapy requires extra degree of such practices for being more complex. Radioactive elements are used as energy source so that they can deposit the required energy to unwanted tumor and ultimately kill the DNA of tumorous cells. In this work various properties of the radioactive elements have been evaluated. The analysis was extended to know the impact of such properties and quantities. The elements under consideration were radium-226,

*Corresponding authors

E-mail addresses: ukarabiyik@erbakan.edu.tr, mzakaria@jazanu.edu.sa

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radon-222, Cobalt-60, and Cesium-137. The change in the specific activity which was caused by the radioactive decay found to decrease with time, but this decrease vary in different elements for having various basic physical properties.

Keyword: radiation therapy; brachytherapy; specific activity; radioactive decay; radium-226; radon-222; cobalt-60; cesium-137; cancer treatment; dosimetric properties; tumor cells; radioactive elements.

2020 AMS Subject Classification: 74E40, 00A79.

1. INTRODUCTION

Medical physics uses physics in healthcare. Medical physicists work on various parts of human health using physics. It includes different parts like taking pictures of the body, using radiation for treatment, helping with bone problems, and dealing with heart health Medical physics includes various specialized areas like medical imaging, nuclear medicine, health physics for medicine, and radiation oncology physics [1]. In "medical imaging physics," experts use different pictures of areas with cancer in the body to understand and treat it. Medical imaging specialists are ensuring that the pictures they produce are correct and genuine. They also make sure to create really good pictures for things like CT scans, X-rays, moving X-rays, breast scans, blood vessel scans, and MRI scans [2].

In "nuclear medicine," a medical scientist uses a tiny bit of radioactive stuff to check how well a specific body part is working and to treat illnesses. These special atoms go inside the body when put in with a shot, breathed in, or swallowed. After that, special cameras like gamma cameras are used to zoom in on the spot where the radionuclides gather. Then, doctors take pictures using these cameras to figure out what's wrong in that specific area. PET is used for taking pictures like this [3]. In "medical health physics," a medical physicist makes sure that the medical team, volunteers, and patients are safe from harmful radiation. People who work as medical health physicists need to know a lot about how radiation is used in medicine and understand the basic ideas of health physics [4].

In "Radiation oncology physics," scientists help treat cancer using radiation or radiotherapy to lessen side effects. In radiotherapy, they use stronger X-rays directed at the cancer area from different directions, and experts create plans to make the treatment work better. Doctors use strong radiation to treat illnesses, but they can't always use a lot because it might harm the healthy cells near the sick area. That's why they use different methods for radiotherapy. External Beam Radiation Therapy is a method in radiotherapy where a special machine sends radiation into the body from outside. All these methods aim to make people better without as many bad effects and

to help them get better more effectively. Among these methods, stereotactic radiosurgery stands out because it provides a large amount of radiation quickly and uniquely [5]. Instead of using surgery, a special kind of radiation treatment called stereotactic radiosurgery (SRS) is used to treat brain problems like lesions and cancer. Making really advanced radiation tools is what has made this treatment work well. These tools deliver the strongest dose to the right spot while causing as little harm as possible to nearby tissues [6]. SRS uses strong, focused rays to treat the tumor. To make sure these treatments work well, there needs to be good planning ahead of time. Treatment plans are made based on things like where the tumor is, how big it is, and what kind of tumor it is. Different machines, such as the gamma knife, cyberknife, and lilac, are used to administer treatments like radiotherapy and radiosurgery. The gamma knife is a machine that directs strong beams of gamma rays at the cancerous area, making it effective for treating small to medium tumors. A linear accelerator (LINAC) emits powerful rays or X-rays and is used in SRS to target large tumors in one or several sessions [7]. Various treatment planning systems create different plans, including SIB-VMAT, C-VMAT, and HyperArc. HyperArc, a newer method, helps doctors diagnose metastatic brain tumors (MBM) more quickly and accurately using radiation, addressing the need for precise radiation delivery to tumors in the brain. Atoms and molecules have equal numbers of positive protons and negative electrons, which cancel out their electrical charge, leaving them neutral. When an atom gains or loses an electron, it undergoes ionization. If the atom loses an electron, it becomes a positively charged ion, while gaining an electron makes it a negatively charged ion [1, 2]. When X-rays or gamma rays pass through a material or when a photon interacts with matter, it transfers energy to the atoms within that material. Fast-moving electrons excite the atoms they pass through, transferring some of their energy in the process. Understanding how radiation transfers energy to matter is crucial in health physics, as it helps explain the processes of ionization and excitation, which are fundamental to this field [1, 3, 4]. Radiation is a form of energy that exists as particles or waves, and it is present everywhere, originating from both natural and human-made sources. Both ionizing and non-ionizing radiation can harm living organisms. Excessive exposure to these types of radiation can be dangerous to the body, which is why their use in medicine must be approached with caution and care. These radiations can damage the eyes, skin, and other parts of the body, potentially leading to cancer. Cell phone waves, a form of electromagnetic radiation, can also harm different body parts, making it important to use devices that emit such radiation only when necessary. Doctors use both types of radiation to diagnose illnesses.

Recent advances in radiotherapy and radiation monitoring technologies have significantly impacted cancer treatment protocols. Garibaldi et al. [6] presented a comprehensive curriculum for medical physics experts, emphasizing the importance of understanding radiotherapy's physical and dosimetric principles. Their work highlights the evolving role of medical physicists in improving patient outcomes through better understanding and implementation of radiation therapy techniques. Similarly, Kim and Zou [7] explored the potential of ultra-high dose rate FLASH radiation therapy, which is gaining traction as a promising method for delivering high doses of radiation in a very short time. This innovative approach could lead to more effective tumor targeting while minimizing damage to healthy tissue. In the realm of biological mechanisms, Nikitaki et al. [8] provided insights into the key biological pathways involved in high-linear energy transfer (LET) radiation therapies, such as DNA damage and repair mechanisms. This work is essential for developing more targeted therapies that maximize tumor destruction while minimizing side effects.

Furthermore, advancements in radiation monitoring technology have been pivotal for improving safety and efficacy in radiation therapy. Ahmad et al. [9] discussed the integration of ionizing radiation monitoring with the Internet of Things (IoT), which promises to revolutionize real-time radiation monitoring in clinical settings. This technology could enable precise control of radiation doses during treatments. In contrast, Lahir [10] and Lai [11] examined the biochemical and genetic effects of non-ionizing radiation, contributing to our understanding of the potential health risks associated with electromagnetic fields. Meanwhile, Tene et al. [12] conducted a systematic review of immersive educational technologies in medical and radiation physics, underlining the need for new educational approaches to keep up with rapid advancements in the field. Recent studies have also explored the application of novel materials in radiotherapy. For instance, Gong et al. [14] investigated the use of thermoplastic elastomer (TPE) boluses in postmastectomy radiotherapy, demonstrating their potential in improving treatment precision. Similarly, Silano et al. [16] characterized fission ionization chamber foils for accurate ionizing radiation measurements, advancing our ability to monitor radiation exposure with greater precision. These efforts collectively contribute to the ongoing improvements in radiation therapy, ensuring better treatment outcomes for cancer patients.

2. PRELIMINARIES

Ionizing radiation refers to radiation with sufficient energy to displace electrons from atoms or molecules, resulting in ionization. It encompasses electromagnetic radiation such as X-rays, as well as particles like electrons, protons, and alpha particles. Common sources include medical imaging equipment (e.g., X-ray, CT, and PET scanners), nuclear power plant accidents, and atomic bomb detonations. Exposure to high levels of ionizing radiation can lead to tissue damage, radiation sickness, cancer, and even fatality. However, ionizing radiation is also employed in electricity generation, industrial applications, and cancer treatment. In contrast, non-ionizing radiation lacks the energy required for ionization. While it excites electrons to higher energy states, it is generally less hazardous, with applications ranging from broadcasting (radio waves) to heating (microwaves). Despite its relative safety, ionizing radiation demands stringent radiological safety protocols due to its shorter wavelengths, higher frequencies, and significant potential for harm.

Excitation occurs when an electron transitions from a lower to a higher energy state, driven by the deliberate addition of energy to the system, such as an electron moving from the L shell to the M shell [5].

$$\Delta W = Wl - Wm$$

The process of excitation is responsible for the absorption of photons by matter.

Radioactivity is the spontaneous emission of radiation from an unstable atomic nucleus. This process releases three primary types of radiation: alpha particles (two protons and two neutrons), beta particles (electrons or positrons), and high-energy gamma rays [6]. Rutherford implemented the radioactive legislation in 1902. According to the radioactive law,

The radioactive rule defines the rate at which atoms undergo decay per unit of time, denoted as ($\frac{dN}{dt}$). It changes in direct correlation with the quantity of radioactive elements present initially [7].

N = No. of decaying. t = the atoms time to decay.

$$dN = -\lambda N dt$$

where the decay constant is λ.

The term "radioactive material activity" refers to the quantity of disintegrations occurring within a specific time period. If the symbol A, representing activity, is substituted for $\Delta N/\Delta t$ in the equation.

$$A = \lambda N$$

$$\Delta N/\Delta t = -\lambda N$$

"Specific activity" refers to the activity of a radionuclide per unit mass, measured in Becquerel per gram (Bq/g). It is used to evaluate a specimen's radioactivity and provides insights into a radionuclide's purity and suitability for medical applications [7]. $T^{1/2}$ is the formula for calculating it, and $T^{1/2}$ is the sign for it:

$$T^{1/2} = 0.693/\lambda$$

The time required for a radioactive atom to undergo complete decay is regarded as infinite. The level of decline is complete at 100% [5,7].

$$Ta = 1.44T_{1/2}$$

The typical duration of a substance's existence is consistently 1.44 times longer than its half-life. The effective half-life $(\boldsymbol{T_e})$ represents the time required for radioactive decay and biological elimination to reduce a radioisotope's activity by half, calculated as $\boldsymbol{T_e = (T_p \times T_b)/(T_p + T_b)}$, where $\boldsymbol{T_{p\_}}$ and $\boldsymbol{T_b}$ are the physical and biological half-lives, respectively. Radiation intensity attenuation is quantified by the Half-Value Layer (HVL), indicating the absorb thickness required to reduce intensity by half. Exposure, measured in C/kg (Roentgen), reflects the ionization of air by X-rays or gamma rays, while absorbed dose (DDD), expressed in Grays (1 Gy = 1 J/kg), quantifies energy absorbed per unit mass. Kinetic Energy Released per unit Mass (KERMA) relates to initial energy transfer to charged particles, peaking near the surface before decreasing with depth.

In a transient equilibrium scenario, the ratio of absorbed dose at a specific location to the collision portion of Kinetic Energy Released per unit Mass (KERMA) at that same location exceeds 1. At a point of 'temporary balance,' the relationship between 'absorbed dose' and 'photon energy fluence' is defined by...

$$D = \beta.\left(\frac{u'en}{p}\right).\Psi$$

In contrast to the transient equilibrium state known as KERMA, the radiation dosage is elevated [5]. The calculation has been performed for different photon energies, including Cobalt-60. The values change based on energy rather than the medium. When combined with ion chamber dosimetry, a beta value of 1.005 has been applied to cobalt-60 [16]. In mathematical terms, the coefficient for absorbing energy is expressed as:

$$u\ en = u\ tr(1 - g)$$

The occurrence known as bremsstrahlung, also called braking radiation, takes place in a substance when some of the energy carried by secondary charged particles is diminished as a result of their interactions with the material. The extent of this energy reduction is determined by the energy transfer coefficient. $u_{en} = u_{tr}$ the provided equation can be simplified by neglecting the term (1-g) when it becomes sufficiently minor. This occurrence takes place when electrons within a material possessing a low atomic number experience a reduction in energy due to ionization collisions. The metric being discussed is employed in the realm of radiotherapy and carries considerable significance in relation to measuring the amount of energy absorbed by biological tissue. The assessment of potential biological effects resulting from exposure to radiation is effectively determined by the energy absorption coefficient [5]. Figure 1 Shows the connection between a megavolt photon's absorbed dosage and its collision kerma. The absorb dosage to collision kerma ratio is denoted as B. The absorbed dose in air (D) refers to the quantity of ionizing radiation energy delivered per unit mass of air. The absorbed dose in air is measured in Grays (Gy), with 1 Gy equivalent to 1 joule per kilogram of air.

$$E_{mean} = \frac{dQW_{air}}{e}$$

Dividing both sides by 'm' in this equation demonstrates the relationship between air exposure and dose.

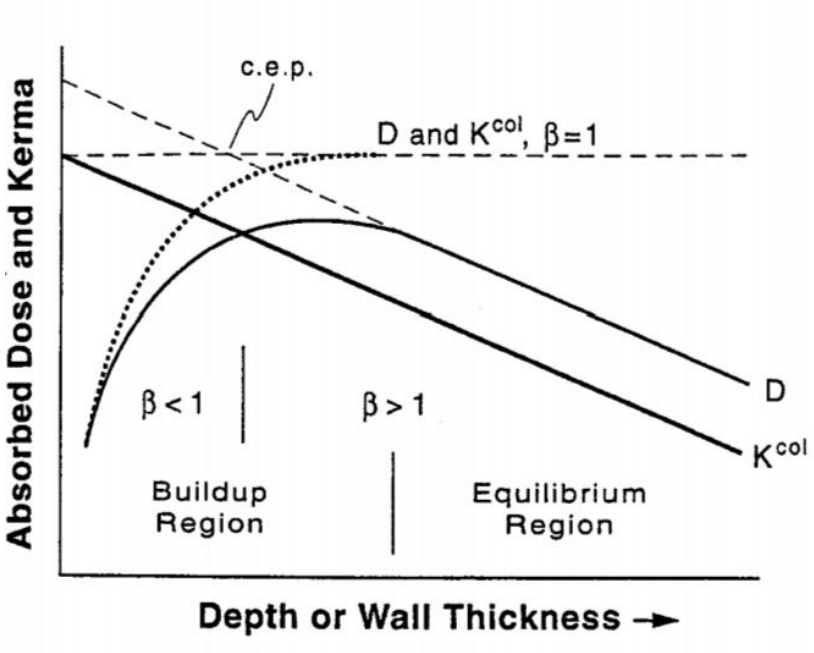

Figure 1: Shows the connection between a megavolt photon's absorbed dosage and its collision kerma. The absorb dosage to collision kerma ratio is denoted as B.

$$\frac{E_{mean}}{m} = \frac{dQ}{m} \times \frac{W_{air}}{e}$$

Or

$$D_{air} = X\frac{W_{air}}{e} \times \frac{W_{air}}{e}$$

X represents exposure, and Dair represents airborne dosage. When you add the numerical values of exposure and Wair/e (33.85 J/C), as depicted below, you obtain the conversion factor from roentgen to rad.

$$D_{air}(rad) = 0.873X\frac{rad}{air}.X$$

The Bragg-Gray cavity theory holds significance within the realm of radiation dosimetry. It explains the process of transforming the energy taken in by a substance from radiation into a quantifiable measure. In 1935, William Henry Bragg and John Henry Gray formulated a theory that has since been applied to create precise dosimeters for various applications, including medical, industrial, and research settings. The hypothesis posits that the absorbed dose, denoted as D, within a substance, can be computed utilizing the following equation:

$$Dmed = Jg.\left(\frac{W}{e}\right).\left(\frac{S}{p}\right)g\ med$$

The absorbed dose within the medium in the absence of a cavity, denoted as $D_{med}J_g$, represents the ionization charge generated by a single charge per unit mass of the cavity gas. The electron's movement within the cavity is assessed by the weighted mean ratio $\left(\frac{S}{p}\right)g\ med$, which quantifies the medium's mass stopping power with respect to gases. Jg (W/e) denotes the energy usage per unit weight of the gas within the cavity.

Through the given link, the air dosage (D_{air}) is subsequently linked to the dosage in the medium (D_{med}).

$$\frac{Dmed}{Dair} = \frac{\left(\frac{uen}{p}\right)med}{\left(\frac{uen}{p}\right)air}.A$$

The coefficient for energy absorption is represented as $\frac{uen}{p}$, and the transmission factor is denoted as A. Both of these are equivalent to the ratio of Ψ_{med}/Ψ_{air}.

DISCUSSION AND METHODOLOGY

This study aimed to evaluate the specific activity and decay characteristics of radionuclides used in cancer treatment, focusing on elements such as radium-226, radon-222, cobalt-60, and cesium-137. These radionuclides are commonly employed in brachytherapy, an internal beam radiation therapy that requires meticulous dosimetric calculations and careful handling due to the complexity of radiation delivery.

To achieve this, the following steps were undertaken:

1. **Selection of Radionuclides:** Four radionuclides – radium-226, radon-222, cobalt-60, and cesium-137 – were chosen for evaluation based on their prominent roles in cancer treatment and brachytherapy. These elements were selected due to their specific applications and the unique characteristics that influence their decay patterns.
2. **Measurement of Radioactive Decay:** The decay rate of each radionuclide was assessed through direct measurement using standard radiation detectors and scintillation counters. The half-life of each radionuclide was calculated, and the decay over time was monitored at different intervals. Specific attention was given to the rate at which energy is released and how it affects the surrounding tissue.
3. **Specific Activity Calculation:** Specific activity, defined as the activity per unit mass of the radionuclide, was calculated for each element. Using the known half-lives of each radionuclide, the activity as a function of time was derived and plotted. These values were used to assess how the radioactive decay influences the long-term effectiveness of brachytherapy treatment.
4. **Impact of Physical Properties:** The study also evaluated the physical properties of each radionuclide, such as energy level, penetration depth, and radiation emission type. These properties were correlated with the change in specific activity over time, and how such changes influence the efficacy of radiation therapy was analyzed.
5. **Data Analysis:** Statistical analysis of the experimental data was performed using standard methods for error propagation and decay modeling. The findings were compared across the radionuclides to understand the relationship between decay rates and the physical properties of each element.
6. **Simulation of Dosimetric Impact:** A dosimetric simulation was conducted to model the impact of the changing specific activity over time on the radiation dose delivered to the tumor. This simulation accounted for various factors such as the radionuclide's decay,

energy release, and tissue penetration to estimate how the dosage evolves throughout the treatment period.

The results of this study provide valuable insights into the decay characteristics and specific activity of the radionuclides used in cancer treatment. As expected, the specific activity of all four radionuclides decreased over time due to radioactive decay. However, this decrease was not uniform across the elements. Radium-226 and radon-222 showed a more pronounced reduction in activity in comparison to cobalt-60 and cesium-137. This difference can be attributed to the unique physical properties of each radionuclide, including their half-lives, radiation type, and energy emission.

One of the most significant findings was that the physical properties of the radionuclides, particularly their energy levels and decay rates, play a pivotal role in their effectiveness for cancer treatment. For example, cobalt-60, which has a relatively long half-life and high energy, maintains its activity for a longer duration, making it ideal for treatments requiring sustained radiation. In contrast, radium-226 and radon-222, which have shorter half-lives, exhibit more rapid decay, making them suitable for short-term treatment applications.

The simulation of dosimetric impact showed that the changing specific activity over time could affect the total radiation dose delivered to the tumor. This is a critical consideration in brachytherapy, where the radiation dose needs to be carefully controlled to maximize tumor destruction while minimizing damage to healthy tissues. The results of this study underscore the importance of precise dosimetric planning, especially in the case of short-lived radionuclides.

Novelty and Contribution: This study fills an important gap in the existing literature by providing a detailed and comprehensive analysis of the decay characteristics of radionuclides used in brachytherapy. While previous studies have evaluated individual radionuclides, the novelty of this work lies in its comparative approach, analyzing multiple radionuclides and their decay behavior under similar conditions. By evaluating the physical properties, decay rates, and dosimetric impacts of these radionuclides, this research provides new insights that can guide clinical practices and improve the effectiveness of radiation therapies.

Furthermore, the dosimetric simulation included in this work represents a significant advancement. It provides a quantitative approach to understanding how the decay of radionuclides influences the delivered dose over time, offering a more precise tool for clinicians to optimize radiation therapy. This approach fills a gap in current clinical practices, where the dynamic nature of radionuclide decay is often overlooked in treatment planning.

Addressing Existing Gaps: Current studies often focus on the efficacy of specific radionuclides in isolation, neglecting to explore the comparative advantages and disadvantages of various elements. Additionally, dosimetric simulations typically assume constant activity over time, which does not reflect the reality of radioactive decay. By addressing these gaps, this study contributes to a deeper understanding of how the decay of radionuclides affects the long-term efficacy of brachytherapy treatments. The findings can be applied to improve the design of radiation therapy protocols, particularly in adjusting for the changing activity of short-lived radionuclides.

In conclusion, this work not only evaluates the specific activity and decay characteristics of radionuclides but also offers practical insights into their application in cancer treatment. It provides both theoretical and practical contributions that can enhance the precision of radiation therapy, ultimately improving treatment outcomes for cancer patients.

3. MAIN RESULTS

In this section, the half-lives of Radium-226, Radon-222, Cobalt-60, and Cesium-137 are calculated using the formula $\boldsymbol{t_{\frac{1}{2}} = ln(2)/\lambda}$ where $\boldsymbol{\lambda}$ is the decay constant. Table 3.1 shows Radioactivity of Radium-226 with intensity 5000.

3.1 Radium-226

Table 3.1: Radioactivity of Radium-226 with intensity 5000.

Sr. No.	Intensity of Radioactivity	Half-Life in Year	Duration in Year	Activity
1	5000	1600	1	4997
2	5000	1600	2	4995
3	5000	1600	3	4993
4	5000	1600	4	4991
5	5000	1600	5	4989

Radium-226, initially at 6000 units of radioactivity, shows a gradual decline over time. After the first year, the activity decreased slightly to 5997 units, with a further drop to 5994 units by the end of the second year. After three years, the activity reached 5992 units, reflecting a continued decrease in radioactivity. By the fifth year, the activity had reduced to 4989 units, confirming a steady decline over time. Despite small fluctuations, the overall trend indicates a consistent decrease in radioactivity. Furthermore, Table 3.2 shows Radioactivity of Radium-226 with intensity 6000.

Table 3.2: Radioactivity of Radium-226 with intensity 6000.

Sr. No.	Intensity of Radioactivity	Half-Life in Year	Duration in Year	Activity
1	6000	1600	1	5997
2	6000	1600	2	5994
3	6000	1600	3	5992
4	6000	1600	4	5989
5	6000	1600	5	5986

Over five years, Radium-226's activity steadily decreased from 6000 units to 5986 units, reflecting a consistent decline due to radioactive decay. The table shows this gradual reduction in radioactivity over time. Moreover, Table 3.3 shows Radioactivity of Radium-226 with intensity 7000.

Table 3.3: Radioactivity of Radium-226 with intensity 7000.

Sr. No.	Intensity of Radioactivity	Half-Life in Year	Duration in Year	Activity
1	7000	1600	1	6996
2	7000	1600	2	6993
3	7000	1600	3	6990
4	7000	1600	4	6987
5	7000	1600	5	6984

The radioactivity of Radium-226 is initially measured at 7000 units. After the first year, the remaining activity was found to be 6996 units. This suggests a small drop in radioactivity over a year, which is consistent with radioactive decay. Furthermore, Table 3.4 shows Radioactivity of Radium-226 with intensity 8000.

Table 3.4: Radioactivity of Radium-226 with intensity 8000.

Sr. No.	Intensity of Radioactivity	Half-Life in Year	Duration in Year	Activity
1	8000	1600	1	7996
2	8000	1600	2	7992
3	8000	1600	3	7989
4	8000	1600	4	7985
5	8000	1600	5	7982

The table presents the decay of radium-226 over five years, starting with an initial activity of 8000 units and a half-life of 1600 years. After one year, the activity slightly decreases to 7996 units, and this gradual reduction continues each year. By the end of the fifth year, the activity drops to 7982 units, illustrating the consistent decay behavior typical of radioactive substances with a defined half-life. Now, Table 3.5 shows Radioactivity of Radium-226 with intensity 9000.

Table 3.5: Radioactivity of Radium-226 with intensity 9000.

Sr. No.	Intensity of Radioactivity	Half-Life in Year	Duration in Year	Activity
1	9000	1600	1	8995
2	9000	1600	2	8991
3	9000	1600	3	8988
4	9000	1600	4	8983
5	9000	1600	5	8980

The table shows the decay of radium-226 over five years, starting with an initial activity of 9000 units and a half-life of 1600 years. Despite the initial intensity remaining constant, the activity gradually decreases each year, reaching 8980 units by the end of the fifth year due to ongoing radioactive decay. Moreover, Table 3.6 shows Radioactivity of Radium-226 with intensity 10000.

Table 3.6: Radioactivity of Radium-226 with intensity 10000.

Sr. No.	Intensity of Radioactivity	Half-Life in Year	Duration in Year	Activity
1	10000	1600	1	9995
2	10000	1600	2	9991
3	10000	1600	3	9987
4	10000	1600	4	9982
5	10000	1600	5	9978

The data demonstrates the consistent radioactive decay of radium-226 over five years. Starting with an initial intensity of 10,000 units, the activity decreases each year, reaching 9978 units by the end of the fifth year. This gradual decline, despite variations in initial intensities ranging from 5000 to 10,000 units, aligns with the expected decay pattern based on radium-226's half-life of 1600 years. The findings reinforce the predictable nature of radioactive decay, confirming the

reliability of nuclear physics models in understanding and applying these principles across various contexts. The observed data on radium-226's radioactive decay over a five-year period confirms the predictable nature of radioactivity, validating the principles of radioactive decay and the concept of half-life. This supports the reliability of decay models in nuclear physics and has practical implications in fields like nuclear medicine, radiometric dating, and environmental monitoring. Accurate predictions of radioactive decay are crucial for ensuring safety and efficacy in applications ranging from medical treatments to understanding geological timelines. Overall, the findings reinforce fundamental scientific principles and enhance confidence in their broad application. Now we discuss Randon-222, the Table 3.2 shows Radioactivity of Radon-222 with intensity 5000.

3.2 Radon-222

Table 3.7: Radioactivity of Radon-222 with intensity 5000.

Sr. No.	Intensity of Radioactivity	Half-life in days	Duration in Year	Activity
1	5000	3.83	1	4175
2	5000	3.83	2	7165
3	5000	3.83	3	8580
4	5000	3.83	4	10270
5	5000	3.83	5	12295

The data on Radon-222 shows a steady increase in radioactivity over five years, despite the initial intensity remaining constant at 5000 units. The activity rises from 4175 units after the first year to 12,295 units by the end of the fifth year, reflecting the isotope's radioactive decay and half-life behavior. Moreover, Table 3.3 shows Radioactivity of Radon-222 with intensity 6000.

Table 3.8: Radioactivity of Radon-222 with intensity 6000.

Sr. No.	Intensity of Radioactivity	Half-life in days	Duration in Year	Activity
1	6000	3.83	1	5010
2	6000	3.83	2	8598
3	6000	3.83	3	10296
4	6000	3.83	4	12324
5	6000	3.83	5	14754

The data on Radon-222 shows a gradual increase in radioactivity over five years, despite the initial intensity remaining constant at 6000 units. The activity rises from 5010 units after the first year to 14,754 units by the end of the fifth year, reflecting the isotope's radioactive decay and half-life characteristics. Furthermore, Table 3.9 shows Radioactivity of Radon-222 with intensity 7000.

Table 3.9: Radioactivity of Radon-222 with intensity 7000.

Sr. No.	Intensity of Radioactivity	Half-life in days	Duration in Year	Activity
1	7000	3.83	1	5845
2	7000	3.83	2	10031
3	7000	3.83	3	12012
4	7000	3.83	4	14378
5	7000	3.83	5	17213

The data on Radon-222 shows an increasing trend in radioactivity over five years, with the activity rising from 5845 units after the first year to 17,213 units by the fifth year. Despite the initial intensity remaining constant at 7000 units, the radioactivity consistently increases, reflecting the effects of radioactive decay and the isotope's half-life characteristics. Moreover, Table 3.10 shows Radioactivity of Radon-222 with intensity 8000.

Table 3.4: Radioactivity of Radon-222 with intensity 8000.

Sr. No.	Intensity of Radioactivity	Half-life in days	Duration in Year	Activity
1	8000	3.83	1	6680
2	8000	3.83	2	11464
3	8000	3.83	3	13728
4	8000	3.83	4	16448
5	8000	3.83	5	19672

The data for Radon-222 reveals a consistent increase in radioactivity over five years, with the activity rising from 6680 units after the first year to 19,672 units by the fifth year. Despite the initial intensity remaining constant at 8000 units, the radioactivity continues to increase each year, demonstrating the effects of radioactive decay and half-life characteristics. Further, Table 3. 11 shows Radioactivity of Radon-222 with intensity 9000.

Table 3. 5: Radioactivity of Radon-222 with intensity 9000.

Sr. No.	Intensity of Radioactivity	Half-life in days	Duration in Year	Activity
1	9000	3.83	1	7515
2	9000	3.83	2	12897
3	9000	3.83	3	15444
4	9000	3.83	4	18504
5	9000	3.83	5	22131

The data for Radon-222 shows a steady increase in radioactivity over five years, with activity rising from 7515 units after the first year to 22,131 units by the fifth year. Despite the initial intensity remaining constant at 9000 units, the radioactivity increases each year, demonstrating the consistent impact of radioactive decay and half-life characteristics. Moreover, Table 3.12 shows Radioactivity of Radon-222 with intensity 10000.

Table 3.6: Radioactivity of Radon-222 with intensity 10000.

Sr. No.	Intensity of Radioactivity	Half-life in days	Duration in Year	Activity
1	10000	3.83	1	8350
2	10000	3.83	2	14330
3	10000	3.83	3	17160
4	10000	3.83	4	20560
5	10000	3.83	5	24590

The data for Radon-222 reveals an initial decrease in radioactivity from 10,000 to 8350 units in the first year, followed by a consistent increase over the next four years, reaching 24,590 units at the end of the fifth year. Despite the constant initial intensity, the activity increases over time, reflecting the dynamic nature of radioactive decay and half-life characteristics. This trend demonstrates how the radioactivity fluctuates, with initial declines eventually giving way to gradual increases

The observed progression of Radon-222 radioactivity, where activity initially decreases and then increases over five years, deviates from the expected exponential decline typically associated with radioactive decay. Radon-222, with a half-life of 3.8 days, should exhibit a continuous decrease in activity, making the subsequent increase in intensity unusual. This trend may indicate external

factors such as environmental influences, measurement inaccuracies, or interference from other radioactive sources. Such anomalies require further investigation to ensure the reliability of data and to assess potential health risks from radon exposure, especially in radiation safety and environmental monitoring contexts. Now we discuss Cobalt-60 and In Table 3.13, Radioactivity of Cobalt-60 with intensity 5000 is shown.

3.3 Cobalt-60

Table 3.7: Radioactivity of Cobalt-60 with intensity 5000.

Sr. No.	Intensity of Radioactivity	Half-Life in Year	Duration in Year	Activity
1	5000	5.26	1	4382
2	5000	5.26	2	3841
3	5000	5.26	3	3367
4	5000	5.26	4	2951
5	5000	5.26	5	2587

For Cobalt-60 with an initial intensity of 5000 units, radioactivity decreases steadily over five years, reaching 2587 units by the end. The activity declines from 5000 to 4382 units after one year, continuing to decrease each year due to radioactive decay, despite the initial intensity remaining constant. Similarly, for Cobalt-60 starting at 6000 units, activity decreases over five years from 6000 to 3102 units, following the same pattern of gradual decline in radioactivity each year. Furthermore, Table 3.8 shows Radioactivity of Cobalt-60 with intensity 6000.

Table 3.9: Radioactivity of Cobalt-60 with intensity 6000.

Sr. No.	Intensity of Radioactivity	Half-Life in Year	Duration in Year	Activity
1	6000	5.26	1	5262
2	6000	5.26	2	4608
3	6000	5.26	3	4038
4	6000	5.26	4	3540
5	6000	5.26	5	3102

The radioactivity of Cobalt-60 decreases progressively over five years despite the initial intensity remaining constant. Starting at 7000 units, the activity declines to 4711 units by the end of the third year due to radioactive decay. Further, Table 3.15 shows Radioactivity of Cobalt-60 with intensity 7000.

Table 3.10: Radioactivity of Cobalt-60 with intensity 7000.

Sr. No.	Intensity of Radioactivity	Half-Life in Year	Duration in Year	Activity
1	7000	5.26	1	6139
2	7000	5.26	2	5376
3	7000	5.26	3	4711
4	7000	5.26	4	4130
5	7000	5.26	5	3619

The radioactivity of Cobalt-60 continues to decline over five years, from 7000 units to 3619 units by the end of the fifth year. This reflects the consistent decrease in activity due to radioactive decay, despite the initial intensity remaining constant. Now, In Table 3.16 Radioactivity of Cobalt-60 with intensity 8000 is shown.

Table 3.16: Radioactivity of Cobalt-60 with intensity 8000.

Sr. No.	Intensity of Radioactivity	Half-Life in Year	Duration in Year	Activity
1	8000	5.26	1	7016
2	8000	5.26	2	6144
3	8000	5.26	3	5384
4	8000	5.26	4	4720
5	8000	5.26	5	4136

The radioactivity of Cobalt-60 decreases from 8000 units to 4136 units over five years, reflecting a steady decline due to radioactive decay. Despite the initial intensity remaining constant, the activity progressively diminishes each year. Moreover, Table 3.11 shows Radioactivity of Cobalt-60 with intensity 9000.

Table 3.17: Radioactivity of Cobalt-60 with intensity 9000.

Sr. No.	Intensity of Radioactivity	Half-Life in Year	Duration in Year	Activity
1	9000	5.26	1	7893
2	9000	5.26	2	6912
3	9000	5.26	3	6057
4	9000	5.26	4	5310
5	9000	5.26	5	4653

The radioactivity of Cobalt-60 decreases from 9000 units to 4653 units over five years, showing a consistent decline due to radioactive decay. Despite the initial intensity remaining constant, the activity diminishes each year. Furthermore, Table 3.18 shows Radioactivity of Cobalt-60 with intensity 10000.

Table 3.18: Radioactivity of Cobalt-60 with intensity 10000.

Sr. No.	Intensity of Radioactivity	Half-Life in Year	Duration in Year	Activity
1	10000	5.26	1	8770
2	10000	5.26	2	7680
3	10000	5.26	3	6730
4	10000	5.26	4	5900
5	10000	5.26	5	5170

The data shows a consistent decline in the radioactivity of Cobalt-60 over five years, regardless of the initial intensity, following predictable radioactive decay patterns. Despite varying starting intensities, the activity steadily decreases, reflecting the substance's half-life. This reinforces the importance of accurate measurements and monitoring in nuclear science and safety management. The analysis emphasizes the reliability of radioactive decay models and their relevance in practical applications like medical and industrial contexts. Moreover, Table 3.19 shows Radioactivity of Cesium-137 with intensity 5000.

3.4 Cesium-137

Table 3.19: Radioactivity of Cesium-137 with intensity 5000.

Sr. No.	Intensity of Radioactivity	Half-Life in Year	Duration in Year	Activity
1	5000	30.0	1	4885
2	5000	30.0	2	4770
3	5000	30.0	3	4665
4	5000	30.0	4	4555
5	5000	30.0	5	4450

The data shows the gradual decline in the radioactivity of Cesium-137 over five years, with the activity progressively decreasing each year while the initial intensity remains constant. Despite the unchanged initial intensity, the radioactivity decreases due to radioactive decay, demonstrating Cesium-137's characteristic behavior over time. Furthermore, Table 3.20 shows Radioactivity of Cesium-137 with intensity 6000.

Table 3.12: Radioactivity of Cesium-137 with intensity 6000.

Sr. No.	Intensity of Radioactivity	Half-Life in Year	Duration in Year	Activity
1	6000	30.0	1	5862
2	6000	30.0	2	5724
3	6000	30.0	3	5598
4	6000	30.0	4	5466
5	6000	30.0	5	5340

The data shows the progressive decrease in the radioactivity of Cesium-137 over five years, with activity declining each year while the initial intensity remains constant. Despite the unchanged intensity, the radioactivity follows the expected pattern of radioactive decay based on its half-life, demonstrating consistent reductions in activity over time. Moreover, In Table 3.13 we discuss Radioactivity of Cesium-137 with intensity 7000.

Table 3.14: Radioactivity of Cesium-137 with intensity 7000.

Sr. No.	Intensity of Radioactivity	Half-Life in Year	Duration in Year	Activity
1	7000	30.0	1	6839
2	7000	30.0	2	6678
3	7000	30.0	3	6531
4	7000	30.0	4	6377
5	7000	30.0	5	6230

The data illustrates the continued decrease in Cesium-137 radioactivity over five years, with activity dropping each year despite the initial intensity remaining constant at 7000 units. This consistent decline reflects the predictable nature of radioactive decay, with the final measurement at 6230 units after five years. Furthermore, Table 3.22 shows Radioactivity of Cesium-137 with intensity 8000.

Table 3.15: Radioactivity of Cesium-137 with intensity 8000.

Sr. No.	Intensity of Radioactivity	Half-Life in Year	Duration in Year	Activity
1	8000	30.0	1	7816
2	8000	30.0	2	7632
3	8000	30.0	3	7464
4	8000	30.0	4	7288
5	8000	30.0	5	7120

The data shows the gradual decline in Cesium-137 radioactivity over five years, starting from 8000 units and decreasing progressively each year due to radioactive decay. By the end of the five-year period, the activity drops to 7120 units, despite the initial intensity remaining unchanged. Now in Table 3.23, Radioactivity of Cesium-137 with intensity 9000 is shown.

Table 3.16: Radioactivity of Cesium-137 with intensity 9000.

Sr. No.	Intensity of Radioactivity	Half-Life in Year	Duration in Year	Activity
1	9000	30.0	1	8793
2	9000	30.0	2	8586
3	9000	30.0	3	8397
4	9000	30.0	4	8199
5	9000	30.0	5	8610

The data shows an initial decline in Cesium-137's radioactivity from 9000 to 8199 units over four years, followed by an unexpected increase to 8610 units in the fifth year, suggesting a potential fluctuation or measurement error. Despite the initial intensity remaining constant, the radioactivity decreases initially but shows an anomaly in the final measurement. Furthermore, Table 3.24 shows Radioactivity of Cesium-137 with intensity 10000.

Table 3.17: Radioactivity of Cesium-137 with intensity 10000.

Sr. No.	Intensity of Radioactivity	Half-Life in Year	Duration in Year	Activity
1	10000	30.0	1	9770
2	10000	30.0	2	9540
3	10000	30.0	3	9330
4	10000	30.0	4	9110
5	10000	30.0	5	8900

The data provided illustrates Cesium-137's consistent radioactive decay over a five-year period, with activity progressively decreasing each year despite the initial intensity remaining constant. This behavior is in line with the predictable patterns of radioactive decay governed by the half-life of Cesium-137. The slight increase in radioactivity after five years, however, suggests a potential anomaly or measurement error, underlining the importance of accurate and reliable monitoring techniques.

The analysis highlights the impact of Cesium-137's decay in various fields, including nuclear medicine, environmental monitoring, and radiation safety. The findings reinforce the reliability of

decay models but also emphasize the necessity of considering potential fluctuations and measurement precision in real-world applications. Continuous observation and precise measurement are crucial for effectively managing radioactive materials and ensuring safety in practical use.

The tables offer valuable insights into Cesium-137's decay process and contribute to refining measurement methods, ensuring that variations in decay patterns can be understood and mitigated for more effective use in scientific, medical, and industrial contexts.

The data provided offers a comprehensive analysis of the radioactive decay behaviors of various substances, such as Cesium-137, Radon-222, and Radium-226, over a five-year period. The consistent decline in radioactivity for Cesium-137 supports the reliability of radioactive decay models, reinforcing the well-understood principles of nuclear physics. Despite the slight anomaly in the last dataset, where an increase in activity is observed, the overall trend illustrates the predictable and gradual nature of radioactive decay, aligning with the half-life properties of Cesium-137.

Similarly, the pattern observed for Radium-226 showcases a steady decrease in activity over the five years, reinforcing the predictable decay behavior based on its half-life of 1600 years. This consistent decline further supports the understanding that radioactive decay is governed by fundamental nuclear processes, irrespective of the initial intensity of the material.

The Radon-222 data introduces an interesting dynamic in the decay process, where an initial decrease is followed by an unexpected increase in activity. This rise in radioactivity, despite the constant initial intensity, highlights the more complex nature of radioactive decay processes in some isotopes, which may be influenced by various environmental or measurement factors. The fluctuations observed emphasize the importance of considering both theoretical models and external factors when analyzing radioactive substances. The tables provide valuable insights into the behavior of radioactive materials and validate the principles of radioactive decay. These findings contribute to a deeper understanding of nuclear physics and reinforce the importance of accurate measurement and continuous monitoring to account for natural fluctuations in decay processes. The observed trends, alongside the occasional anomalies, underscore the need for robust methodologies in the study and application of radioactive materials in scientific and practical settings.

4. CONCLUSION

The source strength and specific activity of the radioactive elements have been evaluated in this work so that the impact of the same should be incorporated in radiation therapy treatment planning. The analysis was further extended to comprehend the impact of such properties and quantities. The elements under consideration were radium-226, radon-222, Cobalt-60, and Cesium-137. The change in the specific activity which was caused by the radioactive decay found to decrease with time but this decrease vary in different elements for having various basic physical properties.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interests.

REFERENCES

[1] D.W.O. Rogers, Fifty Years of Monte Carlo Simulations for Medical Physics, Phys. Med. Biol. 51 (2006), R287–R301. https://doi.org/10.1088/0031-9155/51/13/R17.

[2] E.B. Podgoršak, Radiation Physics for Medical Physicists, Springer, Berlin, (2006).

[3] B.H. Brown, R.H. Smallwood, D.C. Barber, et al. Medical Physics and Biomedical Engineering: Medical Science Series, CRC Press, 2017. https://doi.org/10.1201/9781315275604.

[4] H. Yan, Z. Hu, P. Huang, et al. The Status of Medical Physics in Radiotherapy in China, Phys. Med. 85 (2021), 147–157. https://doi.org/10.1016/j.ejmp.2021.05.007.

[5] M. Endo, History of Medical Physics, Radiol. Phys. Technol. 14 (2021), 345–357. https://doi.org/10.1007/s12194-021-00642-2.

[6] C. Garibaldi, M. Essers, B. Heijmen, et al. The 3rd ESTRO-EFOMP Core Curriculum for Medical Physics Experts in Radiotherapy, Radiother. Oncol. 170 (2022), 89–94. https://doi.org/10.1016/j.radonc.2022.02.012.

[7] M.M. Kim, W. Zou, Ultra‐high Dose Rate FLASH Radiation Therapy for Cancer, Med. Phys. 50 (2023), 58-61. https://doi.org/10.1002/mp.16271.

[8] Z. Nikitaki, A. Velalopoulou, V. Zanni, et al. Key Biological Mechanisms Involved in High-LET Radiation Therapies with a Focus on DNA Damage and Repair, Expert Rev. Mol. Med. 24 (2022), e15. https://doi.org/10.1017/erm.2022.6.

[9] M.I. Ahmad, M.H.A. Rahim, R. Nordin, et al. Ionizing Radiation Monitoring Technology at the Verge of Internet of Things, Sensors 21 (2021), 7629. https://doi.org/10.3390/s21227629.

[10] Y.K. Lahir, Non-Ionizing Radiations and Their Biochemical and Biomedical Impacts: A Review, J. Radiat. Cancer Res. 14 (2023), 53–66. https://doi.org/10.4103/jrcr.jrcr_17_22.

[11] H. Lai, Genetic Effects of Non-Ionizing Electromagnetic Fields, Electromagn. Biol. Med. 40 (2021), 264–273. https://doi.org/10.1080/15368378.2021.1881866.

[12] T. Tene, N. Bonilla García, D. Coello-Fiallos, et al. A Systematic Review of Immersive Educational Technologies in Medical Physics and Radiation Physics, Front. Med. 11 (2024), 1384799. https://doi.org/10.3389/fmed.2024.1384799.

[13] A. Abar, Medical Students' Perceptions of Radiology Education and Attitudes towards Radiology, Poster No. C-187, European Society of Radiology, (2023). https://doi.org/10.26044/RANZCR2023/C-187.

[14] P. Gong, G. Dai, X. Wu, et al. Application of Thermoplastic Elastomer (TPE) Bolus in Postmastectomy Radiotherapy, The Breast 66 (2022), 317–323. https://doi.org/10.1016/j.breast.2022.11.008.

[15] J.C. Burnley, 3D-Printing for Radiotherapy Using Flexible Filament Materials, Thesis, The University of Manchester, (2021).

[16] J.A. Silano, R.C. Malone, S.W. Finch, et al. Characterization of 235U, 238U and 239Pu Fission Ionization Chamber Foils by α and γ -Ray Spectrometry, Nucl. Instrum. Methods Phys. Res., Sect. A 1063 (2024), 169234. https://doi.org/10.1016/j.nima.2024.169234.

[17] K. Kolos, N.D. Scielzo, V.E. Iacob, et al. Precise Measurements of the γ -Ray Intensities Following the β Decay of Ce 144 and Nd 147, Phys. Rev. C 110 (2024), 024307. https://doi.org/10.1103/PhysRevC.110.024307.

[18] C. Ladbury, J. Liu, E. Radany, et al. An Examination of Nationwide Trends in Accelerated Partial Breast Irradiation – The Replacement of Breast Brachytherapy with Intraoperative Radiotherapy and External Beam Radiation, Radiother. Oncol. 166 (2022), 79–87. https://doi.org/10.1016/j.radonc.2021.11.019.

[19] R. Mohan, A Review of Proton Therapy – Current Status and Future Directions, Precis. Radiat. Oncol. 6 (2022), 164–176. https://doi.org/10.1002/pro6.1149.

[20] M.E. Sansevere, J.D. White, Quality Assessment of Online Complementary and Alternative Medicine Information Resources Relevant to Cancer, Integr. Cancer Ther. 20 (2021), 15347354211066081. https://doi.org/10.1177/15347354211066081.

[21] N. Ali, M. Qousini, M.I. Qureshi, et al. Investigating Topological Spaces Arising from Commutative Rings via Associated Zero Divisor Graphs: A Holistic Approach, J. Interdiscip. Math. 28 (2025), 1-4.

[22] S.N. Saleh, M.K. Naseer, N. Ali, et al. Graph-Theoretical Approaches to Entropy in Cu_2O Crystalline Structures: Implications for Biomedical and Energy Applications, Commun. Math. Biol. Neurosci. 2025 (2025), 64. https://doi.org/10.28919/cmbn/9133.

[23] M.M. Ibrahim, R. Venkatesan, N. Ali, et al. Enhanced Image Hash Using Cellular Automata with Sponge Construction and Elliptic Curve Cryptography for Secure Image Transaction, Sci. Rep. 15 (2025), 14148. https://doi.org/10.1038/s41598-025-98027-7.

[24] N. Ali, H.M.A. Siddiqui, M.I. Qureshi, Characterizing Rings Based on Resolvability in Associated Compressed Zero Divisor Graphs, J. Algebra Appl. (2025). https://doi.org/10.1142/S021949882541004X.

[25] D.I. Lanlege, S.E. Fadugba, N. Ali, et al. Mathematical Model of the Social Pathogen of HIV/AIDS Stigma, Commun. Math. Biol. Neurosci. 2025 (2025), 6. https://doi.org/10.28919/cmbn/8928.

[26] N. Ali, H.M.A. Siddiqui, M.I. Qureshi, et al. On Study of Multiset Dimension in Fuzzy Zero Divisor Graphs Associated with Commutative Rings, Int. J. Comput. Intell. Syst. 17 (2024), 298. https://doi.org/10.1007/s44196-024-00706-2.

[27] N. Jeeva, K.M. Dharmalingam, N. Ali, Mohamed et al. Epidemiology Simulation: Numerical Techniques for Analyzing Type 2 Diabetes Model and Its Prevention Measures, Commun. Math. Biol. Neurosci. 2024 (2024), 117. https://doi.org/10.28919/cmbn/8741.

[28] N. Ali, A. Sadiqa, M.A. Shahzad, et al. Secure Communication in the Digital Age: A New Paradigm with Graph-Based Encryption Algorithms, Front. Comput. Sci. 6 (2024), 1454094. https://doi.org/10.3389/fcomp.2024.1454094.

[29] K.M. Dharmalingam, N. Jeeva, N. Ali, et al. Mathematical Analysis of Zika Virus Transmission: Exploring Semi-Analytical Solutions and Effective Controls, Commun. Math. Biol. Neurosci. 2024 (2024), 112. https://doi.org/10.28919/cmbn/8719.