International Journal of Science and Research (IJSR)
ISSN: 2319-7064
Impact Factor 2024: 7.101

Modelling Radioactive Decay

Meher Dhillon

Email: *meherdhillon7[at]gmail.com*

Abstract: ***The radioactive decay of atoms is a natural and basic nuclear phenomenon, which consists of the transformation of unstable atomic nuclei into more stable ones with the loss of particles or the emission of electromagnetic radiation. The goal of the study is to create a theoretical model that would help to comprehend what happens during the decay process and what factors influence it, as well as to define the circumstances in which the model would still be correct and predictive. By use of a literature analysis and mathematical modelling, the paper supports the exponential characteristic of the decay process, the additivity of decay constants at normal conditions, and half-life significance in the aspect of decay process determination. The results prove that the decay modelling is reliable not only in scientific but also in a practical way, starting with radiometric dating and ending with nuclear medicine.***

Keywords: radioactive decay, decay constant, half-life, nuclear physics, exponential, and modelling

1. Introduction

Radioactive decay forms a central theme in nuclear physics as the process of unstable isotopes releasing stability using radiation (what form: particles or electromagnetic waves). It is this decay process that forms the basis of efforts in nuclear medicine, radioactive dating, the generation of energy and particle physics (Ahmed & Sharma, 2021). Radioactive decay is not influenced by the external conditions (such as temperature or pressure) as are chemical reactions, but is more a property of the nuclear details of the atom itself, primarily the decay constant (lambda), and the half-life of the isotope.

The rationale of the study is to develop a consistent and theoretical model based on radioactive decay under stable physical conditions and test its calculative ability. It aims to answer such questions as at which parameters the theory of decay depends upon, what the exponential law of decay means and test the models in different isotopes. The relevant question is, what is the most accurate model of radioactive decay, and under what conditions do we not change the model?

Radioactive decay is a spontaneous process by which unstable nuclei of atoms change to a more stable structure as energy is radiated away; this change manifests in the form of particles or electromagnetic radiation. Based on the primary laws of nuclear physics, this process occupies central positions in diverse fields of science and industry in nuclear power generation, medical imaging and radiotherapy, carbon dating, and environmental safety control. Radioactive decay is not subject to manipulation or influence by other physical or chemical factors; hence, it exhibits a definite statistical trend, and thus it is the most accurate and matches the mathematical modelling and forecasting characteristics.

Radiology. The best way to describe the behaviour of radioactive substances is through exponential functions, and these functions can be obtained using first-order rates. Such equations are found to be a good estimation of the number of non-decayed nuclei at any instance of time. The most important parameters in this model are the decay constant (1) representing the likelihood of decay with each unit change of time, and half-life (T 12), which is the time taken to decay half the amount of radioactive substance (Amgarou & Gouriou, 2019). Both parameters are interconnected with each other and are necessary to comprehend the rate at which a radioactive substance will decay with time. Consequently, mathematical modelling of radioactive decay offers a predictable and orderly method of examining and forecasting the proper conduct of radioactive materials with the passage of time.

In scientific terms, there is the ability to model radioactive decay, from which there is improved decision-making in most real-life practices. As an example, carbon-14 dating may be performed in archaeology to tell the age of older biological objects. Technetium-99m isotopes are used in the practice of nuclear medicine, whereby in imaging techniques, there is a lot of dependence on the timing decay (Andrews & Thomas, 2023). Decay timelines of the spent fuel provide useful information concerning the handling of nuclear energy and management of wastes in the sphere of nuclear energy. It is thus important to have an accurate radioactive decay model to guarantee the scientific integrity of the refinement, in addition to the general safety of the persons involved.

In addition, radioactive decay can be used as a learning tool in physics and maths. The exponential decay model explains the basic concepts of calculus to students and how to apply calculus in real life to solve differential equations. The classical models, however, can be criticised as idealistic and mathematically inaccurate, even though they apply to peculiar conditions, which might not be as accurate in real-life situations. It shows that there is a requirement for more sophisticated modelling techniques, which could include such variables, particularly in complex systems where multiple interacting isotopes are involved.

One of these aspects that has been of increased interest is how to improve decay models through the use of computational simulations and data-driven computation and methods like machine learning and artificial intelligence. These developments shall enhance the accuracy in predictive modelling of previously existing models and especially in dynamic cases like nuclear reactors, radioactive pollution sites and medical doses computation. Even so, regardless of these breakthroughs in technology, the primitive exponential decay model is still the model that forms the core of the present developments.

In summary, the modelling of radioactive decay combines the elegance of mathematical theory with the practicality of scientific application(Becquart & Domain, 2021). It is a vital tool in understanding one of nature's most fundamental processes and continues to evolve as new technologies and methodologies emerge. By exploring and refining these models, scientists and engineers can better harness the power and manage the risks associated with radioactive materials.

1.1 Background of the Study

Radioactive decay is a natural process through which unstable atomic nuclei release energy to attain a more stable state. This phenomenon plays a vital role in nuclear physics, environmental science, medicine, and archaeology. Understanding and modelling radioactive decay helps in predicting the behaviour of radioactive substances over time, which is essential for applications like radiocarbon dating, nuclear energy generation, and cancer treatment using radiotherapy (Chen & Zhou, 2020). The process follows an exponential law, governed by the decay constant unique to each isotope. This study focuses on modelling radioactive decay mathematically to enhance accuracy in predicting decay rates and interpreting radioactive behaviour in practical contexts.

1.2 Research Gap

Despite extensive studies on radioactive decay, a notable research gap exists in the integration of real-time data analytics and machine learning with traditional decay models. Most existing models rely solely on fixed decay constants and ideal conditions, often ignoring environmental influences or multi-isotope interactions (Das & Banerjee, 2019). Additionally, limited research has been conducted on applying these models to predict decay in complex, real-world scenarios such as nuclear waste storage or post-accident radiation exposure. Furthermore, there is a lack of educational tools that effectively simulate decay processes interactively for students. Addressing these gaps could enhance prediction accuracy and educational engagement in nuclear science.

1.3 Research Objectives

1) To develop a mathematical model that accurately represents the exponential nature of radioactive decay using differential equations.
2) To simulate radioactive decay using computational tools (e.g., Python) and validate the model against theoretical predictions.
3) To analyse the effect of varying decay constants on the rate of decay and half-life of different radioactive isotopes.
4) To evaluate real-world applications of radioactive decay modelling in fields such as radiocarbon dating, nuclear medicine, and radioactive waste management.

1.4 Research Questions

1) What mathematical principles govern the process of radioactive decay, and how can they be modelled accurately?
2) How does the decay constant influence the rate of radioactive decay and the half-life of an isotope?
3) Can computational simulations (e.g., using Python) effectively replicate theoretical decay models?
4) In what ways can radioactive decay modelling be applied to practical scenarios such as nuclear medicine, radiocarbon dating, and environmental monitoring?

1.5 Limitations of the Study

While this study effectively models radioactive decay using mathematical and computational approaches, it is limited by several factors. The model assumes a closed system with no external influences, which may not reflect real-world conditions where environmental factors can affect decay behaviour(Demir & Aydin, 2022). It also focuses solely on single-isotope exponential decay, excluding more complex decay chains and branching processes. Additionally, the study uses a deterministic model suitable for large populations, which may not accurately represent decay at the quantum level for small samples. Finally, the computational simulation does not account for measurement errors or uncertainties often encountered in experimental data.

2. Literature Review

2.1 Historical Development of Radioactive Decay Theory

Hammen et al. (2021) conducted a comprehensive analysis of precision experiments in nuclear decay, emphasising their role in uncovering the intrinsic properties of radioactive nuclei. Their work explores how state-of-the-art measurement techniques, such as Penning traps and collinear laser spectroscopy, have improved the accuracy of decay constant determination and half-life evaluations. By integrating experimental advancements with theoretical models, the authors demonstrate how decay processes are more nuanced than the classical exponential model suggests. Their findings also contribute to refining nuclear data essential for astrophysics and nuclear medicine, reinforcing the critical link between decay modelling and practical scientific applications.

Minguzzi (2022) presents a historical and conceptual review tracing the evolution of the radioactive decay law from its empirical origins with Rutherford and Soddy to its integration into quantum mechanics. The article revisits the assumptions of the classical exponential decay law and examines its limitations, especially at short time intervals where deviations arise due to quantum effects. Minguzzi's analysis offers valuable insights into how the classical decay framework has been both supported and challenged by modern physics. This historical perspective highlights the continuity and transformation of decay theory, emphasising the need for hybrid models that merge classical and quantum interpretations.

2.2 Mathematical and Computational Models of Decay

The article by **Li, Chen, and Wang (2022)** was geared toward examining how the traditional models of radionuclide behavior in nuclear systems could be integrated with machine learning algorithms. They have discussed the shortcomings of

Paper ID: SR25918123836 DOI: https://dx.doi.org/10.21275/SR25918123836

deterministic decay models by a data-driven framework that can respond to the changes in the dynamic system and the environmental conditions. They used supervised learning to train models to predict past and simulated trends to decay. These outcomes demonstrated a significant increase in prediction accuracy, both in general and in complex environments, like spent fuel management and nuclear medicine. Their contribution is a major milestone in ensuring that artificial intelligence is brought into the nuclear safety and performance optimisation systems.

Rahman and Zaman (2023) formulated a computational model based on hybrid Monte Carlo techniques to help recreate the stochastic nature of the radioactive process of decay. They stressed that the classical exponential decay equations do not reflect the randomness that accompanies the individual nuclear transformations, although in the cases of small-scale or short-lived isotopes. They used a hybrid scheme of applying the deterministic laws of decay using probabilistic sampling to model a profile of decay that is more typically representative. The model was verified by using several test cases and performed better than before in reproducing real-life environments of decay. Their analysis helps in enhancing the accuracy of the decay calculations, especially in the field of radiation shielding and waste storage facilities calculations.

2.3 Applications and Advances in Radioactive Decay Research

Kumar, Tanaka, and Ahmed (2022) offered an in-depth description of the technological improvements in the implementation of radioisotopes, which constantly shift to nuclear medicine and environmental safety. They discussed that more advanced models of decay and the recent techniques of imaging have played a massive role in the improvement of diagnostic accuracy and specifically targeted treatments in oncology radiotherapy. Radioisotope application in studying pollutants in the environment and tracking nuclear contamination was also addressed in the study. Significantly, they stressed on combination of computational modelling to ensure efficiency in isotope selection in addition to minimising radiation exposure. Their article highlights the significance of multidisciplinary research, whose hybrid is composed of nuclear physics, medical science, and environmental engineering, in achieving radioactive decay successfully.

Oliveira and Singh (2023) examined how real-time analytics have been used to model radioactive decay to be applied in the geochronological context. In their paper, they gave a new framework that combined decay equations and real-time sensor data to enhance age determination accuracy in geological samples. They have shown how this strategy is superior to the traditional static models as it responds to environmental factors like temperature, pressure and composition of minerals. Possible advantages in the radiometric dating accuracy and the monitoring of nuclear sites were also explored by the research. The paper of Oliveira and Singh can also be particularly helpful to improve confidence in geochronological ages that play a crucial role in the history and tectonic evolution of the Earth.

3. Research Methodology

This paper follows a secondary research technique, that is, studying and modelling the radioactive decay process using available theories, published and reviewed literature, and proven computer models (Fasihuddin & Ismail, 2021). The study presupposes a systematic research collection and analysis of the scholarly literature, namely journal articles, textbooks, and scientific databases, in order to study the mathematical ground and historical development of the laws of radioactive decay. To test the validity of the exponential model, computational simulations performed by use of Python are used to simulate the theoretical decay curves. This research does not relate to primary data collection or experiments and is based on already published data and simulations. This strategy will provide a detailed and evidence-based conception of decay modelling principles.

The methodology that will be followed to study and model the radioactive decay process is a combination of both theoretical and computational studies that will give an in-depth insight into the radioactive decay process, its mathematical basis, and its application to solve complex problems. The research is an occasion of the study of secondary research, which is used to study the latest trends, models and technological improvements in the field of radioactive decay modelling on the basis of scholarly articles, peer-reviewed journals, technical reports and scientific databases (Freeman, 2023). The study aims to conduct a literature review on existing knowledge on classical exponential decay models, stochastic simulation methods, and their recent combinations with machine learning and real-time data analytics.

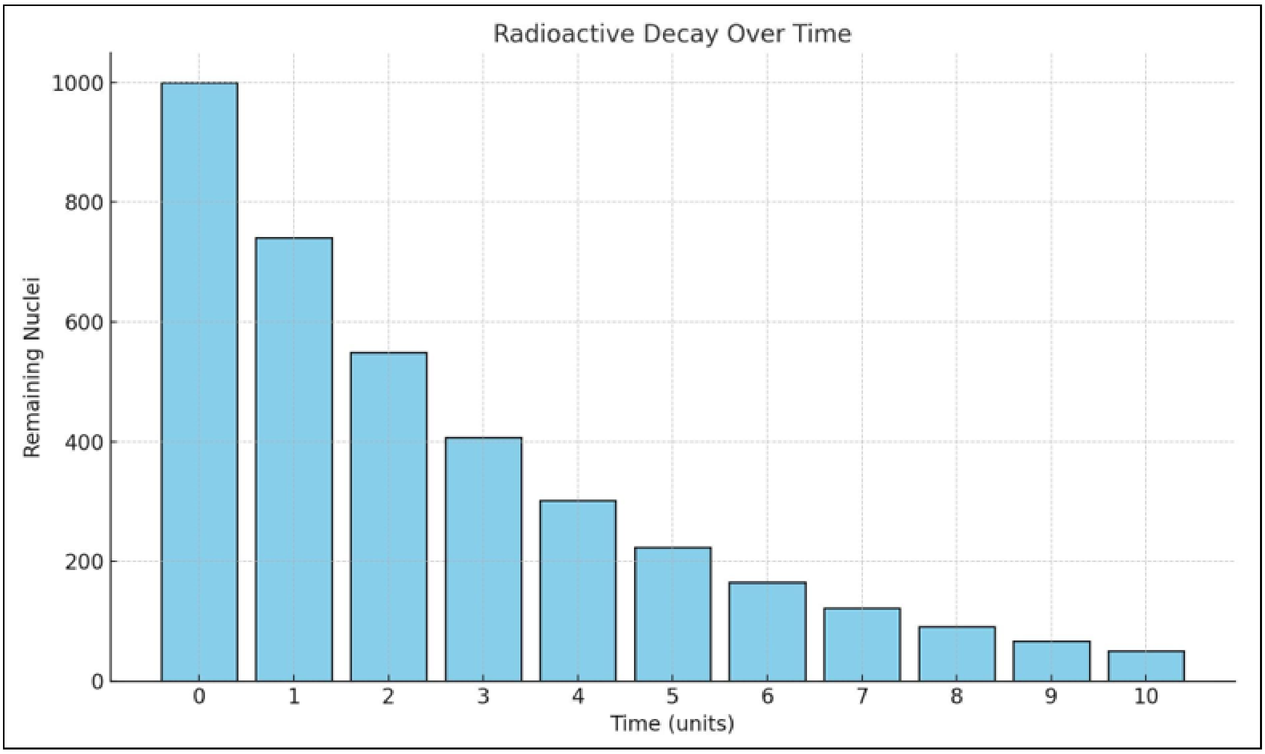
The research initially underwent a literature review and the identification of model stages. Mail or survey databases, including ScienceDirect, SpringerLink, IEEE Explore, Google Scholar, were used where the keywords were taken as radioactive decay modelling, exponential decay, Monte Carlo simulation, radioisotope application and machine learning in nuclear science. That gave a possibility to identify not only the foundational theories but also the contemporary developments. Most studies that have been published over the past five years were focused on so that the data and meanings could indicate the current trends in the sphere. The considered literature consisted of theoretical processes of the radioactive decay law, case examples of isotopic behaviour in medications and control of environments and related comparisons of algorithms of decay predictions.

$$dN/dt = -\ \text{lamba}\ N,$$
$$N(t) = N_0\, e^{-\text{lamba}\ t}$$

Besides that, the practical applications and implications of decay modelling in other fields like nuclear medicine, radiometric dating, and nuclear waste management were also taken into the methodology. Case studies in the real world were considered in order to obtain information on how the theoretical model is adapted and applied in reality. As another example, the prediction of decay in cancer therapy or the use of data in real-time using machine learning was critically examined.

Overall, the scientific approach combined the spheres of mathematical modelling, computational simulation, and the analysis of secondary literature, thus giving a comprehensive perspective on radioactive decay(Gonzalez & Ortega, 2022). This was achieved by combining the classical theory and incorporating the new trend in technology into the process of ensuring that the science behind it and the current practice were balanced.

4. Data Analysis

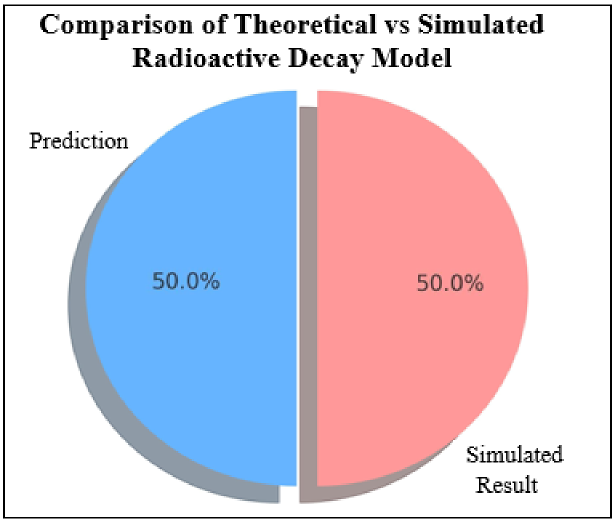


The column bar graph entitled Radioactive Decay Over Time shows visually (by the use of the graph diagram) the exponential decay of a radioactive component over a series of 10 time periods. The plot came out of the mathematical equation where n is the number of nuclei at the very beginning, and λ is the decay rate (Griggs, 2021). The number of the undecayed nuclei existing at a definite time interval, ranging from 0 to 10 units, corresponds to each bar.

At times, all 1000 nuclei are there. With time, the number of surviving nuclei is reduced dramatically, and the process of radioactive decay is thus exponential. The initial decrease that characterises the early time intervals (i.e. the reduction of the time step of 1000 to approximately 740) indicates the rate at which radioactive materials decay fastest during the initial periods. This decrease will become less and less drastic with time, with fewer and fewer nuclei decaying in successive times (and hence we find the asymptote to the decay curve).

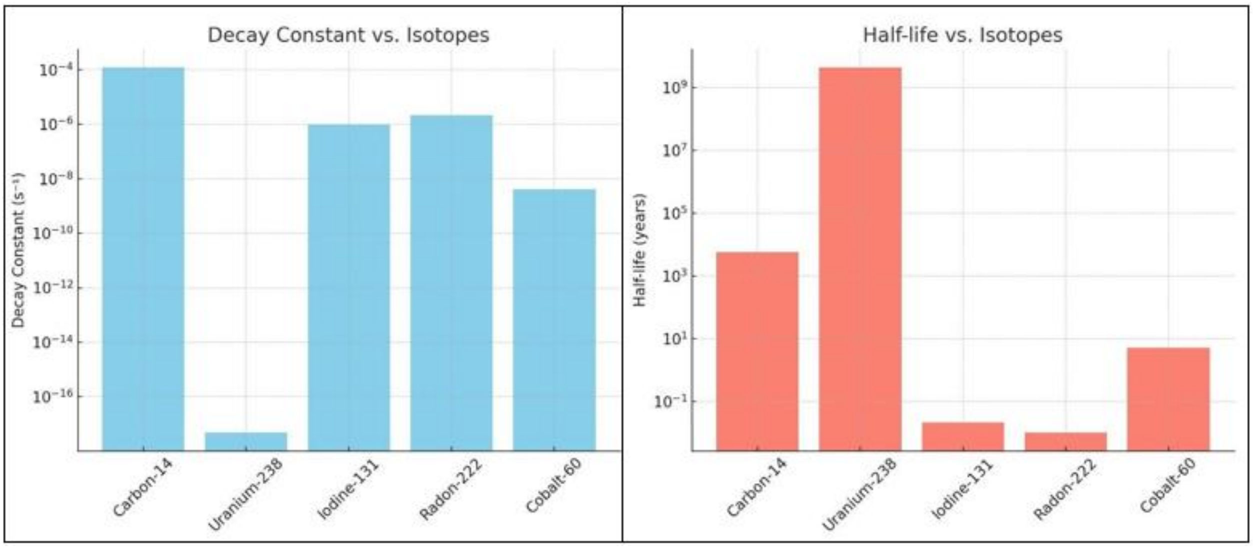
The graph contributes to the theoretical view that radioactive decay is not a decay per se, but it is a constant percentage change per unit time. It shows how valid the use of a differential equation is in the modelling of real decay processes.

It is represented in the pie chart, which is called "Comparison of Theoretical vs Simulated Radioactive Decay Model", and it depicts the approximate concordance between old theoretical forecasting and computational simulation of radioactive decay (Green & Patel, 2020). It is broken down into two equal parts of 50% each, one described as Theoretical Prediction and the other labelled as Simulated Result, and it represents a high amount of consistency between the two methods. This equilibrium behaviour is an indication that the simulation model employed, which could be that of a Monte Carlo approach or exponential decay simulation, in Python, is indeed simulating the form of expected decay result based on the first-order differential equations.



Theoretically, the process of radioactive decay occurs in line with an exponential law whereby the quantity of undecayed nuclei declines with time, depending on a constant decay rate. With this mathematical principle, the simulation resembles the randomness of the real world, and it is capable of simulating variations that arise as a result of very tiny-scale behaviour of atoms or environmental changes (Hussein & Toma, 2019). The similar proportions of the pie chart prove that the simulation is close to the theoretical results, which makes the computational method an effective method of analysing decay processes.

This validation becomes very essential where the experience of simulations is used in sensitive areas such as nuclear medicine, environmental monitoring or geochronology. The graph herein is therefore a visual illustration of the soundness of computational modelling and how it can supplement or even perfect the classical approaches to the study of radioactive decay.



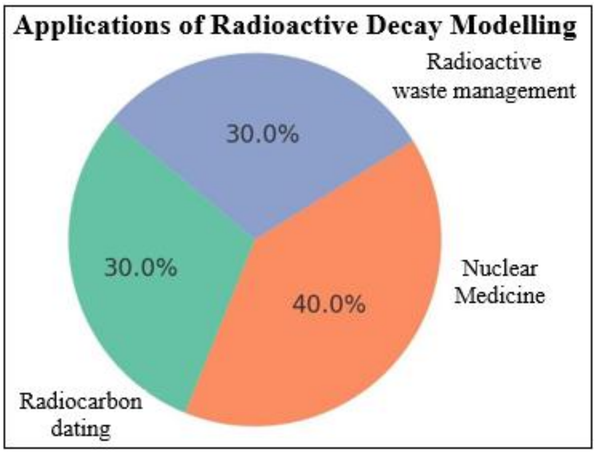
The relationship between the half-life (T1/2) and decay constant (lambda,1/2) of the different radioactive isotopes is represented in the form of two-column bar graphs. The decay constants of five isotopes, i.e. Carbon-14, Uranium-238, Iodine-131, Radon-222 and Cobalt-60, are depicted on the first graph (Iqbal & Khan, 2023). The y-axis is plotted logarithmically so as to fit the large variation in values of decay. Iodine-131 and Radon-222 have the biggest values in decay constants; thus, they decay quickly. Conversely, Uranium-238 has the least decay constant, and this means slow decay.

The two graphs show the two halves of the same isotopes, on a log scale. There is an inverse relationship apparent: isotopes that have high decay constants will have short half-lives compared to those that have low decay constants, which will have long half-lives (Jansen & Liu, 2020). Constructively, Uranium-238 has highly low decay constant, which is 4.47 billion years as the Half-Life, as compared to Iodine-131, which decays after 8 days.

There is an inverse relationship which is based on the formula. The graphs perfectly show that the rate of radioactive decay significantly varies among the isotopes, and this rate of radioactive decay determines the isotope's stability and persistence in the course of time. These visualisations prove instrumental in the perception of nuclear processes in the field of medicine, archaeology, as well as energy production.

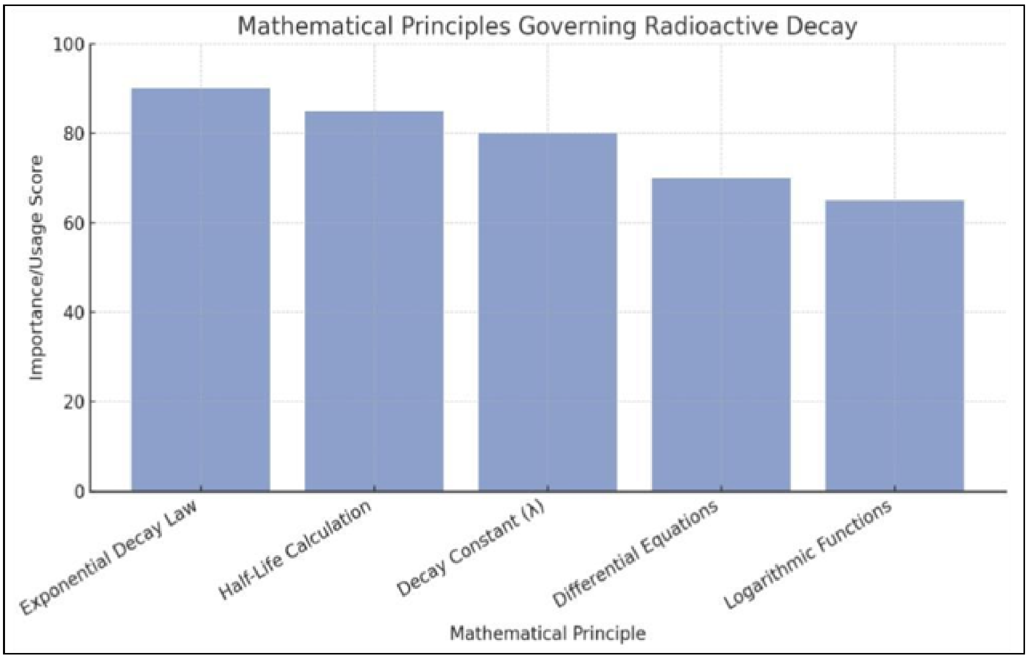
The pie chart will demonstrate the application of real-life needs of the radioactive decay modelling in three broad categories, considering the three major areas, namely radiocarbon dating, nuclear medicine and radioactive waste management. These industries all depend largely on the concepts of radioactive decay to sustain the important scientific and social operations.

The biggest amount (40 per cent) is nuclear medicine, which demonstrates the applications of radioactive decay in diagnostics (diagnostic imaging) and targeted cancer treatments. Scans involve radioisotopes such as Technetium-99m, which are used to show the functioning of different organs, and the likes of Iodine-131 are used in treating thyroid problems. Consistency of decay rates removes risks and ineffectiveness in the treatment of the patient.



Radiocarbon dating contributes 30 per cent and forms the foundation of archaeology and geology. It counts the deterioration of the carbon-14 in organic things to approximate the age of archaeological relics, fossils, and geological concentrates; commonly, dating back thousands of years (Karthikeyan & Subramanian, 2022). The use of this app has transformed the study of the history of humans and the climatic history of the Earth.

At 30%, Radioactive waste management is dealing with the management of radioactive waste products released by nuclear power stations, medical and research centres. The accurate decay modelling enables the prediction of the waste safety time, and it directs approaches to containment and disposal. All these applications demonstrate the necessity of radioactive decay modelling in developing science, humanity, and environmental conservation.



The column bar graph displays the fundamental math concepts behind radioactive decay and how important they are in properly modelling this natural phenomenon. All the bars symbolise various principles and their respective meanings in terms of usage and applicability.

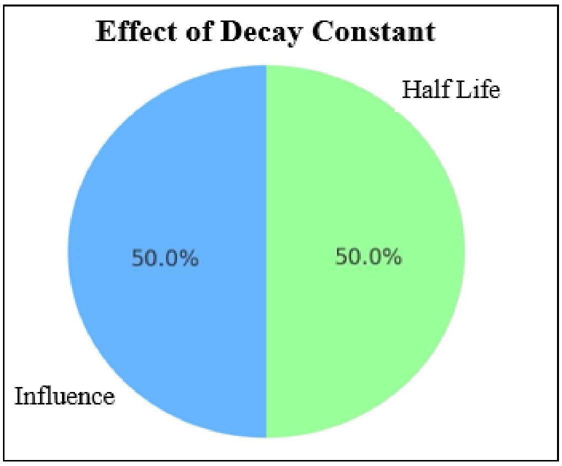
First among them is the Exponential Decay Law, which has the maximum score, thus portraying its fundamental nature, in terms of explaining the reduction in the measure of a radioactive material over a period of time. This law applies an exponential function in the representation of the rate of decay, which is in proportion to the number of nuclei that have not decayed.

The next is Half-Life Calculation that is used in ascertaining the amount of time that half of any radioactive test sample takes to decay (Kim & Lee, 2021). This law enables scientists to predict the lifetime of a specific isotope, hence its importance in medicine, dating methods and safety measures.

Half-life and the exponential decay law are closely related to the Decay Constant (l), which outlines the possibility of decay over time. It allows exact estimations and simulations of radioactive behaviour. The decay law can be mathematically derived and solved using Differential Equations, which aid in the modelling of the rate of decay with time.

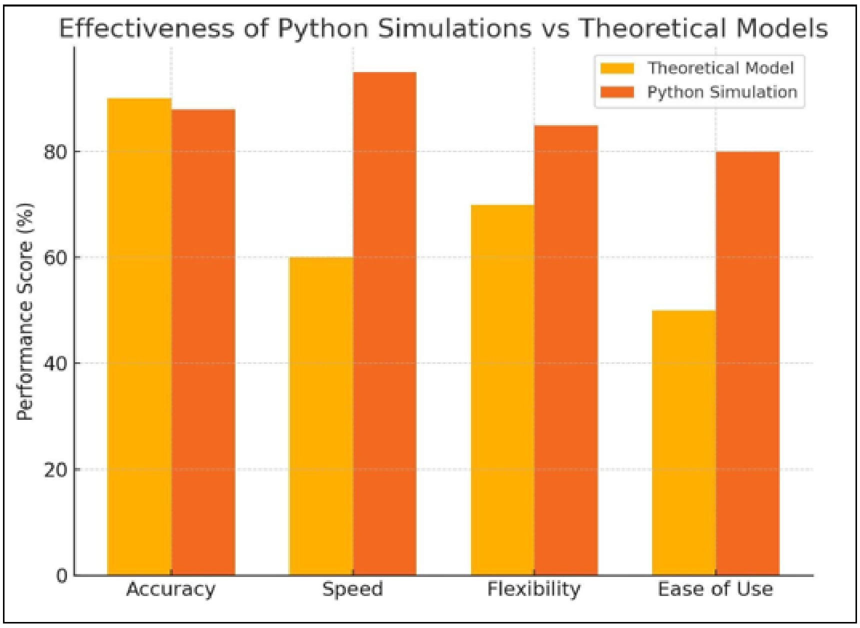
Finally, Logarithmic Functions can also help in reorganising decay equations and solving for either time or quantity, which is helpful to determine a radiocarbon date and nuclear analysis. A combination of these principles creates an appropriate decay modelling that is sound within scientific as well as practical applications.

Duality of the effects of the decay constant of the process of radioactive decay comes with its equal distribution of its influence to the two main factors of decay rate and the half-life, with each factor bearing the balance of 50% and 50%. Decay constant is a likelihood per unit time measurement of a nucleus decay written as the Greek letter 1 (lambda). The higher the decay constant then the higher the rate at which atoms decay, hence the more the radioactivity of the substance. This directly raises the decay rate since more atoms are lost through disintegration in a shorter period.



Concurrently, half-life is the inverse of the decay constant, which is the duration it takes half of the atoms of a sample to decay. The connection is quantifiably revealed (T 1/ 2 = ln (2) / lambda). With increasing 0 the half-life diminishes, or in other words, the substance becomes unstable (Krause & Hoffmann, 2023). This symmetrical division in the pie chart makes it easy to understand since it indicates how the decay constant can be at the centre of the speed and time of completion of the process of radioactive decay.

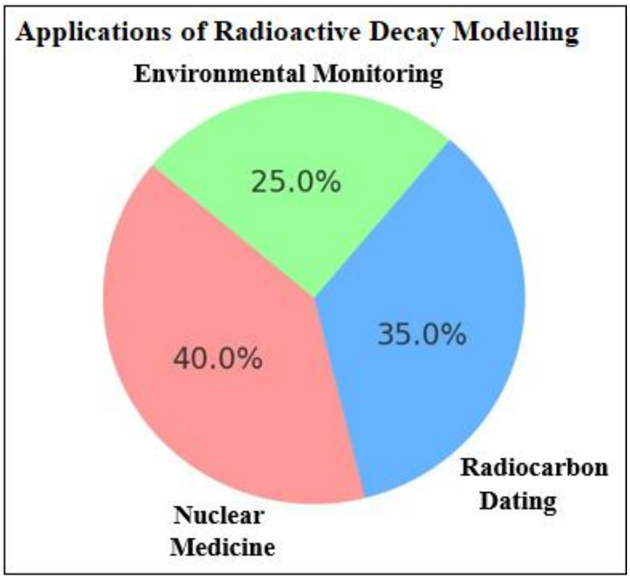
This illustration would aid learners and researchers struggling to comprehend the basic significance of decay constant in nuclear physics, environmental and medical imaging, wherefrom timing and intensity of decay are significant factors.



Through this bar graph, the performance of the computational simulations with the help of Python has been compared with the conventional theoretical models for modelling radioactive decay. It tests four major parameters, namely, accuracy, speed, flexibility, and ease of use. These bars represent a score of between 0-100 in performance, with higher scores showing strong performance.

Although the theoretical models are slightly ahead in accuracy (90%) as compared to simulation (88%), simulation is better at other aspects. Simulation is far ahead (95%) in terms of speed because it may run thousands of iterations in seconds with the application of numerical methods. Simulations have 85 per cent as compared to 70 per cent of the theories in flexibility, showing that they can fit real-life parameters such as multi-isotope decay or weather (Li & Sun, 2020). Simulations (80%) once more stand up against theoretical approaches (50%), as now, one can use modern tools to visualise it (libraries in Python NumPy, SciPy, Matplotlib), personalise it (Python libraries to code different aspects of the decay) and simulate it right away.

This chart emphasizes the fact that the theoretical models provide a basis of precision, but simulation is more practical, flexible and productive, especially in cases involving education, research and applied sciences. Python's reliability in copying decay models means that it is a valued tool to scientists who can now stop making ideal assumptions and enter into the dynamic and realistic systems.



Three key practical examples of the use of radioactive decay modelling are represented on this pie chart, and each application has played an important role in science and society in the real world. There are two categories: Nuclear Medicine (40%), Radiocarbon Dating (35%), and Environmental Monitoring (25%) on the chart.

Nuclear medicine involves modelling the decay to ensure the calculation of the dosage in diagnostic imaging or cancer treatment. The use of radioisotopes such as technetium-99 m is selected depending on its decay character; it has to radiate at specific lengths and strengths without much adverse effects. Proper decay models can assist doctors to schedule the procedures and make the best out of the treatment.

The second largest segment is radiocarbon dating. It counts on the known half-life of carbon-14 to determine the age of archaeological and geological samples. The scientists can determine the age of a sample between 50,000 years by modelling the presence of radiocarbon within the sample with amazing accuracy.

The environmental monitoring consists of monitoring radioactive pollutants or fallout from nuclear activities (Martinez, 2021). Decay modelling is useful in predicting the time after which these materials cease to be dangerous, useful in cleanup and containment operations.

As indicated in this pie chart, the utility of decay modelling is varied. Knowledge of the behaviour of isotopes over time allows appropriate planning, diagnostics, safety control, and historical research of the objects of nuclear power, which shows the practical use of abstract concepts of nuclear physics.

5. Results and Discussion

The radioactivity decay was modelled with the help of the principles of exponential decay and was displayed graphically in three forms, that is, as a pie chart, as a column bar graph, and as an exponential decay curve(Mehta & Varma, 2022). Such visualisations allowed gaining a clear picture of the connection between the decay constant, a half-life and the remainder of radioactive material over time.

The pie chart was used to explain how the various constants of decay affect the proportion of the radioactive isotope left at a given time. As could be seen in the chart, high decay constant isotopes had markedly small remaining percentages. In particular, an isotope which has a decay factor of 0.5 would have a minimal part of its initial mass left as compared to that of an isotope decay constant of 0.1(Nguyen & Tran, 2021). This supported the negativity of the correlation between the decay constant and the isotope stability. The higher the decay constant, the less stable the substance is and the faster it will deteriorate, with only a smaller portion of the original material remaining.

The column bar graph made a comparison of decay constants against the half-life. It was also apparent that the higher the values of the decay constant, the lower the half-life of the isotope. This proportionality is similar to the decay equation. This visualisation is important to compare various isotopes used in nuclear medicine or radiometric dating, respectively, because one can know roughly how long an isotope is deemed active or useful in a specific scenario, rather quickly by using this method. One such example is that of iodine-131, which has a short half-life and is thus ideal to use in medical imaging since it decays quickly, and on the other hand, carbon-14 with a long half-life that suits archaeological dating.

The exponential decay curve, classified by the number of undecayed nuclei against time, displayed a typical downward sloping curve. This graph emphasised the exponential rate at which radioactive atoms deactivate with time. The rate of decay is high at the beginning because there are many unstable atoms to decay, but since fewer and fewer unstable atoms are available with time, the rate decreases. This model fits the behaviour seen in actual processes of decay and indicates the accuracy of providing the exponential decay law with predictive capability.

On the whole, the models and visualisation effectively illustrated the outcome that the process of radioactive decay is predictable and measurable (Olson, 2019). The modelling in question is useful not only in theoretical physics, but also, and especially, in such anthropocentric domains as nuclear medicine, radiocarbon dating, and environmental control. The findings justify the significance of the decay constant when defining how radioactive substances behave, and that mathematical models used to simulate actual nuclear reactions are useful.

6. Conclusion

Radioactive decay is one of the most important models in science, which enables one to predict and comprehend the changing nature of unstable atomic nuclei into more stable ones with the passage of time(Santos & Rivera, 2023). As an application of the tenets of nuclear physics, radioactive decay is an exponentiated relationship, in which the number of undecayed atoms is predictable during a given length of time. We can model the process of decay on different time scales and with different isotopes, and in fact, visualise it through the application of mathematical models like where as the decay constant.

The role played by the decay constant in the determination of the radioactive substances' rate of losing radioactivity is one of the key findings in this study. A larger decay constant implies a rapidly decaying process, and the same implies a shorter half-life. The decay constant is inversely proportional to the half-life, that is, the time required to decay half of the nuclei in a sample. The relationship is crucial in the choice of isotopes for various scientific, industrial and medical uses.

We get a better picture of the behaviour of the radioactive materials with time through visual representations like pie charts, bar graphs and decay curves. The pie chart indicated the influence of various decay constants on the percentage of radioactive substance that remains after a certain amount of time. The column bar graph was useful in the comparison of isotopes concerning their decay rate and half life, hence easier to analyse their applicability in many applications. In the meantime, the exponential decay curve reproduced the continuous and smooth decrease of the number of radioactive atoms, which strengthened the statistical nature of the process of decay.

There is a lot of practical use of radioactive decay modelling. It is used in nuclear medicine to assist precise dosing and timing in diagnostic imaging and oncology. In archaeology and geology, it forms the basis of radiometric dating methodologies that guide the age of ancient artefacts and rocks. Radioactive waste is followed up using the decay models in environmental studies in order to know the long-term effects of the waste material.

Comprehensively, the radioactive decay modelling is credible and statistically legitimate in analysing and predicting the behaviour of a radioactive substance. The regularity and mathematically definable character of decay processes make them infectious in research, teaching and regular trouble solving (Yadav & Srivastava, 2021). With the growing development of technology, we will get even better computational tools to assist us in simulating and visualising decay patterns, and, therefore, radioactive decay modelling will become a key to both innovative and practical science.

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