NUCLEAR RADIATIONS AND THEIR APPLICATIONS

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Atoms are tiny building blocks of matter that make up everything. The central part of the atom is called nucleus and the electrons revolve around it. The nucleus has protons that are positively charged while the neutrons are neutral. Electrons revolve around the nucleus in different orbits. In the year 1909, a famous scientist Ernest Rutherford, performed an experiment where alpha scattering on thin gold foil was studied and showed that almost entire mass of the atom is concentrated at its centre called the nucleus. We know that the nucleus is made up of protons and neutrons and these are compactly packed together because of strong forces. When some nuclei are not stable, they change and give off particles or energy. This helps them become stable. The time it takes for half of the atoms to convert into new more stable ones is called half-life. Marie Curie found out about radioactivity. She showed that there are three main types of radiation: alpha, beta and gamma. These types have many applications in medicine and other fields. In medicine, radio-isotopes help us to see inside the body. Technetium-99m is an example and has many applications in medical sciences. Radiation is also used to keep the food safe and clean by the process called food irradiation. Sometimes, people think radiation is not good for food but this is not the case. Caution needs to be taken to irradiate the food with controlled amount of radiation as prescribed by regulatory bodies. There are always risks with different activities we do, like making electricity from oil, coal, solar and nuclear energy. While we can't get rid of all risks, we try to make them as small as possible. The nuclear industry follows strict safety rules to reduce risks. Nuclear technology, in general, helps in medicine, industry, agriculture, energy and research. We must understand that nothing we do is completely risk-free but we want the benefits from nuclear technology to be higher than the possible problems. We need to educate people about the benefits of the nuclear radiations and use it safely for the benefit of mankind.

Keywords: Nuclear Radiation, Nuclear Technology, Nuclear Medicine, Sustaibaible Nuclear Energy, Radiation theraphy

Introduction

An atom is full of surprises. It has a structure that comprises a tiny central nucleus surrounded by electrons. The nucleus, has a very small size (≈10^{-14} m) consisting of protons and neutrons. The protons carry positive charge and neutrons are electrically neutral. Negatively charged electrons orbit the nucleus in specific energy levels or electron shells. Ernest Rutherford, an eminent physicist, conducted the groundbreaking alpha-particle scattering experiment in 1909, revealing the nucleus as the central part of the atom, challenging the prevailing 'plum pudding' model proposed by J. J. Thomson. The nucleus, with most of the mass of the atom and positive charge is concentrated at the centre with electrons orbiting in energy levels. Protons are positively charged while neutrons are neutral, both protons and neutrons are called nucleons. These are held together by strong nuclear forces inside the nucleus. The nucleus is responsible for nuclear reactions, while electrons play a role in chemical reactions. In the realm of nuclides, the pursuit of their lowest energy state leads to a stable nucleus. Unstable nuclides undergo radioactive decay. A typical nucleus is represented by the symbol $^{A}_{Z}X$, where X refers to the chemical symbol of the element, A is the atomic mass number which is equal to the sum of neutron number (N) and proton number (Z) inside the nucleus. For stable nuclides with lower atomic masses, the number of neutrons approximately equals to the number of protons. However, as the atomic mass number 'A' increases, stability necessitates a greater ratio of neutrons 'n' to protons 'p,' more than unity, to counteract electrostatic repulsion caused by an increased number of protons, requiring additional nuclear forces. A typical plot of atomic number (Z) versus neutron number (N) is shown in Fig. 1. Furthermore, excess energy can render the nucleus unstable, leading to an excited state. For instance, adding a neutron to ^{238}U results in an excited nuclide (^{239}U*), which eventually transitions to a stable state by undergoing radioactive decay emitting radiation.

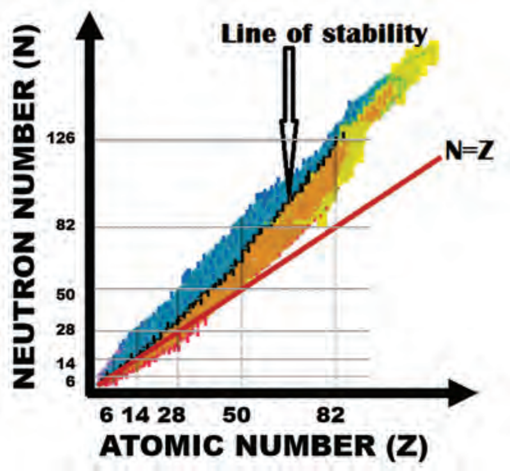

Fig. 1: A plot of proton versus neutron number of nuclides

Henry Becquerel conducted a study in 1886, in which he observed the effects of light on uranium salt. To his surprise, he discovered that the salt emitted radiation spontaneously, affecting photographic plates. This groundbreaking revelation led to the identification of the phenomenon now known as 'radioactivity'. The process of spontaneous radiation emission from a sample is termed 'radioactive decay'. Becquerel's significant contributions to the discovery of natural radioactivity were acknowledged and honored with the Nobel Prize in Physics in 1903. His pioneering work in this field opened the doors to a deeper understanding of atomic and nuclear processes and laid the foundation for further research in radiation and nuclear physics. [Singh, et al. 2022]

Radioactive decay is a natural and spontaneous process wherein certain unstable atomic nuclei undergo transformations to achieve more stable configurations by emitting electromagnetic radiation or particles. In the field of nuclear physics, a diverse array of nuclei has been extensively studied, revealing intriguing properties. When analysing the neutron and proton numbers of naturally occurring nuclei, these tend to cluster around a stability line. Nuclei positioned away from this line often exhibit radioactive behaviour, decaying to attain stability via emission of alpha, beta particles or gamma radiations or undergoing electron capture. Throughout decay, the unstable nucleus emits radiation eventually transmuting into a different nuclide with improved stability. The concept of half-life holds immense significance as it serves to predict decay rates and indicates the time required for half of the radioactive atoms in a sample to undergo decay, representing a unique property for each radionuclide. The half-life of radiaoactive nuclides is pivotal in measuring decay rates, determining artefact and geological formations' age and managing radioactive waste. Moreover, it plays a crucial role in nuclear medicine, ensuring the efficacy and safety of radiopharmaceuticals utilised in medical imaging and cancer treatment.

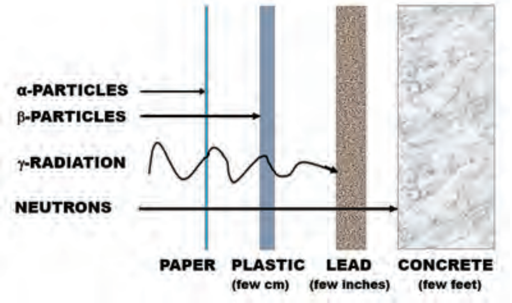

Fig. 2: Depth of penetration in different materials

Radiation, in general, refers to energy in the form of waves or particles. It can exist as waves or particles and is classified into ionizing and non-ionising radiation. In nuclear science, common types of radiation emitted from the nucleus include alpha particles, beta particles, gamma rays and neutrons. Additionally, X-rays are often associated with nuclear radiation due to their electromagnetic nature and ability to penetrate through materials, even though their origin lies in the de-excitation of atoms. However, not all types of radiation fall under the category of nuclear radiation. Each type of radiation exhibits different penetration capabilities into materials. Alpha particles can be stopped by a thin sheet of paper, while beta particles can be stopped by a few centimeters of plastic. Gamma radiation, on the other hand, can penetrate several inches of lead and neutrons possess the highest penetration capability, reaching a few feet within concrete. For the purpose of nuclear radiography, Fig. 2, illustrates the distinguishing capabilities of alpha, beta, gamma and neutron radiation, based on their depth of penetration in different materials. This figure also helps in understanding various radiation types and their respective penetrating abilities into materials.

The influential study of the effects of electrical and magnetic fields on radioactive emissions was undertaken by the renowned scientist, Marie Curie. Interestingly, the term 'radioactivity' was coined by Marie Curie in 1898 while conducting investigations into this phenomenon alongside her husband, Pierre Curie. During their experiments, they allowed the emitted radiation from uranium salt to pass through a magnetic field, leading to the observation that one type of particles was deflected in one direction, while another type of particles was deflected in the opposite direction. Some radiation remained unaffected. Subsequently, these distinct types of radiation were named alpha, beta and gamma radiation. Fig. 3, illustrates the effect of the magnetic field on the emitted radiation from uranium salt.

The study of radioactivity encompassed various substances and materials and Marie Curie's groundbreaking research revealed that pitchblende exhibited higher radioactivity than uranium. This discovery led her to hypothesize the presence of other radioactive elements. Later, she successfully isolated two unknown elements, polonium and radium, both displaying higher radioactivity than uranium. In recognition of their significant contributions, Marie Curie and her husband, Pierre Curie were jointly awarded the Nobel Prize in Physics in 1903 and the Nobel Prize in Chemistry in 1911. During her extensive research, Marie Curie was exposed to a considerable number of radioactive materials and her health was seemingly disregarded in her later years. Spending long hours daily in the pursuit of her scientific endeavours, she may have fallen victim to the adverse effects of radioactivity, potentially leading to blood cancer. Tragically, she passed away at the age of 66 on 4 July, 1934, in a hospital in France. Her research works, books and even her cookbook, which are highly radioactive, are carefully stored in lead-lined boxes for safety. Anyone wishing to view her works is required to wear protective masks to minimize exposure.

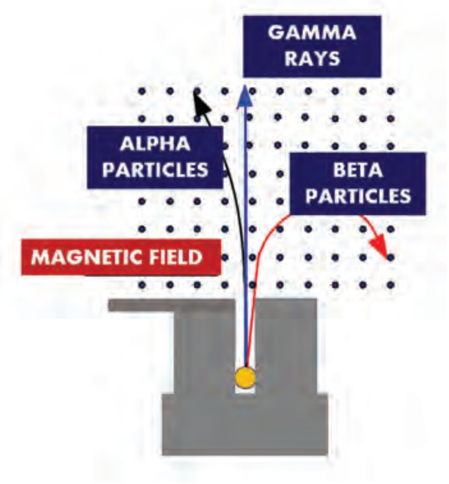

Fig. 3: Deflection of different types of radiations in a magnetic field

As already mentioned, the radioactive elements undergo a process called radioactive decay, wherein their unstable nuclei spontaneously transform into more stable forms, releasing radiation in the form of alpha particles, beta particles and gamma rays. The decay rate is quantified by the half-life, representing the time required for half of the original sample of radioactive atoms to decay. Various naturally occurring radioactive elements possess distinctive half-lives. Uranium-238, with a half-life of approximately 4.5 billion years, are found in the Earth's crust, rocks and minerals, and play a crucial role in radiometric dating and nuclear power generation. Potassium-40, with a half-life of about 1.25 billion years, is present in rocks and soils, and is vital for geological dating. Carbon-14, with a half-life of approximately 5,730 years, is produced in the atmosphere and is widely utilised in carbon dating for estimating the age of archaeological remains. Tritium or hydrogen-3, with a half-life of around 12.3 years, is formed in the atmosphere and nuclear reactors, serving as a valuable tracer in environmental research.

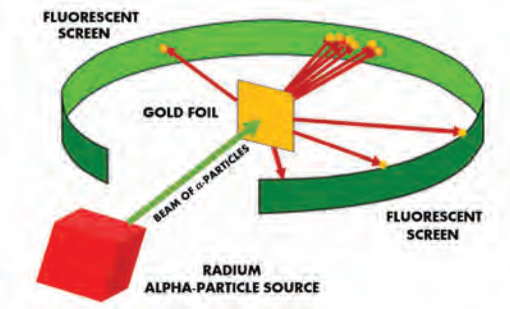

Fig. 4: Schematic representation of Rutherford experiment

In 1909, a renowned team led by Ernest Rutherford, along with Ernest Marsden and Hans Geiger, conducted the iconic alpha scattering experiment at Victoria University in Manchester, England. Rutherford and his team designed an ingenious setup, aiming to explore the structure of the atom, particularly the distribution of positive charge within it. The experiment involved bombarding alpha particles from a radioactive source on a thin gold foil. Alpha particles, which are positively charged and relatively massive, were incident on to a thin foil of gold. A screen coated with a light-emitting material was placed behind the foil to detect the behaviour of the alpha particles after passing through it. A typical layout of the Rutherford's experiment is presented in Fig. 4. The results were striking and unexpected, defying the predictions of the existing 'plum pudding' model, which assumed a uniform distribution of positive charge within the atom. Most of the alpha particles passed straight through the gold foil, as anticipated. However, what surprised them were the few alpha paricles that were significantly deflected at large angles and a small fraction even bounced directly backward. These findings challenged the prevailing model and led to groundbreaking conclusions. This groundbreaking experiment led to the discovery of the atomic nucleus. Rutherford's reaction to the results was famously expressed as, "It was as if you had fired a 15-inch shell at a piece of tissue paper and it came back and hit you." This unexpected outcome could only be explained by the assumption that the atom's nucleus, containing nearly all its mass and positive charge, is concentrated at the centre. By that time, significant advancements had already been made in understanding alpha, beta and gamma radiations. According to the current knowledge about atoms, a small, positively charged nucleus composed of protons and neutrons exists at the centre of an atom. Electrons orbit around this nucleus in various energy levels or orbits. This fundamental understanding of atomic structure has laid the groundwork for further advances in nuclear physics and chemistry, shaping our comprehension of matter and the universe.

The process of radioactive decay follows statistical laws, wherein a certain number of radioactive nuclei will become half in quantity after a specific time interval, known as the half-life. This phenomenon continues in subsequent half-lives, resulting in a rapid reduction of undecayed nuclei. Approximately six half-lives lead to a diminishment of the original nuclei count to a negligible 1.5 per cent of its initial value. The time required for the number of nuclei to halve is referred to as the 'half-life' of the radioactive substance. It's important to note that this statistical nature of decay is applicable only when considering a significant number of nuclei. Radiation exposure can arise from both natural and man-made sources [Krane, 1987]. In our daily lives, we encounter radioactive substances through dietary intake, water consumption and breathing air. Common natural sources of radiation include cosmic rays, solar radiation, radon, living organisms, soil and rocks. Conversely, man-made sources encompass activities such as medical and dental X-rays, nuclear and coal power plants, smoke detectors and various industrial, research, and university laboratory applications. Examples of natural radioactive sources and their respective half-lives include 238^{U}, found in soil, with a half-life of 4.5 billion years; ^{40}K, present in living organisms (humans, plants, trees) with a half-life of 1.3 billion years; and 3H (tritium), occurring in water with a half-life of 12.0 years. Each sample of radioactive substance exhibits distinct half-life values, which allow for valuable applications like carbon dating to determine the age of once-living objects. The ratio of ^{14}C to ^{12}C in living organisms provides insights into their lifespan once the supply of ^{14}C ceases.

In medical applications, common radioactive substances like ^{131}I (used in thyroid treatment) with a half-life of 8 days; ^{99m}Tc (used in nuclear medicine) with a half-life of 6 hours; and ^{198}Au (used in tumour therapy) with a half-life of 2.7 days are employed. Medical practices utilise both gamma radiation and emitted particles for various purposes. The slowing down of energetic charged particles within a medium is influenced not only by the medium's nature but also by its stopping power on the particles. For instance, in air, alpha particles with 3 MeV energy have a range of ≈ 2–3 centimetres, while beta particles of the same energy can traverse up to 10 metres in air. The Bethe-Bloch relation indicates that as monoenergetic charged particles enter a medium, their energy decreases, leading to an increase in the stopping power per unit path length due to ionization. This stopping power reaches a maximum and drops abruptly to zero at the boundary. At this boundary, the particles lose the maximum energy. Plotting the energy loss per unit path length as a function of depth in a medium result in the Bragg curve, Fig. 5. Such insights are crucial in understanding radiation interactions and are applicable in various scientific and medical contexts.

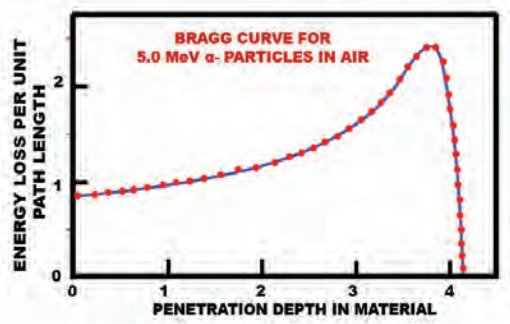

Fig. 5: A typical Bragg curve indicating maximum energy deposition towards the end of range

In Fig. 6, the plot of energy loss per unit path depth within a substance is shown for electrons, gamma rays and an appropriate initial energy for an incident proton particle. It has been observed that the gamma rays deposit more energy in the initial part and as these penetrate the medium, the relative deposited energy decreases. On the other hand, for the incident particle, the maximum energy is deposited towards the end of its path and the minimum relative deposited energy is towards the front of the medium. The Bragg curve holds significant importance in proton therapy, a form of cancer treatment that utilises a linear accelerator. This curve allows for precise energy deposition at a specific depth, as most of the energy is deposited towards the end of the range, with no excess energy beyond the target depth. Moreover, it results in relatively low energy deposition in the front part of normal tissues. This precise targeting of tumours enables the delivery of a high radiation dose to the tumour area, making the treatment more efficient.

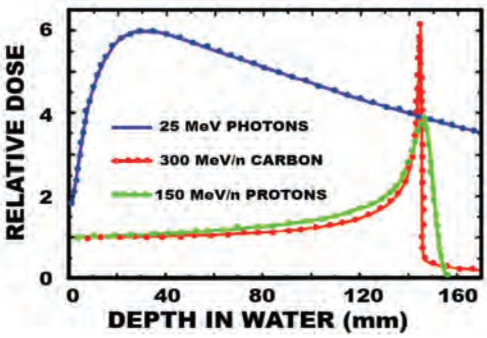

Fig. 6: Maximum energy is deposited towards the end of range for charged particles.

In the field of medical applications, different forms of radiation find use in both diagnosis and treatment. X-rays, commonly employed in radiographs, fluoroscopy, CT scans, dental X-rays, mammograms and more, are utilised for imaging and involve low to moderate radiation exposure for short durations. In therapeutic applications, higher radiation doses are administered based on specific treatment needs. Nuclear medicine is one such therapeutic application, where radioisotopes are injected into the body and emitted gamma radiation is analysed via computer systems to detect tumours or assess the functioning of internal organs. An important radioisotope in nuclear medicine is Technetium-99m (^{99m}Tc), which acts as a radioactive tracer in over 80 per cent of nuclear medicine diagnostic procedures. The decay scheme of ^{99m}Tc is shown in Fig. 7. With a half-life of approximately 6 hours, Technetium-99m is well-suited for investigating various physiological processes and is rapidly cleared from the body. Emitting 140 keV gamma rays, it produces sharp and easily detectable images with gamma cameras. The use of ^{99m}Tc scans is crucial in diagnosing injuries, infections, tumours, heart diseases, thyroid disorders, kidney conditions and certain cancer processes. In the broader context, radiation oncologists consider factors like energy, particle type and contact time with the administered radioisotope to plan medical diagnosis and treatment. Beyond medical applications, nuclear radiation finds use in diverse areas such as industrial and manufacturing processes, food irradiation, consumer product safety, reactors, research applications, power supply in spacecraft and more all contributing to human welfare worldwide. It is essential to recognise varying levels of radiation hazards associated with different forms of radiation and the differing sensitivity of body tissues to various radiation types. Radiation oncologists diligently assess these factors to achieve the desired treatment outcomes.

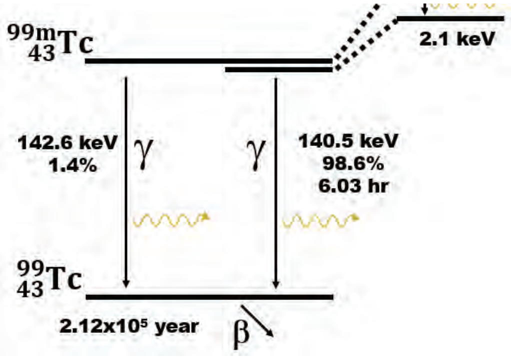

Fig. 7: Decay scheme of $^{99m}_{43}$Tc

As previously mentioned, nuclear radiation finds applications in the manufacturing industry for testing and measurement purposes. During production, radiation is utilised to accurately measure the thickness of various materials such as metal sheets, aluminum foil and paper. Measuring the thickness of very thin sheets or foils using traditional tools like vernier calipers or screw gauges becomes challenging due to their small increments, often in the range of 0.01 mm and 0.001 mm. However, with nuclear radiation techniques, precise measurements of extremely small thicknesses become possible. These radiation-based techniques are also employed for measuring wear on cutting and drilling tools, offering valuable insights into tool performance and longevity. Additionally, radiation is used to determine the amount of adhesive on postage stamps and to measure the liquid level in containerised beverages during the canning process. For automated container filling operations, a radiation source is positioned on one side, and the intensity of radiation is monitored on the other side. As soon as the container is filled to the desired level, the radiation source is electronically moved, allowing the next container to take its place. This process ensures accurate and efficient container filling, as depicted in Fig. 8.

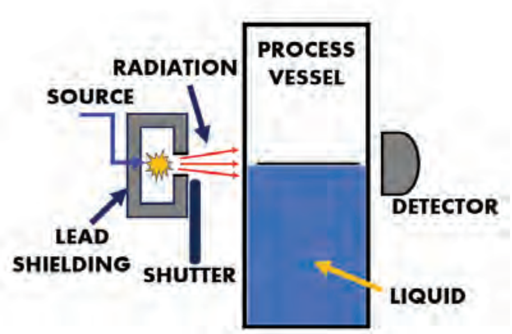

Fig. 8: **Filling of liquid vessels being checked by radiation**

As responsible and informed individuals, it is crucial to debunk common myths surrounding nuclear radiation and educate the public about its benefits. One such myth is the belief that irradiated food is dangerous and radioactive but, nuclear radiation effectively kills harmful bacteria and organisms in food, making it safe for consumption without rendering it radioactive or harmful [Diehl, 2002]. It is important to note that we are exposed to various forms of radiation in our daily lives such as from the air we breathe and the food we eat. Medical procedures involving radiation like X-rays and MRI scans, utilise low-level radiation that poses no long-term health risks or adverse effects to patients. Another misconception is related to nuclear power plants emitting dangerous levels of radiation and causing cancer in their vicinity. However, the truth is that a person receives minimal radiation exposure, approximately 0.01 millirem per year, within 50 miles of a nuclear power plant. Natural sources like the sun and rocks, expose us to about 300 millirem per year, far more than nuclear power plants. Even coal-fired power plants emit a slightly higher amount of radiation, around 0.03 millirem, due to uranium and thorium content in the coal. Nonetheless, the radiation from all these sources is very low and poses no cancer risk.

An important radioisotope, Plutonium-238, is a potent alpha particle source with 5.593 MeV of decay energy, making it ideal as a heat source (battery power) for delicate electrical components in satellites through its decay process. This isotope is produced from uranium in nuclear reactors and is a byproduct of nuclear energy and weapons production. It is 87.7 years half-life that makes it a reliable long-term battery power source. For instance, nuclear-powered pacemakers use a small amount of Plutonium-238 to generate electrical impulses that stimulate regular heartbeats in patients with irregular or malfunctioning natural electrical pacing systems. A pacemaker of Medtronic company that employs 238Pu radiactive source is shown in Fig. 9. These nuclear batteries offer extended life but cannot be buried with individuals due to the radiation risk. Nonetheless, they have revolutionised medical technology and significantly improved patients' lives. Understanding nuclear radiation and its applications allows us to make informed decisions and harness its safe use across various fields [Cutter, 2009]. Dispelling myths helps promote the responsible and beneficial use of nuclear radiation for the betterment of society.

Fig. 9: The picure of the pacemaker of Medtronic company that employs 238-Plutonium radioactive source

Radiation plays a crucial role in ensuring food security and preservation, addressing the significant issue of contaminated food causing illnesses and deaths worldwide. Each year, around 600 million people fall sick due to consuming unsafe food, resulting in approximately 420,000 deaths and the loss of 30 million healthy life years. This poses a significant economic burden, with low and middle-income countries facing an annual loss of about 100 billion US dollars in productivity and medical expenses. The impact is particularly severe on children under five years, accounting for 40 per cent of foodborne disease-related deaths, amounting to 130,000 fatalities annually. This not only strains healthcare systems but also affects national economies, tourism and businesses, hindering social and economic development. Apart from contamination issues, a considerable amount of food is lost globally due to pests, bacteria and spoilage after harvest, accounting for around 25 per cent of the world's food production. In the US alone, this leads to an annual economic loss of 10–15 billion dollars. Globally, approximately 14 per cent of produced food is lost between harvesting and retail sale, causing a loss of about 400 million dollars each year. Moreover, food losses and waste contribute to around 10 per cent of total greenhouse gas emissions, leading to the wastage of valuable land and water resources.

To address these challenges, food irradiation offers a valuable solution with various applications. It inhibits the sprouting of items like onion, ginger, garlic and sterilises insects in grains, pulses and dried fruits. The benefits of food irradiation are evident in reducing foodborne disease incidents, improving the global food supply and enhancing the quality assurance levels in domestic markets. During the food irradiation process, precautions are taken to control the dosage to food, damaging the DNA of pests and pathogens that spoil food and inhibiting their sprouting or reproduction. Importantly, nutrients, proteins, carbohydrates and fats in the food remain unaffected and there is no alteration in taste. As an example, strawberries, a valuable crop in regions like Mahabaleshwar, Uttarakhand, Punjab, Himachal Pradesh, and northeastern states of India, have a short shelf life and quickly deteriorates. Studies have shown that both gamma and electron beam irradiation can effectively preserve strawberries during storage, extending their shelf life by three weeks or more. By harnessing food irradiation, we can address critical food security challenges, reduce foodborne illnesses and ensure a safer and more sustainable food supply for the global population.

Fig. 10: Irradiation treated strawberries, with radura symbol

There is a common misconception surrounding irradiated food, often leading to concerns about its nature. However, it is crucial to understand that other food processing methods also bring about similar changes. When we heat, microwave or fry food, it undergoes transformations, just like irradiation. The effects of irradiation on food are not fundamentally different from these common cooking methods. To ensure consumers can make informed choices, it is essential to look for the 'radura' symbol when purchasing irradiated food. Regulatory bodies mandate the display of the 'radura' symbol and the statement "Treated with radiation" on packaged food items and wholesale containers of unpacked food items. Moreover, placards should be visible at the point of purchase for fresh produce and on invoices for irradiated materials and products sold to food processors.

India has several facilities for food irradiation, utilising three different types of technologies: electron beams, X-rays and gamma rays. Electron beam irradiation, for instance, accelerates a beam of electrons toward the food, acting like a steriliser. However, its limitation is that electrons can only penetrate slightly more than an inch into the food; meaning treated food should not be thicker than that. In such cases, two opposing beams can treat the food from both sides, doubling the thickness that can be treated. Importantly, electron beam irradiation does not require radioactive materials, making it easily controllable and safer, without the need for thick walls, control pools or handling of radioactive substances. Understanding the benefits and safety measures surrounding food irradiation is essential in making informed decisions about the food we consume. By dispelling myths and promoting proper information, we can ensure food security and safety for everyone.

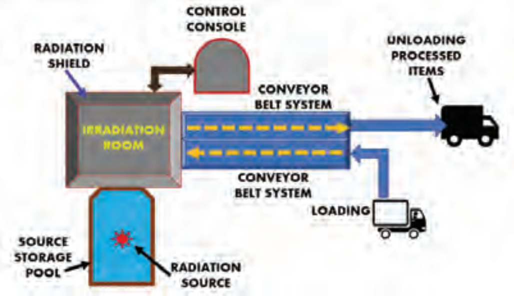

Fig. 11: A typical block diagram of food irradiation facility

The X-ray irradiation facility utilises advanced machines like those used in hospitals and dental clinics for taking X-ray images. These powerful X-rays can penetrate thick food packets, but to ensure safety, these require appropriate shielding. On the other hand, gamma rays have been effectively used for sterilising medical, dental and household products for over four decades, as well as for cancer radiation therapy. The advantage of gamma rays lies in their ability to penetrate several feet into food items without making them radioactive. These gamma rays are emitted from a non-radioactive source, usually a 'pencil' made of non-radioactive cobalt-59 (^{59}Co), which is converted to radioactive cobalt-60 (^{60}Co) by bombarding it with neutrons in a reactor. Due to the continuous radiation emission from cobalt-60 (with a half-life of 5.27 years), the source can be safely stored in a storage pool, sealed for protection. According to the Department of Atomic Energy (DAE), Government of India, gamma irradiation effectively addresses the concerns of food producers and exporters. The high energy of gamma rays allows for the irradiation of spices even after packaging, regardless of the carton size, ensuring no contamination occurs when the package is opened. While it is true that like any food processing method, irradiation may increase the cost of food, with its widespread adoption, the cost is expected to decrease over time. Comparatively, specific food irradiation facilities may have slightly higher costs compared to other common fruit treatments like pasteurisation or small-scale steam heat treatment. Food irradiation is an essential aspect of food safety, complementing existing safety practices. It should be noted that irradiated food should be stored, handled and cooked just like non-irradiated food.

Currently, over 60 countries, including India, have approved food irradiation processing, with nearly 500,000 metric tons of food products being irradiated annually worldwide. Food irradiation has been approved and utilised in numerous countries worldwide to ensure food safety and preservation. Some of these countries include the United States, Canada, Australia, Japan, China, Brazil, Argentina, India and many European nations. In the United States, the Food and Drug Administration (FDA) and the US Department of Agriculture (USDA) have approved the use of food irradiation for various products such as fruits, vegetables, poultry and certain meat products. Similarly, Canada has approved the use of irradiation for a wide range of food items, including fruits, vegetables, spices and poultry. In Australia, the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) regulates and approves food irradiation applications, primarily for fruits, vegetables and herbs. Japan, with its Ministry of Health, Labour and Welfare (MHLW), has approved the irradiation of various foods, including rice, wheat, potatoes and certain fruits. In China, the approval of food irradiation is overseen by the China National Center for Food Safety Risk Assessment (CFSA), permitting the irradiation of grains, fruits and vegetables. Across South America, countries like Brazil and Argentina have also embraced food irradiation to enhance food safety and extend shelf life. In India, the Food Safety and Standards Authority of India (FSSAI) regulates and approves the irradiation of various food products, including spices, onions and potatoes. European countries, including Germany, France, the United Kingdom and the Netherlands, have also approved food irradiation for specific applications such as herbs, spices and certain fruits. The approval of food irradiation in these countries demonstrates its widespread recognition as a safe and effective method to ensure food quality, reduce foodborne illnesses, and prevent food spoilage. By embracing this technology, these countries are taking proactive measures to safeguard public health and enhance food security for their populations.

However, it is essential to exercise caution and avoid excessive irradiation, as it can make food radioactive like how anything burns if left in an oven for too long. In the context of human life, there is always some level of risk associated with various activities, including electricity generation from oil, coal, solar energy and nuclear energy. While risks can never be eliminated, efforts are made to minimise them. The nuclear industry maintains high safety standards to reduce risks as much as possible. In various fields such as medicine, industry, agriculture, energy and scientific research, nuclear technologies provide significant benefits to society. It is important to recognise that no human activity is entirely risk-free, and the goal is to ensure that the benefits derived from nuclear irradiation and other substances outweigh the potential harm. Our responsibility lies in educating the public about the benefits of nuclear irradiation and embracing its safe and beneficial applications for the betterment of humanity.

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