



Impacts of Radiation on Human Health: A Narrative Review

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Abstract

Radiation, both natural and man-made, is ever-present in our environment and is integral to various industrial, medical, and scientific applications. Understanding its various forms, sources, and biological effects is essential for modifying potential health risks and maximizing its beneficial uses. This review explores the multifaceted interactions between radiation and human health, encompassing historical perspectives, biological mechanisms, health effects, regulatory frameworks, and emerging challenges. Beginning with an overview of the discovery and development of radiation science, we examine into the biological mechanisms underlying radiation-induced cellular damage, including DNA damage and repair processes. The review explains the spectrum of health effects resulting from radiation exposure, ranging from acute effects such as radiation sickness to long-term consequences like cancer induction and hereditary disorders. Regulatory efforts and protective measures implemented by international and national bodies are examined, emphasizing the importance of dose limits, radiation monitoring, and safety standards in minimizing radiation-related risks. Epidemiological studies investigating health outcomes in exposed populations provide valuable insights into the quantification and characterization of radiation risks. Furthermore, the integral role of radiation in medicine, highlighting its applications in diagnostic imaging, cancer therapy, and biomedical research. Environmental and public health concerns related to nuclear accidents, radioactive waste management, and emergency preparedness are also addressed, emphasizing the need for robust risk assessment and management strategies. The impact of nuclear power stations on radiation exposure and public health is discussed, including safety measures, accident prevention, and community engagement.

Introduction

Radiation, in its various forms, pervades our environment and plays a crucial role in numerous aspects of modern life. As defined by the International Atomic Energy Agency (IAEA), radiation encompasses the emission and propagation of energy through space or a material medium. It exists in natural sources

such as cosmic rays, terrestrial radiation, and radon gas, as well as in man-made sources like medical procedures, industrial activities, and nuclear power generation [1]. Radiation exists in two primary forms: Electromagnetic (EM) radiation, characterized by alternating electric and magnetic waves transmitting



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energy, and particle radiation involving accelerated particles like electrons and protons. EM radiation can be broadly classified into non-ionizing radiation and ionizing radiation. Both types can be encountered in clinical or environmental settings, potentially yielding positive or negative effects on tissues and organisms [2].

Alternative types of radiation, which include charged particles such as alpha (α), beta (β), and protons, have the capacity to interact with biological systems and possess clinical relevance, as demonstrated in practices like proton therapy and encounters with cosmic radiation during space exploration. Understanding the various types and sources of radiation is fundamental to understanding its effects on human health [2].

Historical Perspective

The study of radiation and its health effects has a rich history marked by significant discoveries and paradigm shifts. From Wilhelm Conrad Roentgen’s serendipitous discovery of X-rays in 1895 to Marie Curie’s pioneering research on radioactivity, each milestone has contributed to our understanding of the complex interplay between radiation and biology [3]. Subsequent events, such as the atomic bombings of Hiroshima and Nagasaki and nuclear accidents like Chernobyl and Fukushima, have underscored the profound consequences of radiation exposure on human health and the environment.

Biological Mechanisms of Radiation

At the cellular level, radiation interacts with biological tissues primarily through the process of ionization, wherein energy is transferred to atoms or molecules, resulting in the formation of charged particles or free radicals [4]. This ionizing radiation can induce various forms of DNA damage, including single-strand breaks, double-strand breaks, and base modifications, which, if left unrepaired or misrepaired, may lead to mutations, chromosomal aberrations, or cell death [5]. Cellular responses to radiation exposure, such as DNA repair mechanisms, cell cycle arrest, and apoptosis, are critical determinants of the ultimate biological outcome.

Health Effects of Radiation Exposure

The health effects of radiation exposure span a spectrum of acute and long-term consequences. Acute effects, such as radiation sickness or Acute Radiation Syndrome (ARS), manifest shortly after high-dose exposures and may include nausea, vomiting, diarrhea, and bone marrow suppression [5]. Long-term effects, notably cancer induction, hereditary effects, and cataract formation, may occur following chronic or cumulative exposure to lower doses of radiation over an extended period [6]. Specific organs and tissues, such as the thyroid, lungs, and bone marrow, exhibit differential susceptibilities to radiation-induced damage, reflecting their varying cellular compositions and physiological functions.

Types of radiation exposure and health effects

| TYPES OF RADIATION | DEFINITION | HEALTH ISSUES |
|-----------------------|--|---|
| ALPHA | The most massive type of radiation particle consists of a combination of two protons and two neutrons. Many naturally occurring radioactive elements on Earth, such as uranium and thorium, release alpha particles. The presence of radon in our homes frequently serves as a typical example of this phenomenon [1]. | "Alpha particles possess the capacity to harm lung cells, leading to lung tissue scarring and the advancement of lung diseases and cancer. Plutonium can traverse the lungs and travel via the bloodstream to reach the kidneys, thus exposing both the kidneys and the bloodstream to the effects of alpha particles." |
| BETA | "This unbound electron carries a negative charge and has a minuscule mass. Tritium, a substance ubiquitously present and generated by cosmic radiation in the atmosphere, emits beta radiation. Beta particles are also released by carbon-14, a radioactive isotope employed in dating fossils and other artifacts through carbon dating. In carbon dating, only the radioactivity of carbon-14 is utilized. By measuring the emitted beta particles, it is possible to determine the remaining amount of carbon-14 in the fossil, allowing the estimation of how long ago the organism was alive" [1]. | "Beta particles have the capability to penetrate the skin, potentially causing radiation injuries such as skin burns. Much like alpha emitters, beta emitters pose the greatest risk when they are inhaled, ingested, or enter the bloodstream through open wounds." |
| NEUTRONS | "This is a neutral particle located within the atomic nucleus. When uranium atoms undergo fission in a nuclear reactor, neutrons are often released. Without neutrons, it would be impossible to sustain the nuclear reaction responsible for generating energy" [1]. | "These neutrons possess the ability to modify the functioning of a cell, potentially hindering its ability to replicate, ultimately causing harm to the body. Neutrons can particularly pose a threat to delicate tissues, such as the cornea of the eye, leading to damage." |
| ELECTROMAGNETIC WAVES | The last category of radiation is electromagnetic in nature and includes types like X-rays and gamma rays. These forms of radiation are perhaps the most familiar due to their extensive application in medical procedures. Despite their higher energy, these beams share similarities with sunlight. Unlike other types of radiation, electromagnetic radiation has no mass or charge. Dental X-rays employ relatively low energy, while the irradiators required for disinfecting medical equipment utilize significantly higher levels" [7]. | Reports have surfaced regarding symptoms such as headaches, anxiety, feelings of sadness, nausea, suicidal thoughts, and a decrease in libido. Presently, there is no scientific evidence supporting a link between these symptoms and exposure to electromagnetic fields. |

According to WHO [8] and international atomic energy agency [9] radiation exposure can have various effects on health depending on the dose, duration, and type of radiation. These effects can range from mild to severe, including: (Figure 1).

Acute Effects: High doses of radiation over a short period can cause immediate symptoms such as nausea, vomiting, skin burns, and hair loss. In extreme cases, it can lead to radiation sickness, which may be fatal.

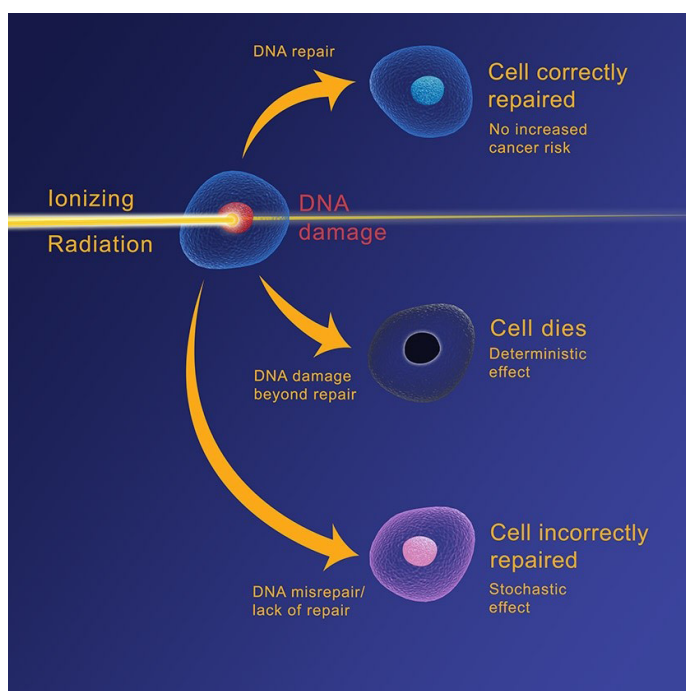


Figure 1: Statistics of patients discharged before and after the report.

Chronic Effects: Long-term exposure to low doses of radiation may increase the risk of developing cancer, particularly leukemia, thyroid cancer, and solid tumors. It can also lead to other health issues such as cataracts and cardiovascular disease.

Genetic Effects: Radiation exposure can damage DNA, potentially leading to genetic mutations that can be passed on to future generations, increasing the risk of birth defects and hereditary diseases.

Localized Effects: Radiation exposure to specific parts of the body, such as the thyroid or reproductive organs, can cause organ-specific health problems or increase the risk of developing certain types of cancer in those areas.

5. **Radiation Burns:** Exposure to high doses of radiation can cause burns to the skin and underlying tissues, similar to thermal burns but with specific characteristics due to radiation damage.

Radiation Protection and Regulation: In response to the inherent risks posed by radiation exposure, various regulatory frameworks and protective measures have been established to safeguard public health and minimize occupational hazards. Organizations such as the Nuclear Regulatory Commission (NRC) in the United States and the International Commission on Radiological Protection (ICRP) internationally have developed guidelines and standards for radiation protection, encompassing dose limits, radiation monitoring, and exposure strategies [10]. In India, the Atomic Energy Regulatory Board (AERB) plays a crucial role in regulating and ensuring the safe use of radiation and nuclear energy for peaceful purposes.

Environmental and Public Health Concerns: Environmental contamination and public health risks restricting from nuclear accidents, radioactive waste disposal, and industrial releases of radioactive materials remain pressing concerns in the 21st century. Events such as the Chernobyl disaster in 1986 and the Fukushima Daiichi accident in 2011 have underscored the far-reaching consequences of radiation emergencies, including displacement of populations, long-term health effects, and

socio-economic disruptions [11,12]. In India, environmental monitoring and remediation efforts are undertaken by organizations such as the Department of Atomic Energy (DAE) and the National Disaster Management Authority (NDMA) to mitigate the impacts of radiation incidents and safeguard public health.

Impact of Nuclear Power Stations on Health and Illness: Nuclear power stations play a crucial role in electricity generation, providing a significant portion of the world's energy supply. However, concerns persist regarding the potential health impacts associated with routine operations, accidents, and radioactive waste management. While nuclear power generation is considered a low-carbon energy source, the potential risks to public health from radiation exposure cannot be overlooked [11]. Chronic exposure to low levels of radiation from nuclear facilities has been associated with an increased risk of certain cancers, including leukemia, thyroid cancer, and childhood cancers [13]. Additionally, accidents such as the Chernobyl and Fukushima disasters have led to acute radiation injuries, including acute radiation syndrome (ARS) and increased rates of thyroid cancer among affected populations [14].

Furthermore, the psychological and socio-economic impacts of nuclear accidents on affected communities can be profound, leading to increased anxiety, stress, and economic hardships [15]. Efforts to address these challenges require comprehensive risk communication, community engagement, and long-term support for affected individuals and populations.

Epidemiological Studies: Epidemiological studies play a pivotal role in elucidating the relationship between radiation exposure and human health outcomes. Cohort studies of atomic bomb survivors, populations living near nuclear facilities, and occupationally exposed groups have provided valuable insights into the risks of cancer and other diseases associated with radiation exposure [16]. In India, studies such as those conducted by the Bhabha Atomic Research Centre (BARC) and the Tata Memorial Centre have contributed to our understanding of radiation-related health effects and risk factors in the Indian context [17].

Risk Assessment and Management: Effective risk assessment and management strategies are essential for minimizing the potential harms of radiation exposure while optimizing its beneficial applications. Quantitative risk models, such as the excess relative risk model and the lifetime attributable risk model, enable the estimation of cancer risks attributable to radiation exposure at various dose levels [17]. By integrating dose-response relationships, exposure pathways, and population characteristics, risk assessments inform decisions regarding radiation safety standards, environmental remediation efforts, and emergency preparedness measures.

Radiation in Medicine: Radiation plays a major role in modern medicine, serving as a powerful tool for diagnosis, treatment, and research. Diagnostic imaging modalities such as X-rays, Computed Tomography (CT), and nuclear medicine techniques enable the visualization of internal anatomical structures and the detection of pathological abnormalities with high sensitivity and specificity [10].

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Emerging Issues and Future Directions: As scientific knowledge and technological capabilities continue to advance, new challenges and opportunities in radiation research and management are on the horizon. Emerging fields such as radiogenomics, radiation hormesis, and nanotechnology offer novel insights into the biological effects of radiation and the development of targeted interventions [18,19]. Integrating multidisciplinary approaches, harnessing big data analytics, and fostering international collaboration are critical for addressing these complex issues and shaping a sustainable future for radiation science and public health.

Conclusion

In conclusion, radiation exerts diverse and profound impacts on human health, encompassing acute effects, such as radiation sickness, and long-term consequences, including cancer induction and genetic mutations. Understanding the biological mechanisms, health effects, and risk management strategies associated with radiation exposure is essential for safeguarding public health, promoting responsible use of radiation technologies, and addressing emerging challenges in the 21st century. Implementing appropriate safety measures, individuals and communities can reduce the risks associated with radiation exposure and protect human health.

Conflict of interest: Nil.

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