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The Adverse Effects of Radiation on the Human Body: A Comprehensive Review

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Abstract
Radiation exposure, from both natural and man-made sources, is an ongoing concern due to its potential adverse effects on human health. Ionizing radiation, which can cause damage at the cellular and molecular levels, is linked to a variety of health conditions, including cancer, genetic mutations, cardiovascular disease, and acute radiation syndrome (ARS). This paper explores the sources of radiation—natural (cosmic radiation, radon, and terrestrial sources) and man-made (medical imaging, nuclear accidents, and occupational exposure)—and their respective impacts on the human body. A review of literature and recent studies sheds light on the mechanisms behind radiation damage and the long-term health risks. Understanding these risks is crucial in mitigating the harmful effects of radiation while benefiting from its uses in medicine, energy, and industry.

Keywords: Radiation, Sievert, Segmental Bronchi

Introduction

Radiation refers to the emission or transmission of energy in the form of waves or particles. It can be classified into two main categories: ionizing and non-ionizing radiation. Ionizing radiation carries enough energy to remove tightly bound electrons from atoms, creating ions, while non-ionizing radiation does not have sufficient energy to ionize atoms but can excite them, leading to various molecular and cellular effects.

Ionizing radiation includes X-rays, gamma rays, alpha particles, beta particles, and neutrons, and is most commonly associated with medical imaging, nuclear power generation, and certain industrial applications. Non-ionizing radiation includes visible light, ultraviolet (UV) radiation, radio waves, microwaves, and electromagnetic fields (EMFs), which are emitted by electrical devices, power lines, and wireless communication technologies.

While radiation has numerous practical uses, overexposure to certain types of radiation can lead to severe biological damage, with effects that may range from acute radiation sickness to long-term genetic mutations and cancers. Understanding the mechanisms by which radiation affects human health is essential for mitigating risks associated with exposure.

Types of Radiation and Mechanisms of Interaction with the Human Body

Ionizing Radiation

Ionizing radiation possesses enough energy to dislodge electrons from atoms or molecules, leading to the creation of charged particles (ions). These particles can cause direct or indirect damage to DNA, proteins, and other critical cellular components. There are three primary types of ionizing radiation:

1. **Alpha particles (α):** Consist of two protons and two neutrons, alpha particles are relatively large and carry a positive charge. Although alpha particles have low penetration power (they can be stopped by a sheet of

paper or human skin), they are highly damaging when inhaled or ingested, as they release a significant amount of energy in a localized area.

2. **Beta particles (β):** These are high-energy, high-speed electrons or positrons emitted during radioactive decay. Beta particles have greater penetration power than alpha particles but can typically be stopped by materials like plastic or glass. Beta radiation can cause damage to living tissues through ionization of cellular structures, leading to mutations or cell death.
3. **Gamma rays (γ) and X-rays**: Both gamma rays and X-rays are forms of electromagnetic radiation with very high energy and the ability to penetrate through the human body. While they are less damaging per interaction compared to alpha or beta particles, their ability to travel deep into tissues means they can affect a large volume of cells, potentially causing DNA damage or mutations. Gamma rays and X-rays are commonly used in medical imaging and cancer therapy but can also contribute to the development of cancer when exposure is excessive.
4. **Neutron radiation**: Neutron radiation, often produced in nuclear reactors, is less common but highly penetrative. Neutrons can interact with atomic nuclei and release secondary radiation, which can further damage biological tissue.

Mechanisms of Biological Damage

Ionizing radiation primarily causes biological damage by generating reactive oxygen species (ROS) within cells, which can lead to oxidative stress. These ROS can cause single or double-strand breaks in DNA, and if the damage is not properly repaired, it may result in mutations or chromosomal aberrations. If the DNA damage is severe, it can lead to cell death or cancer formation. The stochastic nature of radiation means that damage does not have a predictable outcome, and even low doses of ionizing radiation can increase the likelihood of cancer or genetic damage.

Non-Ionizing Radiation

Non-ionizing radiation, while not capable of causing direct ionization, can still have biological effects, especially with prolonged or intense exposure. Some common sources of non-ionizing radiation include:

1. **Ultraviolet (UV) Radiation**: UV radiation is emitted by the sun and artificial sources like tanning beds. It is categorized into three types: UVA, UVB, and UVC. UVB radiation is most responsible for sunburn and skin cancer, as it can cause direct DNA damage, while UVA is associated with aging of the skin and deeper tissue damage.
2. **Electromagnetic Fields (EMFs):** These fields are produced by electrical devices, power lines, and wireless communication technologies (e.g., smartphones, Wi-Fi). Though the scientific community has not reached a consensus on the health risks of EMFs, prolonged exposure has been investigated for potential links to conditions like leukemia, brain cancer, and electromagnetic hypersensitivity, although the evidence remains inconclusive.
3. **Microwaves and Radiofrequency Radiation**: Microwaves are used in communication technologies and household appliances. Although non-ionizing, they can cause heating effects in tissues, which can lead to thermal burns and damage to sensitive biological systems at high intensities.

Sources of Radiation

Natural Radiation

1. **Cosmic Radiation**: Cosmic radiation originates from the Sun and outer space. It constantly bombards the Earth, and its intensity is influenced by factors such as geographic location and altitude. At higher altitudes and latitudes, cosmic radiation levels tend to be more significant, which is why airline crew members and astronauts are subject to higher doses of radiation. Despite its omnipresence, cosmic radiation is usually at low levels and does not pose a significant health threat under normal circumstances. However, prolonged exposure at high altitudes, especially for those in aviation or space exploration, may lead to increased risks.
2. **Terrestrial Radiation:** The Earth's crust contains trace amounts of radioactive elements, including uranium, thorium, and radium, which emit radiation. This radiation, primarily in the form of gamma rays, is a natural source of ionizing radiation. People living in areas with high concentrations of radioactive minerals are more likely to experience increased exposure. For example, granite formations can contribute

higher levels of radiation, although the risks are generally low unless people are exposed over extended periods.

3. **Radon Gas**: Radon, a colorless, odorless gas produced by the decay of uranium in the Earth's soil, is a significant source of natural radiation. Radon seeps into buildings, especially in poorly ventilated areas like basements. Prolonged exposure to elevated radon levels has been linked to an increased risk of lung cancer, particularly in individuals who smoke. According to the Environmental Protection Agency (EPA), radon is the second leading cause of lung cancer in the United States, after smoking.

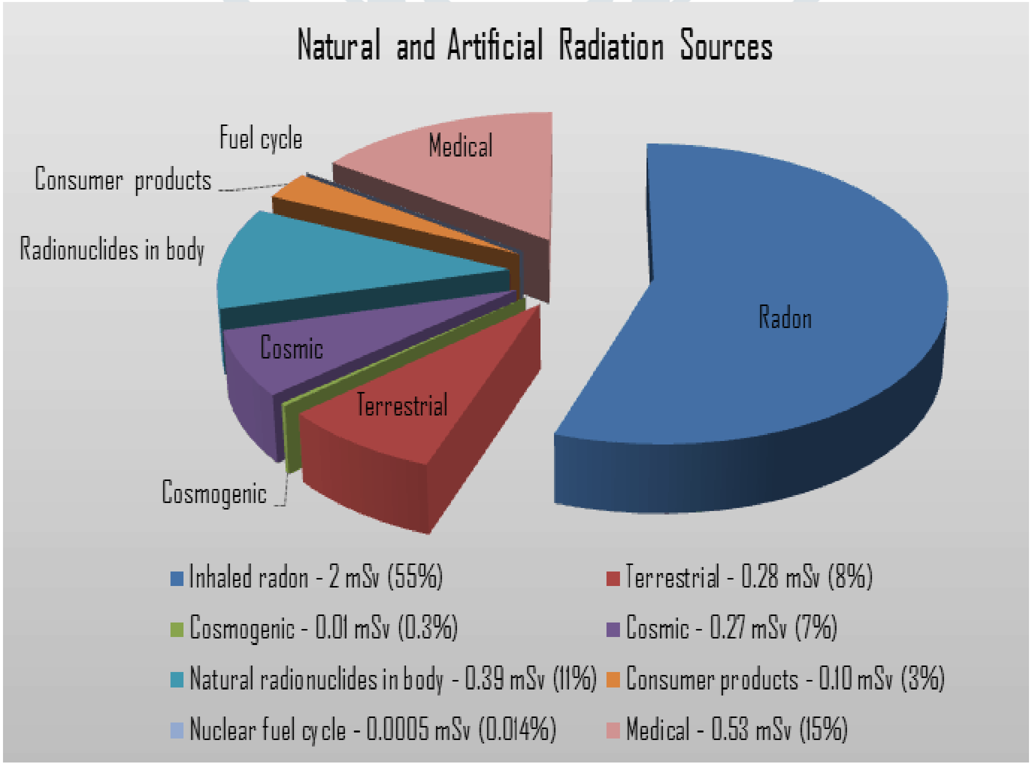
Man-Made Radiation

Medical Radiation, One of the most common sources of radiation exposure in modern life is medical imaging. Procedures like X-rays, computed tomography (CT) scans, and fluoroscopy involve ionizing radiation to produce images of the inside of the body. While these diagnostic tools are invaluable in detecting and treating medical conditions, the increasing use of such technologies raises concerns about the cumulative radiation dose individuals receive over their lifetimes. Studies have shown that medical radiation is now a significant source of ionizing radiation exposure in the general population (Brenner & Hall, 2007).

Radiation therapy for cancer treatment is another major source of medical radiation. Although it is used to target cancerous cells and tumors, healthy tissues in the path of radiation can also be damaged, leading to side effects and increasing the risk of secondary cancers in the future.

Occupational Exposure Certain professions involve higher levels of radiation exposure, such as those working in nuclear power plants, medical imaging, and research involving radioactive materials. Workers in these fields are at an elevated risk of developing radiation-induced health issues, including cancer and other diseases. Stringent regulations are in place to limit exposure, but workers in certain high-risk occupations still face greater radiation exposure than the general public.

Nuclear Accidents and Weapons Testing, The detonation of nuclear weapons and accidents at nuclear power plants have led to widespread radioactive contamination and increased radiation exposure for the affected populations. The Chernobyl disaster (1986) and the Fukushima Daiichi nuclear accident (2011) are two of the most significant events that have raised concerns about the environmental and human health consequences of nuclear accidents. The radioactive fallout from these incidents has caused long-term health effects, including a rise in thyroid cancer and other cancers among survivors (Cardis et al., 2006; Yablokov et al., 2009).



Adverse Health Effects of Radiation Exposure

Acute Effects

High doses of ionizing radiation can cause immediate and severe health effects. This is referred to as acute radiation syndrome (ARS), which occurs when the body absorbs a significant dose of radiation over a short period of time. Symptoms of ARS include:

- Nausea and vomiting
- Fatigue and weakness
- Skin burns and hair loss
- Bone marrow suppression, leading to a reduced ability to produce blood cells
- Organ failure in severe cases

The severity of symptoms depends on the dose and the duration of exposure. At doses greater than 1,000 millisieverts (mSv), the likelihood of death increases significantly if medical intervention is not provided.

Long-Term Effects

Cancer

Ionizing radiation is a well-established carcinogen. Studies have shown that exposure to high levels of radiation increases the risk of various types of cancer, including leukemia, thyroid cancer, and solid tumors of the lungs, breast, and colon. The risk of cancer is thought to be related to both the dose of radiation and the age at which exposure occurs, with children being particularly sensitive to radiation-induced cancer.

Genetic Mutations

Radiation can induce genetic mutations that are passed down to future generations. These mutations can affect both somatic cells (leading to cancer and other diseases) and germ cells (affecting offspring). The potential for radiation to cause genetic mutations is one of the key concerns in nuclear accidents, such as the Chernobyl disaster, where individuals exposed to high doses of radiation exhibited increased rates of genetic abnormalities.

Cataracts

Exposure to ionizing radiation, particularly from medical imaging, has been linked to the development of cataracts. Cataracts are a condition in which the lens of the eye becomes opaque, leading to impaired vision. While cataracts can develop naturally with age, radiation exposure can accelerate this process.

Non-Ionizing Radiation and Health Effects

While the evidence is less definitive, some research has suggested that long-term exposure to non-ionizing radiation, especially from sources like UV radiation and EMFs, may lead to a variety of health problems:

1. **UV Radiation**: Overexposure to UV radiation can lead to skin damage, premature aging, and an increased risk of skin cancer, including melanoma, squamous cell carcinoma, and basal cell carcinoma. UV radiation is also known to suppress the immune system, potentially affecting the body's ability to fight off infections and tumors.
2. **Electromagnetic Fields (EMFs):** Though studies on EMF exposure and health outcomes are still ongoing, concerns have been raised about the potential link between prolonged EMF exposure and an increased risk of cancer, particularly brain tumors. The International Agency for Research on Cancer (IARC) has classified certain types of EMFs (like those from mobile phones) as possibly carcinogenic to humans, but more research is needed to confirm these findings.

Understanding Radiation Dosage

The health effects of radiation exposure are strongly influenced by the dose received by the body. Radiation dose is a measure of the amount of energy deposited by ionizing radiation in a given mass of tissue and is typically expressed in sieverts (Sv) or millisieverts (mSv). The dosage determines the extent of biological damage and the severity of potential health outcomes. The relationship between radiation dose and its effects on health is non-linear, with higher doses correlating with more severe consequences.

Key Units of Radiation Dose:

1. **Gray (Gy):** The gray measures the energy absorbed by tissues. One gray equals one joule of energy absorbed per kilogram of tissue. This unit is used for measuring the physical dose.

2. **Sievert (Sv):** The sievert accounts for the biological effects of ionizing radiation, incorporating the type of radiation and the sensitivity of different tissues. The sievert is the unit used to measure the potential for health effects, including cancer.

Types of Radiation Dosage and Their Biological Impact

Low to Moderate Radiation Doses

1. **Background radiation:** Humans are exposed to low levels of radiation from natural sources like cosmic rays, soil, and radon gas, which typically results in annual doses of around 2-3 mSv. This amount is generally considered safe, and the risk of cancer from such low exposures is minimal.
2. **Medical radiation exposure:** Medical procedures such as X-rays, CT scans, and nuclear medicine can result in higher doses of radiation. For example, a single chest X-ray delivers a dose of about 0.1 mSv, while a full-body CT scan can deliver up to 10 mSv. Though these doses are considered safe for occasional use, repeated or unnecessary exposure increases the risk of radiation-induced health issues, including cancer.

High Radiation Doses and Acute Effects

1. **Acute radiation syndrome (ARS):** Exposure to doses greater than 1,000 mSv (1 Sv) over a short period can cause ARS, which manifests with symptoms such as nausea, vomiting, hair loss, and immune system suppression. Doses above 3 Sv are life-threatening and may lead to severe organ damage and death if not treated promptly.
2. **High-level occupational or accidental exposure:** Workers in nuclear facilities, radiology departments, or certain industrial sectors may be at risk of high radiation doses. Accidents, such as the 1986 Chernobyl disaster, resulted in doses up to 100,000 mSv for those closest to the explosion, leading to severe illness and death. These high doses are linked to extensive tissue damage, burns, and a significantly increased risk of cancer.

Natural Background Radiation of Earth and Radiation Dosage Received by an Average Human

We are constantly exposed to ionizing radiation, the soil, air, rocks and even from space. One hour of natural background radiation on earth is 0.1 - 0.2 mSv. On average, our radiation exposure due to all natural sources amounts to about 2.4 mSv a year-though this may vary, depending on the geographical location by a several hundred percent.

Main causes of exposure to natural ionizing radiation are inhalation and indigestion:

1. **Inhalation:** On average, a person in the United States inhales enough radioactive materials to cause a radiation dose of 2.28 mSv (228 mrem) per year. About 73% of a person's yearly exposure to natural sources of radioactive material comes from inhalation. This is mostly in the form of radon, which is the largest source of natural radiation exposure. This yearly amount of radiation is similar to the amount of radiation from twenty chest x-rays.
2. **Ingestion:** The overall levels of ingested radioactive materials are low for most people. On average, a person in the United States ingested enough natural sources of radiation to cause a small dose of about 0.29 mSv (29 mrem) per year. About 9% of a person's yearly exposure to natural sources of radioactive material comes from ingestion. This yearly amount of radiation is similar to the amount of radiation from two chest x-rays.

The overall levels of terrestrial external radiation we are exposed to are low. The average annual dose due to terrestrial external radiation exposure is 0.21 mSv (21 mrem) or 7% of a person's yearly exposure due to all natural sources. This yearly amount of radiation is similar to the amount of radiation from two chest x-rays (www.cdc.gov).

The table below depicts average annual dose of radiation received by an average American:

Source	Average Annual Dose	%Average Annual Dose
Internal (by inhalation)	2.28mSv (228mrem)	73%
External (from cosmic exposure)	0.33mSv (33mrem)	11%
Internal (from ingestion)	0.29mSv (29mrem)	9%
External (from Terrestrial exposure)	0.21mSv (21mrem)	7%

Geographical Effects on Annual Radiation Exposure

The total worldwide average effective dose from natural radiation is approximately 2.4 mSv per year; in Canada, it is 1.8 mSv. In some parts of the world, it is naturally much higher – for instance on the Kerala Coast in India, the annual effective dose is 12.5 mSv. The dose varies with the source of the radiation. For example, in northern Iran, geological characteristics result in a dose that can reach 260 mSv a year.

Regions at higher altitudes receive more cosmic radiation. According to a recent study by Health Canada, the annual effective dose of radiation from cosmic rays in Vancouver, British Columbia, which is at sea level, is about 0.30 mSv. This compares to the top of Mount Lorne, Yukon, where at 2,000 m, a person would receive a dose of about 0.84 mSv annually. Flying in an airplane increases exposure to cosmic radiation, resulting in a further average dose of 0.01 mSv per person per year.

The table below shows average annual dose receives by people in different countries:

(For reference, the annual average dose globally is 2.4mSv)

Name of the Country	*Average Annual Radiation Dose*
India	2.3 mSv
United States of America	6.2 mSv
China	2.3 mSv
Japan	4.7 mSv
United Kingdom	2.7 mSv
Germany	2.1 mSv
South Korea	1.83 mSv

Occupational Radiation Exposure

To Note: The International Commission on Radiological Protection (ICRP) recommends limits on occupational radiation exposure: 20 mSv per year effective dose averaged over defined 5-year periods, not exceeding 50 mSv in a single year.

Radiation and Smoking

Contrary to popular opinion, Astronauts are not the ones exposed to most radiation-though they are the profession most exposed to radiation due to constant cosmic exposure (An Astronaut on the International Space Station (ISS) for six months is exposed to radiation of about 80mSv-smokers are.

Review of literature

Radioactivity in Cigarette Smoke: Winters-TH, Franza-JR.

Prior to 1982, research on the carcinogenic effects of cigarette smoke has primarily focused on the tar component, with only benzopyrene identified as a definite chemical carcinogen. However, little attention has been given to the radioactive elements in smoke. Polonium-210 (Po-210) and lead-210, alpha emitters, are concentrated in tobacco trichomes and particles in cigarette smoke, with Po-210 primarily originating from phosphate fertilizers used in tobacco farming.

Studies have shown that Po-210 accumulates in the bronchial epithelium of both smokers and nonsmokers, with the highest concentration found at the bifurcation of segmental bronchi, a common site for bronchogenic cancers. A person smoking 1 ½ packs daily absorbs a radiation dose equivalent to 300 chest x-rays per year. Despite the small range of alpha particles (only about 40 microns), their high energy can deliver significant doses to cells, potentially contributing to cancer through multiple mutations.

Radford and Hunt found that 75% of the alpha activity from cigarette smoke is released into the air, affecting nonsmokers as well. This highlights the underappreciated danger of alpha radiation in cigarette smoke as a possible factor in tobacco-related cancers, suggesting that further research into its role is crucial.

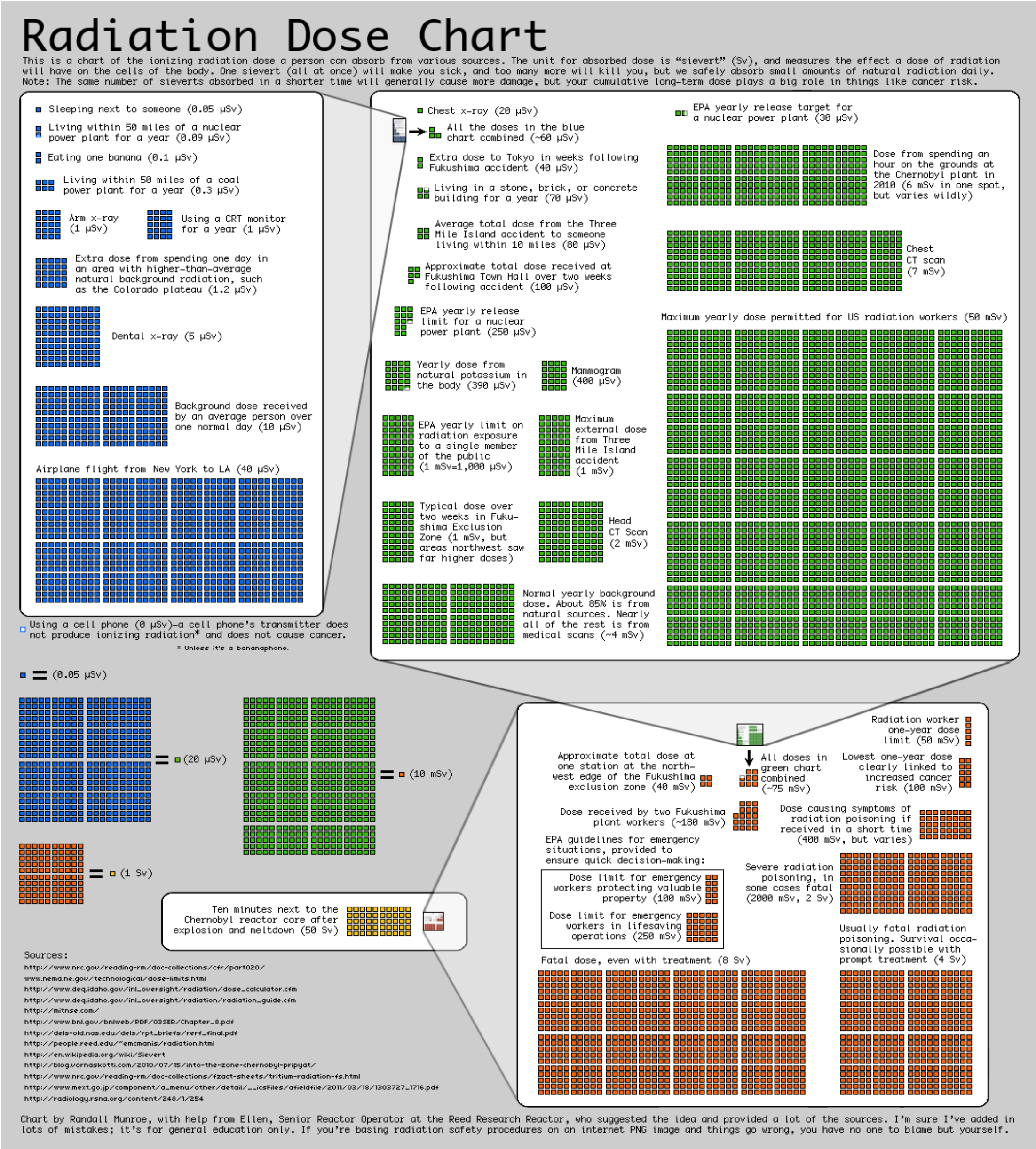
CHEMICAL AND RADIOACTIVE CARCINOGENS IN CIGARETTES: ASSOCIATED HEALTH IMPACTS AND RESPONSES OF THE TOBACCO INDUSTRY, U.S. CONGRESS, AND FEDERAL REGULATORY AGENCIES: Dade W Moeller

Previously, scientists at Harvard University's School of Public Health, collaborating with physicians from nearby teaching hospitals, conducted groundbreaking research on the role of polonium-210 (210Po) in lung cancer. By analyzing lung samples from smokers who had died from lung cancer, they found high concentrations of 210Po, a radioactive substance considered by the International Commission on Radiological Protection to be more hazardous than plutonium-239. The radioactive material was concentrated at the bifurcations of segmental bronchi, the same areas where lung cancer typically develops in smokers.

Further studies aimed at identifying the source of 210Po revealed that it was not absorbed by tobacco from the soil but was instead deposited on tobacco leaves from the air. This occurred due to the decay of radium in the soil, which releases radon and its decay products into the surrounding atmosphere. These products, being electrically charged, easily adhere to surfaces like tobacco leaves. When a smoker lights a cigarette, the 210Po is volatilized and inhaled, depositing in the lungs.

Estimations suggested that the radiation dose to these "hot spots" in the lungs could be as high as 160 millisieverts (16,000 millirem) annually, far exceeding the annual radiation dose limit for the general public. However, while acknowledging the high dose, Harvard scientists were cautious in attributing lung cancer solely to 210Po, recognizing the multitude of carcinogens in cigarette smoke. They concluded that 210Po might play a role in initiating bronchial carcinoma.

The below attached chart will help us in better understanding and picturing about different radiation doses and severity of radiation poisoning and also the need to promote awareness about education in regards to radiation:



Conclusion

The adverse effects of radiation on the human body are complex and wide-ranging, spanning from immediate symptoms like acute radiation sickness to long-term health risks, including cancer, genetic mutations, and cataracts. Both natural sources of radiation—such as cosmic rays, radon, and terrestrial radiation—and man-made sources, like medical imaging, occupational exposure, and nuclear accidents, contribute to overall radiation exposure. While natural radiation is an unavoidable part of life, human activities and technological advancements have introduced higher levels of exposure, raising concerns about cumulative health risks.

The severity of radiation's impact depends on factors such as the type, dose, and duration of exposure, as well as individual susceptibility. Medical radiation, while invaluable for diagnostics and treatment, underscores the need for careful management to avoid unnecessary or excessive exposure. Additionally, emerging sources of radiation, such as the radioactive elements in cigarette smoke, further complicate our understanding of the health risks posed by radiation in daily life.

Ultimately, reducing the adverse effects of radiation requires a multifaceted approach: continued research, improved safety protocols, and public awareness initiatives. As radiation remains integral to many aspects of modern life, ensuring its safe use is critical for protecting public health while maximizing its benefits in medicine, industry, and beyond. Through education, regulation, and innovation, we can mitigate the risks associated with radiation and safeguard human health for future generations.

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