HOW DANGEROUS ARE LOW DOSES OF RADIATION

[redacted]

CONTENT

ABSTRACT

The biological effects on humans of low-dose and low-dose-rate exposures to ionizing radiation have always been of major interest. There are a lot of committee, standards and regulations that have been designed to to extrapolate existing epidemiological data at high doses and dose rates down to low doses and low dose rates relevant to radiological protection. This research describes the historical development in light of emerging scientific evidence on dose and dose-rate effects and summarizes the conclusions recently drawn by a number of international organizations e.g. ICRU, ICRP, IAEA, UNSCEAR, and WHO. Mentions current scientific efforts to obtain more data on low-dose and low-dose-rate effects at molecular, cellular, animal and human levels, and discusses future options that could be useful to improve and optimize the purpose of radiological protection.

INTRODUCTION

(1) (source 1)

The biological effects of low levels of radiation have been investigated and debated for more than a century. Today, we know more about the sources and effects of exposure to ionizing radiation than to almost any other hazardous agent, and the scientific community is constantly updating and analysing its knowledge.

(2) (source 2)

The sources of radiation causing the greatest exposure of the general public are not necessarily those that attract the most attention. the greatest exposure is caused by natural sources ever present in the environment, and the major contributor to exposure from artificial sources is the use of radiation in medicine worldwide. The health effects of low levels of ionizing radiation are important to understand but there are a lot of challenges into the research of the dangers of low dose radiations. Despite these challenges, a great deal about this topic is well understood.

(3) (source 3)

Specifically, substantial evidence exists that exposure to high levels of ionizing radiation and long term exposure to low dose radiations can cause illness or death. Further, scientists have long known that in addition to cancer, ionizing radiation at low doses over a certain threshold causes mental retardation in the children of mothers exposed to radiation during pregnancy. Recently, data from atomic bomb survivors suggest that low doses are also connected to other health effects such as heart disease and stroke.

Because ionizing radiation is a threat to health, it has been studied extensively. This report will bring to light the differences between high and low dose radiation, also the dangers of low dose radiation to human life and if they should really be a cause to fear or panic since it has always been amongst us through nature, technology and medicine.

RADIATIONS

The word radiation arises from the phenomenon of waves radiation (i.e. travelling outward in all directions) from a source in order words is the emission or transmissions. Radiation is often categorized as either ionizing or non-ionizing depending on the energy of the radiated particles. This is an important distinction due to the large difference in harmfulness to living organisms. A common source of ionizing radiation is radioactive materials that emit alpha, beta, gamma radiation and x-rays.

Gamma radiations is the most penetrating. Even small levels can penetrate air, paper or thin metal. Higher levels can only be stopped by many centimetres of lead, or many metres of concrete. They are able to ionize other atoms (ionizing radiation), and are thus biologically hazardous. Gamma rays typically have frequencies above 10 hertz (or $>10^{19}$ Hz), and therefore have energies above 100 keV and wavelengths less than 10 Pico meters (10^{-11} m), which is less than the diameter of an atom.

Alpha radiation is the least penetrating. It can be stopped or absorbed by a sheet of paper. Due to the mechanism of their production in standard alpha radioactive decay, alpha particles generally have a kinetic energy of about 5 MeV, and a velocity in the vicinity of 5% the speed of light. They are a highly ionizing form of particle radiation, and have low penetration depth. They are able to be stopped by a few centimetres of air, or by the skin. When alpha particle emitting isotopes are ingested, they are far more dangerous than their half-life or decay rate would suggest, due to the high relative biological effectiveness of alpha radiation to cause biological damage.

Beta radiation can penetrate air and paper. It can be stopped by a thin sheet of aluminium. Of the three common types of radiation given off by radioactive materials, alpha, beta and gamma, beta has the medium penetrating power and the medium ionising power. Beta particles can be used to treat health conditions such as eye and bone cancer and are also used as tracers. Strontium-90 is the material most commonly used to produce beta particles.

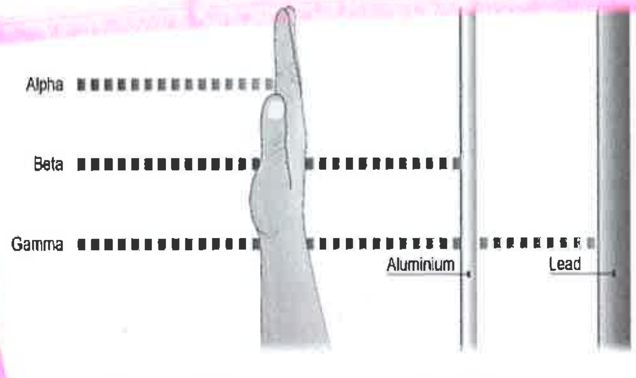

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Figure: Different in ranges and radiation particles

X-radiation (X-rays) is a form of electromagnetic radiation. Most X-rays have a wavelength ranging from 0.01 to 10 nanometres, corresponding to frequencies in the range 30 petahertz to 30 exahertz (3×10^{16} Hz to 3×10^{19}Hz) and energies in the range 100 eV to 100 keV. X-ray wavelengths are shorter than those of UV rays and typically longer than those of gamma rays. X-rays with high photon energies (above 5–10 keV, below 0.2–0.1 nm wavelength) are called hard X-rays, while those with lower energy are called soft X-rays. Due to their penetrating ability, hard X-rays are widely used to image the inside of objects, e.g., in medical radiography and airport security.

Since the wavelengths of hard X-rays are similar to the size of atoms they are also useful for determining crystal structures by X-ray crystallography. By contrast, soft X-rays are easily absorbed in air; the attenuation length of 600 eV (~2 nm) X-rays in water is less than 1 micrometre.

X-rays interact with matter in three main ways, through photo absorption, Compton scattering, and Rayleigh scattering. The strength of these interactions depends on the energy of the X-rays and the elemental composition of the material, but not much on chemical properties, since the X-ray photon energy is much higher than chemical binding energies. Photo absorption or photoelectric absorption is the dominant interaction mechanism in the soft X-ray regime and for the lower hard X-ray energies. At higher energies, Compton scattering dominates. Rayleigh scattering is the dominant elastic scattering mechanism in the X-ray regime. Inelastic forward scattering gives rise to the refractive index, which for X-rays is only slightly below

Though there are so many other forms of radiations such as Cosmic, Radio waves, Electromagnetic waves, Ultraviolet light and Microwaves. I choose to discuss the above into details because they form the basis of my research.

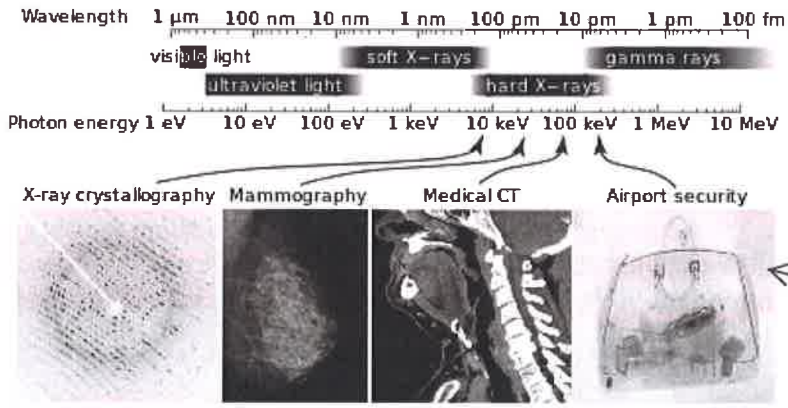

figure: Various forms of X-rays and its ranges

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source 9 (14)

RADIATION DOSE

Radiation dose is the total amount of ionizing radiation absorbed by a material or tissue and can be expressed as absorbed dose, equivalent dose, effective dose and dose rate. It is measure in Milligrays (mGy), Millisiviert (mSv) and is dependent on intensity and length of exposure.

Absorbed Dose (D) is a physical dose quantity representing the mean energy imparted to matter per unit mass by ionizing radiation. The unit of measure is joules per kilogram, and its special name is Milligrays (Gy). It also describes the intensity of the energy deposited in any small amount of tissue located anywhere in the body. Absorbed dose is used in the calculation of dose uptake in living tissue in both radiation protection and radiology. It is also used to directly compare the effect of radiation on inanimate matter. It is fundamentally important in radiological protection for calculating radiation dose. However, absorbed dose is a physical quantity and used unmodified is not an adequate indicator of the likely health effects in humans.

Equivalent dose (H_T) is a measure of the radiation dose to tissue where an attempt has been made to allow for the different relative biological effects of different types of ionizing radiation. The SI unit of measure for equivalent dose is the Sievert, defined as one Joule per kg. In quantitative terms, equivalent dose is less fundamental than absorbed dose, but it is more biologically significant.

Effective dose is a biological dose commonly used in radiological protection, as it determines how dangerous an individual's exposure to radiations can be. It takes into consideration not only the nature of the incoming radiation but also the sensitivities of the body parts affected. It's unit is the Sievert, the same unit as is used for the equivalent dose absorbed locally by an organ, a gland or any other part of the body. (17) (source 12)

Dose rate is the dose absorbed in unit time and indicates the amount of radioactive dose received by a person within a certain period of time. The dose rate is often given in thousandths of Sieverts per hour. (18) (source 13)

HIGH DOSE RADIATION

High radiation doses particularly over a short period of time have a tendency to kill cells. In fact, high doses can irreparably damage or even eliminate so many cells that tissues and organs end up dead immediately. (19) (source 14) This may causes a rapid whole-body response, which is called "acute radiation syndrome" and is grouped into three hematopoietic, gastrointestinal, and neurological or vascular. Exposures from high dose radiation are large and effects are rapid and long term generally the higher the radiation dose, the sooner the effects will appear, and the probability of death is directly proportional to the amount of radiation dose. Information and data collected from past disasters like the Chernobyl disaster and Hiroshima and Nagasaki atomic bomb attacks help us understand more on high dose radiation example such as the time between radiation exposure and cancer occurrence known as the latent period. This syndrome was observed in many atomic bomb survivors in 1945, as well as emergency workers who responded to the Chernobyl nuclear power plant accident in 1986. Approximately 134 plant workers and firefighters battling the fire at the Chernobyl power plant received high radiation doses of 70,000 to 1,340,000 rem (700 to 13,400 mSv) and suffered acute radiation sickness. Of those 134,28 died from the radiation injuries that they sustained.

LOW DOSE RADIATION

Exposures to low doses of radiation over a period of time and intensity. There is a degree of recovery of tissue and cells. We are exposed to low-dose radiation every day through common activities, due to natural background radiation exposures. The exposure can range from a few mGy to as high as 260 mGy, depending on geographic location. the effects of low-level radiation are very difficult to observe and highly controversial. This is because the baseline cancer rate is already very high and the risk of developing cancer fluctuates 40% because of individual life style and environmental effects. Most of the information on low dose radiation risks comes from the Japanese atomic bomb survivors, medically exposed populations, occupationally exposed groups, and environmentally exposed groups. (20) (source 15) There have been a number of studies of occupationally exposed persons, who generally receive low doses and low dose rates of ionizing radiation. In all of these worker studies, it is important to recognize that individual doses were accumulated in daily increments over a protracted period of many years. (21) (source 16)

The possibility that low doses of radiation may have beneficial effects, a phenomenon often referred to as Hormesis has been the subject of considerable debate. (22) (source 17) low doses of radiation have only marginal impacts on individual health outcomes. It is therefore difficult to detect the signal of decreased or increased morbidity and mortality due to low-level radiation exposure in the 'noise' of other effects. (23) (source 17)

SOURCES OF LOW DOSE RADIATIONS

(24) (source 18) (25) (source 18) (26) (source 18) (27) (source 18)

The earth's outer atmosphere is continually bombarded by cosmic radiation. Usually, cosmic radiation consists of fast moving particles that exist in space and originate from a variety of sources, including the sun and other celestial events in the universe. Cosmic rays are mostly protons but can be other particles or wave energy. Some ionizing radiation will penetrate the earth's atmosphere and become absorbed by humans, which results in natural radiation exposure. Most of the exposure to natural radiation results from inhalation of radioactive gases that are produced by radioactive minerals found in soil and bedrock. Radon is an odourless and colourless radioactive gas that is produced by the decay of uranium. Once released into the air, these gases will normally dilute to harmless levels in the atmosphere but sometimes they become trapped and accumulate inside buildings and are inhaled by occupants. Trace amounts of radioactive minerals are naturally found in the contents of food and drinking water. For instance, vegetables are typically cultivated in soil and ground water which contains radioactive minerals. Once ingested, these minerals result in internal exposure to natural radiation. Radiation has many uses in medicine and we come into contact with the most well-known are X-ray machines, which use radiation to find broken bones and diagnose disease. X-rays from our airport scanners and other technologies like smoke detectors and exit signs all emit radiations that expose us to low doses of radiations.

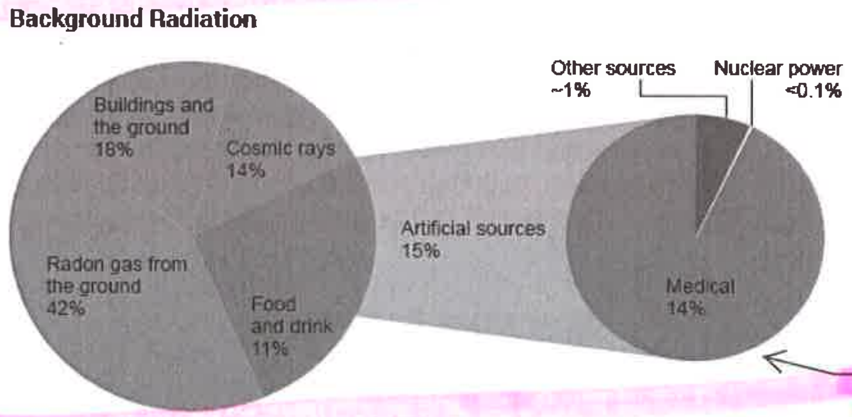

Figure: Sources of radiation sources

Figure not referenced

(28) (Source 19)

Source	Annual Dose (Bq)
1 adult human	7.00E+03
1 kg of coffee	1.00E+03
1 kg of brazil nuts	5.18E+26
1 L of beer	1.44E+25
1 L of milk	5.18E+25
1 household smoke detector	3.00E+04
Radioisotope for medical diagnosis	7.00E+07
Radioisotope source for medical therapy	1.00E+14
1 kg of bananas	1.11E+26
1 luminous Exit sign (1970s)	1.00E+12
1 kg uranium	2.50E+07
1 L tap water	7.40E+23
1 kg low level radioactive waste	1.00E+06
1 kg of coal ash	2.00E+03
1 kg of granite	1.00E+03

Figure: Low radiation dose sources

Data not referenced

(29) (source 20) slightly altered

BIOLOGICAL EFFECT OF RADIATIONS

Whether the source of radiation is natural or man-made, whether it is a small dose of radiation or a large dose, there will be some biological effects. All biological damage effects begin with the consequence of radiation interactions with the atoms forming the cells. Biological effects are so minute that they are not detected at low levels of exposure. The body is able to repair itself from radiations, chemicals and environmental hazards. Damages to living cells exposed to low doses of radiations can be repaired by themselves leaving no damage, death or replacement just like millions of body cells correctly or incorrectly repair themselves which results in a biophysical change. Low doses spread out over a long period would not cause an immediate problem. The effects of doses less than 10,000 mrem (100 mSv) over many years would occur at the cell level.
There are three main categories of effects resulting from low dose radiation over a period time they are, Genetic where the effect is transferred to the offspring of the individual exposed and cancer would be about five times more likely than a genetic effect. Genetic effects include, congenital abnormalities, decreased birthweight, and infant and childhood mortality. These effects are as a result from mutations in the cells of an exposed person and is passed on to their offspring. These effects may appear directly on offspring if the damaged genes are dominant or appear several generations later if the genes are recessive.
Somatic whereby the effect is primarily suffered by the individual exposed. Since cancer is the primary result, it is sometimes called the Carcinogenic Effect. In-Utero effect where its often mistakenly considered to be a genetic consequence of radiation exposure, because the effect, suffered by a developing embryo/foetus, is seen after birth. However, this is actually a special case of the somatic effect, since the embryo/foetus is the one exposed to the radiation. Thanks to the work of a unique body in the UN system, UNSCEAR, the biological effects of ionizing radiation are better known than those of many other chemical and physical agents affecting human beings and the environment. However, there are still many unanswered questions in radiobiology, in particular in relation to the effects of low radiation doses.

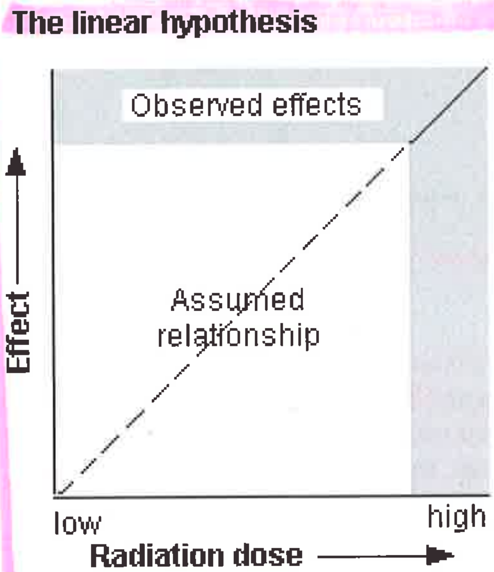

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Figure: Graph of effect of Radiation dose

MECHANISM OF DAMAGE

36 (source 21) Radiation effects on humans proceed from the lowest to the highest levels i.e. atoms, molecules, cells, tissues, organs and whole body. There are two mechanisms by which radiation ultimately affects cells. These two mechanisms are commonly called direct and indirect effects.

37 (source 21) Direct effect involves radiation interacting with the atoms of the DNA molecule, or some other cellular component critical to the survival of the cell. Such an interaction may affect the ability of the cell to reproduce and thus, survive. if there is significant alteration in the information carried by the DNA molecule, then the cell may be destroyed by “direct” interference with its life-sustaining system.

38 (source 21) Not all living cells are equally sensitive to radiation. Those cells which are actively reproducing are more sensitive than those which are not. This is because dividing cells require correct DNA information in order for the cell’s offspring to survive. A direct interaction of radiation with an active cell could result in the death or mutation of the cell, whereas a direct interaction with the DNA of a dormant cell would have less of an effect. Living cells can be classified according to their rate of reproduction, which also indicates their relative sensitivity to radiation. This means that different cell systems have different sensitivities. Lymphocytes (white blood cells) and cells which produce blood are constantly regenerating, and are, therefore, the most sensitive. Reproductive and gastrointestinal cells are not regenerating as quickly and are less sensitive. The nerve and muscle cells are the slowest to regenerate and are the least sensitive cells.

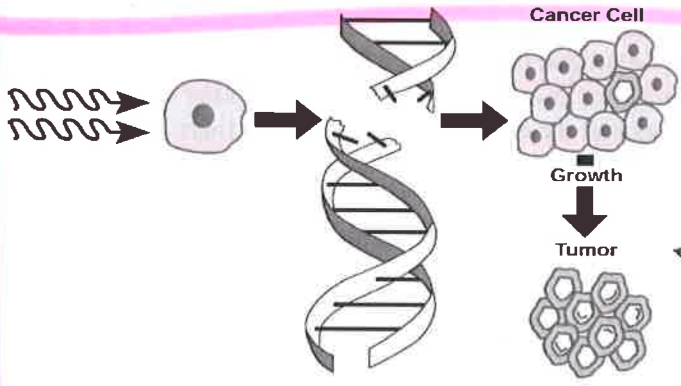

Figure 1. Development of cancer from mutation produced by ionizing radiation.

Figure not referenced

39 (source 25)

CANCER

Cancer is a group of diseases involving abnormal cell growth with the potential to invade or spread to other parts of the body. Signs and symptoms include lumps, abnormal bleeding, prolonged cough, unexplained weight loss and a change in bowel movements. While these symptoms may indicate cancer, they may have other causes. There are a lot of types of cancers that affect humans and even some animals but can all be classified into three main groups by the type of tumor cell they resemble these groups are Carcinoma, Sarcoma, lymphoma and Leukaemia, Germ cell, Blastoma. Up to 10% of invasive cancers are related to radiation exposure, including both ionizing radiation and non-ionizing ultraviolet radiation. Additionally, the majority of non-invasive cancers are non-melanoma skin cancers caused by non-ionizing ultraviolet radiation, mostly from sunlight. 40 (source 26) 41 (source 26) 42 (source 26)

Ionising radiation has enough energy to cause damage to cells which can increase the risk of 43 (source 27)

cancer later in life. However, these risks to health are actually low and ionising radiation is widely used in cancer therapy. In general, the health effects of ionising radiation are dependent on the dose received. While low doses increase the risk of cancer later in life, very high doses act like a poison and can be fatal.
It caused about 8.2 million deaths or 14.6% of human deaths in the year 2012. Some examples of cancers are lung cancer, prostate cancer, colorectal cancer and stomach cancer, breast cancer, colorectal cancer, lung cancer and cervical cancer, acute lymphoblastic leukaemia and brain tumor .

PREVENTION AND TREATMENT

Cancer treatment depends on the type of cancer, the stage of the cancer, age, health status, and additional personal characteristics. There is no single treatment for cancer, and patients often receive a combination of therapies and palliative care. Treatments usually fall into one of the following categories: surgery, radiation, chemotherapy, immunotherapy, hormone therapy, or gene therapy. Prevention of cancer is possible through dietary, medication, vaccination and regular screening.

RADIATION THERAPY

Though radiation is a major cause of cancer is also used in the treatment of cancers. Though this time in a controlled and well managed environment through a process known as radiation therapy. Radiation therapy involves the use of ionizing radiation in an attempt to either cure or improve symptoms. It works by damaging the DNA of cancerous tissue, killing it. To spare normal tissues such as skin or organs, which radiation must pass through to treat the tumor. Shaped radiation beams are aimed from multiple exposure angles to intersect at the tumor, providing a much larger dose there than in the surrounding, healthy tissue. Radiotherapy utilizes high-energy gamma-rays that are emitted from metals such as radium or high-energy x-rays that are created in a special machine. Early radiation treatments caused severe side-effects because the energy beams would damage normal, healthy tissue, but technologies have improved so that beams can be more accurately targeted.

Figure not referenced

Figure: Radiation therapy machine

STANDARDS AND REGULATIONS

Three international organizations recommend radiation protection levels: The International Commission on Radiological Protection **(ICRP),** the International Atomic Energy Agency **(IAEA)** and the International Commission on Radiation Units and Measurements **(ICRU).**

(48) (source 29)

ICRP was formed in 1928. It covers safety for all sources of radiation. Its mission is to deal with the basic principles of radiation protection and to leave to various national protection committees the responsibility of introducing the detailed technical regulations, recommendations or codes of practice best suited to the needs of their individual countries. It is the principal source of recommendations on safe radiation levels.
IAEA was formed in 1956, to promote the peaceful uses of nuclear energy, the IAEA is a specialized agency of the United Nations. The IAEA publishes both standards and recommendations in addition to books on nuclear science and technology written by consultants or groups of experts invited from member states.
The ICRU was Created in 1925, the ICRU develops international recommendations regarding quantities and units of radiation and radioactivity, procedures for their measurement and application in clinical radiology and radiobiology, and physical data needed to ensure uniformity in reporting on their applications.

(49) (source 29)

Two series of reports provide much of the data used in setting radiation standards. The reports are produced by National Academy of Sciences (NAS) and United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).

RESEARCH WORK

(50) (source 30)

Research has shown that a major, and increasing, source of low-dose radiation comes from the medical world, the amount of radiation a person receives in a year on average has doubled, mostly because of medical procedures. Computed-tomography (CT) scans are to blame for most of the rise; a typical abdominal scan delivers more than 10 mSv.

(51) (source 29)

The BEIR VII report, "Health Risks From Exposure to Low Levels of Ionizing Radiation," is the current scientific basis for radiation safety standards in the United States. The 2006 report concluded that scientific studies and radiation data accumulated since publication of the BEIR V report support previous estimates of health risks associated with low doses of radiation, defined as ranging from zero to 10,000 mrem. To put this in perspective, the average American is exposed to approximately 600 mrem of radiation annually from all sources. The report concluded that one percent of individuals receiving a dose of 10,000 mrem would be expected to develop cancer, compared with the 42 percent likely to develop cancer from other causes. Research has shown that low dose radiation exposure within range of 0.5 Sv was associated with circulatory disease and leukaemia. Use of CT scans in children with low dose of about 50 mGy might triple the risk of brain cancer and leukaemia. Radon exposure was from household was found to be not directly linked directly to lung cancer and other radiation related diseases.

CURRENT AND FUTURE RESEARCH

(52) (source 30)

A lot of research is ongoing into this area of science some include epidemiological studies that suggest that radiation exposure has health effects beyond cancer. The IARC-led consortium is now looking at the effect on solid cancers, and also on diseases such as heart attack and stroke. Other studies are under way to study the long-term impact of low-dose radiation on different cohorts. One, the Epi-CT study, is recruiting one million people from nine European countries who had CT scans as children; its analysis will be complete by 2017. Until now, very few studies have measured the effects of low doses of radiation delivered over a long period of time. A new study from MIT scientists suggests that the guidelines governments use to determine when to evacuate people following a nuclear accident may be too conservative. (52 (contd))

This study is the first to measure the genetic damage seen at a level as low as 400 times background (0.0002 cGy per minute, or 105 cGy in a year). Almost all radiation studies are done with one quick hit of radiation. That would cause a totally different biological outcome compared to long-term conditions," says Engelward, an associate professor of biological engineering at MIT.Experts gathered in Japan in 2015 to discuss low dose radiation and Dose and Dose Rate Effectiveness Factor (DDREF) relevant to radiological protection using existing epidemiological data and Research into other possibilities using emerging scientific evidence on DDREF drawn from conclusion from international organizations like WHO,SSK,ICRP. (53 (source 31))

Taken from final paragraph of ESC editorial

CONCLUSIONS

In conclusion, more research is necessary, both at the level of basic science to understand the interaction between toxic effects of ionizing radiation and hormesis phenomena, and at the level of epidemiology. It is our responsibility as physicians to take all precautions in reducing any potential hazard to our patients, our colleagues, and ourselves. (54 (source 32)) Also there is substantial evidence in data and research that provides suggestive evidence in support of a causal association between moderate- and low-level radiation exposure and circulatory disease. (55 (source 33)) The available data on biological mechanisms do not provide general support for the idea of a low-dose threshold. There is still some uncertainty over its danger to the human body.

Though the risk of low dose radiations is uncertain but I think its benefit in technological advancement and medical use outweighs the risk. In summary, the total body of relevant research for the assessment of radiation health effects provides compelling reasons to believe that the risks associated with low doses of radiation are no greater than expected on the basis of the LNT model. (56 (source 3) p22)

RECOMMENDATIONS

Organizations and stakeholders in the industry should insist and employ and invest into the three basic radiological principles, Justification, Optimization, Dose Limitation.

Development into future options that could be useful to improve and optimize the DDREF concept for the purpose of radiological protection. Other areas of research that can be researched into includes; Genetic factors in radiation cancer risk, Future medical radiation studies, Future occupational radiation studies etc.

Industry and governmental organisation should insist and organise regular workshops to emphasise the need of workers who are at risk of radiation doses to follow these basic simple rules i.e. limiting time, distance of source, proper shielding of workers and containment of accidents and nuclear site.

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