BACKGROUND RADIATION – NATURAL AND ARTIFICIAL

N. R. DAS*

Life on Earth are always exposed to background ionizing radiations from both natural and artificial radioactive sources. The natural sources like cosmic radiation and radioactive terrestrial materials cause direct external background radiation exposure to humans, whereas, inhalation of radon from air and dwellings, ingestion of radiotracers through food and drinks and the biologically essential functional elements, potassium (K – 40) and carbon (C – 14) in the body itself, result natural background exposure through internal radiation. Background radiation exposure (> 80%) due to natural radioactive materials is unavoidable as the sources are of natural origin. In addition to natural background radiation, human activities involving creation and utilization of artificial radioactivity for general benefits, particularly in medical imaging, radiotherapy, generation of nuclear electricity, etc., also produce a significant amount of artificial background radiation (<20%). The natural average background radiation dose for population has been estimated to be about 2.4 mSv/yr. In some parts of the world, however, much higher natural background radiation doses even up to ~ 260 mSv/yr have been recorded.

Introduction

Life on Earth has always been exposed to varieties of natural radiations as radioactivity has existed all along as a part of the planet. Thus, humans, just being on the Earth,[1] have been subjected to ionizing radiation from terrestrial radioactive materials originated during the formation of the solar system as well as through interaction of cosmic radiation from outer space with the molecules in the atmosphere. Ionizing radiation, a part of the electromagnetic radiation, is composed of alpha, beta, gamma, X-rays and neutron radiation that are generally emitted by the radioactive materials. In the environment, the visible light, ultraviolet light, infrared light, microwaves and radio and television waves, are some of the examples of non-ionizing radiation.

The term 'background radiation' usually refers to ionizing radiations emitted from both natural and artificial radioactive sources. The background radiation contributed by the naturally occurring radioactive sources like cosmic radiation and terrestrial materialsis known as the natural background radiation. Besides natural radiation, comparatively a smaller amount of ionizing radiation is being added to the background radiation by artificial or man-made radioactivity as the artificial background radiation. This originates mainly through human activities involving medical, industrial and nuclear technology. The natural and the artificial background radiations account for the total background radiation. Generally, the ionizing radiation emitted from varieties of naturally occurring radioactive sources is constant and for most people, it is the main environmental source of background radiation.

The radiation dose is related to the effect on a material that is exposed to radiation and for humans, it indicates the amount of energy absorbed by a material resulting potential biological effect in tissues subjected to radiation. The term, background radiation, can have different meanings, depending whether it is considered as an ambient radiation dose or for differentiation between an incidental background and a particular source of radiation. If no specific radiation source is of concern, then the total radiation dose measured at a location is generally called the background radiation and this is usually the case where

* Former Professor, Saha Institute of Nuclear Physics, 1/AF, Bidhannagar, Kolkata - 700064, e-mail : nrdas84@gmail.com

an ambient dose rate is estimated for environmental purposes. Generally, the radiation dose is measured in the unit of Sieverts (Sv), the International System (SI) unit for dose equivalent, equal to 1 joule per kilogram in tissue. One sievert is equal to 100 rem. Radiation dose is more commonly expressed in units of either millisieverts (mSv) or microsieverts (ìSv). On Earth, the common people are constantly being exposed to natural background radiation (> 80 %) from natural radioactive sources as well as to artificial background radiation (< 20 %) from artificial radioactive sources used for human welfare.[2] In addition, the radioactive fallout from nuclear weapon testing and accidents also constitute an important artificial source of artificial background radiation in specific areas.

In the urbanized world, people thus live in a sea of radiation due to the existence of natural radioactivity everywhere and production of artificial radioactivity for human welfare. Ionizing radiation with high enough energy can remove an electron from an atom or molecule resulting ionization in the object which comes in contact with it and if it hits a human being, it has the potential to be harmful to health. A higher dose of radiation is always associated with the effect of damaging human health and eventually developing risk of cancer, even death. The background radiation doses contributed by different natural and artificial sources[3] are presented in Figure - 1.

Natural Background Radiation

The natural sources of background radiation is mainly comprised of cosmic radiation (radiation that reaches the Earth from outer space), terrestrial materials (naturally occurring radioactive rocks and minerals that give off different radioisotopes including radon), air (containing radioactive gases like radon and tritium), food and water (living things like plants and animals absorb radioactive materials from soil and water and pass up to the food chain) and others such as biologically essential elements like potassium and carbon containing respective radionuclides, ^{40}K and ^{14}C .

Cosmic Radiation: Radiation from outer space is called cosmic radiation or cosmic rays, fractions of which reaches the Earth's surface through the atmosphere. It usually originates from the sources like sun, stars and different celestial events in the universe. This radiation is primarily consisted of positively charged ions from protons to iron and larger nuclei derived from sources outside the solar system. A constant stream of ionizing cosmic particles from outer space penetrates the Earth's atmosphere and continually bombards the atmospheric particles and all living things on Earth just like radiation from the radioactive materials in the Earth's crust below. It interacts with atoms in the atmosphere to create an air-shower of secondary radiations like electrons, protons, neutrons, alpha particles, X-rays and many others. The ionizing radiation that reaches the ground becomes absorbed by humans resulting in natural background radiation exposure.

In the atmosphere, high energy cosmic radiation causes elemental transmutation. In the process, cosmic radiation interacts with different atomic nuclei in the atmosphere to generate the cosmogenic radionuclides, like ^{3}H, ^{14}C and ^{7}Be.

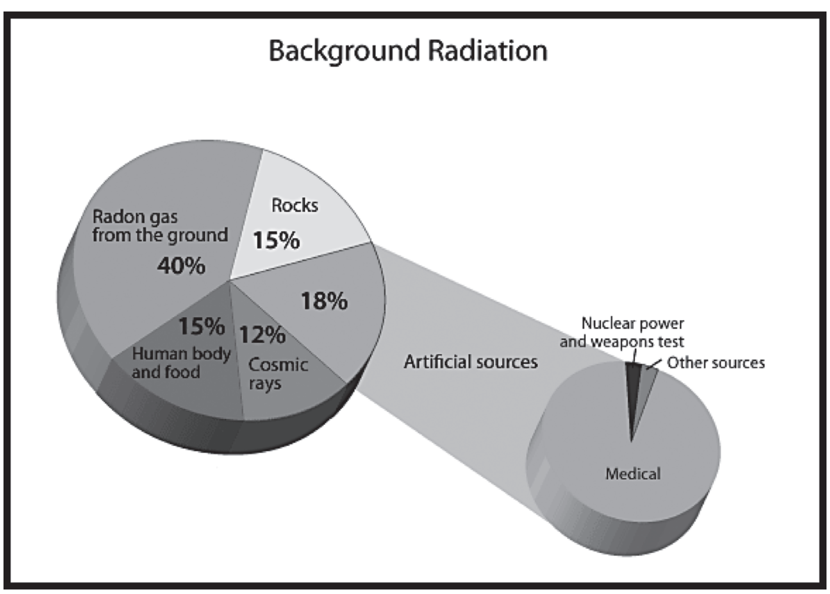

Figure 1. Average contribution of radiation doses by natural and artificial radioactive sources to total background radiation

In cosmic radiation, the flux of neutrons is dependent on geomagnetic latitude, with a maximum near the magnetic poles. The higher neutron flux in the vicinity of larger heavier objects like buildings or ships, is known as "cosmic ray induced neutron signature" or "ship effect", as it was first detected with ships at sea.[4] The background radiation doses to human body in the immediate vicinity of particles of high atomic number materials, have a small enhancement due to the photoelectric effect.[5]

The cosmic radiation doses in different parts of the world vary depending largely on the atmospheric conditions, altitude and geomagnetic field.[6] Since Earth's atmosphere blocks a portion of cosmic rays, exposure to cosmic radiationis always greater at the regions of higher altitudes. For example, in upper troposphere, around 10 km altitude, comparatively the cosmic radiation is much more intense and the people, especially the airline crews and frequent passengers, who spend longer periods in this environment, in general, are exposed to higher levels of cosmic radiation during their air-flights. The flight personnel and the airline crews during flights typically get an average extra dose of radiation in the order of about 2.2 mSv (220 mrem) per year.[7] It causes a higher background radiation exposure dose of ~100 mSv or more to an astronaut in a single mission.The ionizing cosmic radiation from space that reaches the earth generally contributes an average radiation dose of about 0.39 mSv/yr that makes up about 12% of the total average dose from background radiation.

Terrestrial Radiations: The terrestrial or Naturally Occurring Radioactive Materials, known by the acronym 'NORM", have mostly been produced during the formation of the solar system and the NORM occurring in the Earth's crust has now become the major source of terrestrial radiation. Radionuclides that were present during the formation of Earth are called as primordial radionuclides. Primordial nuclides were formed in the Big Bang by nucleosynthesis in stars and supernovae.[2,8] In nature, there are 33 primordial radionuclides of 28 elements that have half-lives long enough to have survived since the formation of the Earth (4.58×10^9 yr or 4.6 billion years). Of these 33 primordial radionuclides, only four nuclides, namely, ^{238}U (4.47×10^9yr), ^{235}U (7.04×10^8 yr), ^{232}Th (1.40×10^{10}yr) and ^{40}K (1.28×10^9yr), have half-lives comparable to, or less than, the estimated age of the universe. The naturally occurring radiogenic nuclides, radon, polonium and radium, found in terrestrial radioactive ores are the daughter products of uranium and thorium decay series and are non-primordial.

However, in comparison to a half-life of billion years, the human history on Earth is very short and effectively the activities of these long-lived isotopes have been constant throughout human existence on this planet.

The main contributors of terrestrial radiation are the natural deposits of primordial uranium and thorium and their intensely radioactive decay products. The radiogenic short-livedisotopes such as ^{226}Ra and ^{222}Rn, because of their on-going natural production in the decay chains, have not been decayed out of the terrestrial environment.The primordial uranium, thorium and ^{40}K are found everywhere in nature and some regions containing higher deposits of these radioactive elements receive more terrestrial radiation from the soils. Many of the daughter products of these elements are strong gamma emitters and are easily detectable via their characteristic gamma peaks.[4]

Traces of NORM are sometimes found in building materials used in construction of houses and other structures and thus the common people have the possibility of always being exposed to natural background radiation both in indoors and outdoors. The average worldwide terrestrial radiation dose due to scattered NORM beneath the ground is about 0.48 mSv/yr, constituting about 15 % of the total average dose of background radiation.The background radiation dose from terrestrial materials varies depending on location and geology, for example, it reaches as high as 90 mSv/yr in Nigeria and 260 mSv/yr in Northern Iran.[9]

Air: Variation in human exposure to natural background radiation primarily causes from inhalation of the radioactive gases, mostly radon, in the environment.The airborne radioactive gas radon along with its progenies, the levels of which depend on uranium and thorium contents of the soil, constitutes the biggest source of natural background radiation for most people. Radioactive radon, a chemically inert, colourless and odourless gas, produced as an alpha-decay product in uranium and thorium series, seeps out of the terrestrial ore deposits into the atmosphere and ground water. In air, it is unevenly distributed as its concentration changes greatly with wind direction and meteorological conditions. Radon can be released from the ground in bursts and then form "radon clouds" capable of traveling tens of kilometers.[4]

Radon along with other gases also becomes trapped and accumulated inside buildings, particularly in those built on granitic ground, resulting higher radiation exposure to the occupants through inhalation. The intensity of radon exposure in houses varies considerably depending on the choice of building materials in their construction. Some specific building materials, for example, lightweight concrete with alum shale, phospho-gypsum and Italian tuff, may emanate radon, as they sometimes contain radium and are porous to the gases. The concentration of radon inside buildings, are usually higher especially in the ground at basement levels and in inadequately ventilated houses. Radon concentrations of over 500 times the world average have been detected inside buildings in Scandinavia, the United States, Iran, and the Czech Republic.[10] United States hold the record for the most radioactive dwellings in the world.[11] Build-up of higher concentration of radon in dwellings can pose a long-term health hazard.

Radon radioisotope, ^{222}Rn, with a short half-life (~ 3.8 d) decays into different solid particulate radium-series radioactive nuclides. These radionuclides when inhaled, remains lodged in the lungs for a specific time period causing continued internal exposure. Effectively, radon along with its parents and progenies contributes a worldwide average annual dose of about 1.26 mSv/yr. Higher doses of internal exposure to these species, over the time, accounts for a large number of cancer deaths per year in different countries.[12] Inhalation of radon is assumed to be the second leading cause of lung cancer after smoking. Exposure to radon is always higher for the workers in uranium and thorium mines and can pose a health risk to the miners. Essentially, NORM are present everywhere from Earth's crust to building materials and hence exposure to natural radiation can occur from both outdoors as well as indoors.

Food and Water: Radiotracers from natural radioactive sources penetrate human bodies through different pathways like breathing, food and drinking, resulting in internal radiation. The essential biological functional elements such as potassium and carbon that make up the body, have the respective radioactive isotopes, ^{40}K and ^{14}C which act as the main sources of internal radiation after radon. Humans have been habituated to internal radiation due to the presence of these naturally occurring radionuclides, ^{40}K (primordial) and ^{14}C (non-primordial), inside their bodies from birth. An average human contains about 30 milligrams of ^{40}K and about 10 nanograms of ^{14}C, with respective half- lives of 1.28×10^9 years and 5,730 years. In human body, potassium is the largest source of internal radiation exposure. The global average internal dose from radionuclides, other than radon, is ~ 0.29 mSv/yr of which ~ 0.17 mSv/yr comes from ^{40}K and ~ 12 ìSv/yr comes from ^{14}C.[13]

The soils and ground waters in which the common vegetables and foodstuffs are cultivated may contain traces of terrestrial radionuclides along with their decay products in varying concentrations depending on the composition of the soils and locations. The radionuclides, especially potassium in the foodstuffs, once ingested, enter the blood stream directly and gets distributed to all tissues and organs. Similarly, occurrence of ^{210}Po in fish and other marine organisms may cause its presence in human bodies. Tobacco accounts for a significant fraction of internal radiation dose to smokers as ^{210}Po originated from radon, sticks to tobacco leaves. Heavy smoking results in a radiation dose of ~ 160 mSv/yr to the lungs from the decay of ^{210}Po.[14] Internal exposure from natural radiation cannot be avoided as people cannot stop breathing of air, eating of foods or drinking of water, just because these contain radioactivity, but it can be minimized through change of some human habits like smoking.The background radiation doses from major natural radioactive sources[3]are presented in Figure - 2.

High Natural Background Radiation Areas: Generally, the range of natural background radiation levels world-wise varies from 1.5 to 3.5 mSv/yr depending on variation in types and occurrences of natural radioactive sources.[13]Some specific areas in Europe[15], India[16] and Iran[9] have exceptionally high doses of natural background radiation than that of the country-wide averages. For example, the average annual natural background dose level in Europe ranges from ~ 2 mSv to 7 mSv, in Kerala and Madras in India, the highest background radiation dose level is over 15 mSv/yr, in addition to a similar exposure dose from radon, and in Ramsar, a city in Northern Iran, geological characteristics result in the highest dose level of about 260 mSv/yr.[9]

In Ramsar, the local people generally use the naturally occurring radioactive limestone as building materials. The average external effective radiation dose in theresidential areas was found to be ~ 6 mSv/yr which is about six times the limit for public exposure to artificial sources as recommended by the International Commission on Radiological Protection (ICRP).[17] In a house, the effective radiation dose levels due to ambient radiation field and the internal committed dose from radon were respectively recorded as 131 mSv/yrand 72 mSv/yr. The general dose level was found to be over 80 times higher than the world average natural exposure dose of radiation. The highest

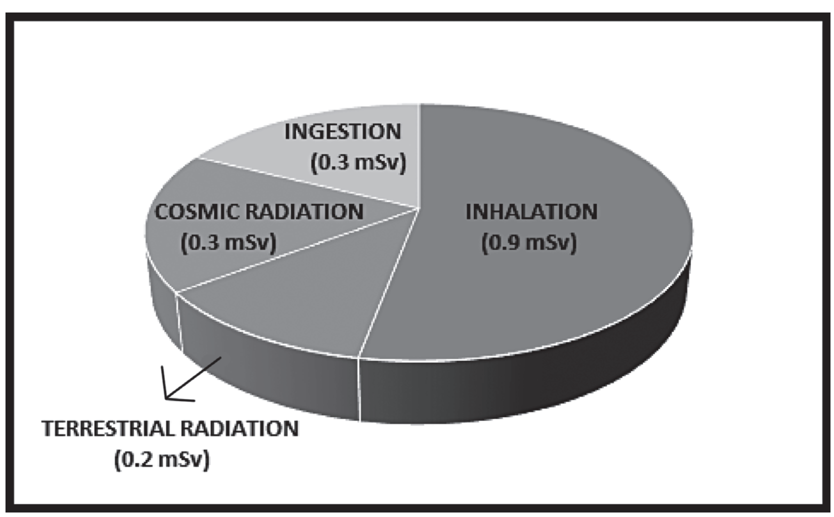

Figure 2. Average doses of background radiation from natural sources

level of natural background radiation ever recorded on earth's surface was 90 μGy/h on a Brazilian black beach mainly composed of the thorium mineral, monazite.[18]

The people in these higher radiation areas may have lifetime natural background radiation exposure in the range of several thousand millisievert.It is unique that in Ramsar, the epidemiological studies on health effects associated with the high doses of radiation, so far could not establish any co-relation between this elevated level of natural background radiation and the risk of negative health effects.[19] It is interesting that instead of any evidence of adverse health effect due to high doses of ionizing radiation, a support for beneficial effects like longer lifespan due to this chronic background radiation has been reported in the city.[17]Similarstudies in Indiaduring 1990-99 also did not show any adverse health effect attributable to high doses of background radiation due to occurrence of large quantities of monazite (8 -10.5 %) in specific areas.[16]

The radioactive radon, generated by the deep underground NORM deposits, is the primary source of radioactivity in hot springs. In early 1900s, it was believed that sitting and bathing in this "radioactive water" (hot spa) and drinking of spring water would be beneficial and effective in dealing with different health problems like aches and pains.[9]

Artificial Background Radiation

In the urbanized world, the unique property of radioactivity, both natural and artificial, has been fruitfully utilized in almost all fields of science to suit human needs such as medicine, agriculture, geology, industry, archaeology, nuclear technology and many others. The creation and beneficial applications of artificial radioactive sources, however, result in enhancement of the existing background radiation to a significant extent. Currently, the advanced nuclear technology applied in medical imaging has become the major source of artificial background radiation. Occupational and industrial exposure involving treatment and management of radioactive wastes from nuclear power plants, radioactive fallout from atmospheric nuclear tests and accidents,etc. also contribute fractions of background ionizing radiation to common man.

Medical Applications: The production of varieties of radioisotopes and their effective applications in different medical facilities and development of relevant equipment, generate themajor fractions of artificial background radiation. In medical diagnosis and treatment, people are generally exposed to ionizing radiations through the use of different beneficial procedures like X-rays, CT scans, radiation therapy, nuclearmedicines, etc. For example, a typical CT scan delivers an effective dose to the whole body ranging from 1 to 20 mSv, a chest X-ray delivers an effective dose of about 0.02 mSv,[10] and a dental X-ray delivers a dose of 5 to 10 μSv.[20] An American, for instance, receives an average diagnostic medical dose of about 3 mSv per year.[21]Global average human exposure dose of artificial radiation is about 0.6 mSv/yr, mainly through medical imaging. Radio-therapeutic treatment of different diseases also accounts for a significant amount of background dose, both for the individuals and those around. Higher doses of radiation can damage cells and make them cancerous.

Nuclear Reactors: In nuclear reactors, any incident, major or minor, may result in release of radioactivity into the environment increasing the background radiation. Under normal circumstances, large scale release of radioactivity from nuclear reactors is extremely rare, but the small amounts of radioactive gases that are sometimes released, may cause small radiation exposures to the public. In respect of background radiation, the treatment of highly radioactive wastes generated in a nuclear installation and their safe and efficient management are of major concern. For effective disposal, dumping of the nuclear waste, after its appropriate radiochemical treatment, in a low-permeability bed rock below the surface at suitable depth, designed as repository, has mostly been preferred. All nuclear installations are operated under strict regulations of radiological protection under International Authorized Regulatory Bodies like IAEA.[2]

Atmospheric Nuclear Tests and Accidents: The above-ground nuclear weapon tests and explosions during 1940s to 1960s had provided varieties of radionuclides like ^{90}Sr, ^{91}Sr, ^{92}Sr, ^{95}Zr, ^{99}Mo, ^{106}Ru, ^{131}Sb, ^{132}Te, ^{137}Cs, ^{140}Ba, ^{141}La, ^{144}Ce and many others[22] with different half-lives rendering the immediate local surroundings highly hazardous. The radioactive contaminants were carried over for longer distances and dispersed worldwide as nuclear fallout. The radioactive fallout can lead to an immediate external radiation exposure as well as a possible later internal hazard to the people through inhalation and ingestion. However, because of prohibition of the above-ground nuclear tests in 1963, the worldwide radiation dose from nuclear tests has been decreased to about 0.005 mSv/yr by 2000.[1] Atmospheric nuclear weapon tests almost doubled the concentration of ^{14}C in the Northern Hemisphere.[23]

During the period, there were three major nuclear power plant accidents, namely, the Three Mile Island accident (March 28, 1979) in USA, the Chernobyl accident

(April 26, 1986) in Russia and the Fukushima accident (March 11, 1911) in Japan. In Three Mile Island accident, [24]the average dose recorded was about 0.01 mSv and there was no adverse report of health effect or environmental consequences. In Chernobyl accident,[25] the total background radiation dose for the inhabitants of the affected areas ranged from 10 to 50 mSv over 20 years and there were several deaths from acute radiation syndrome. In case of Fukushima accident,[26] the total radiation doses were between 1 and 15 mSv for the inhabitants in the affected areas. However, radiation doses for some workers in the field vary from 100 mSv to 250 mSv. In addition to these major accidents, some other minor accidents[27] like the Windscale fire, nuclear waste contamination of the Techa River and the Kyshtym disaster at the Mayak compound, occurred earlier by nuclear weapon facilities, also released significant amounts of radioactivity into the environment.

Other Sources: Exposure to background radiation is often enhanced by burning of coal. On burning of coal in the plants, different elements including uranium and thorium along with their radioactive disintegration products buried underground in coal deposits, are released in the environment as fly ash.[28] The emitted fly ash containing different radiotracers is incorporated into crops and ingested by the people. It is also used in making bricks. In 1978, Oak Ridge National Laboratory estimated that a coal-fired power plants can contribute a whole-body committed radiation dose of about 19 μSv/yr to their immediate neighbors in a radius of 500 m.[29]The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) in 1988 reported an estimated committed dose of 20 μSv/yr at a distance of 1km for older plants and of 1 μSv/yr for newer plants with improved fly ash capture.[30] In addition, production of oil and natural gas also contributes fraction of doses to background radiation.

The man-made industrial consumer products like phosphate fertilizers, crushed rock and building materials, ceramics, radiation-emitting television sets, compact fluorescent light bulbs, smoke detectors and many others, can also enhance the dose of background radiation. Essential human activities involving advance radiological research in different fields including radiation metrology may sometimes result in increasing the artificial radiation dose in specific areas.

The natural background radiation dose to humans, animals and plants in different parts of the world generally varies with change in natural conditions as well as by variation in occurrences of NORM.[13] Similarly, the generation of artificial background radiation through beneficial applications of man-made radioactive sources very much depends on the availability of appropriate technical facilities, particularly in medical and nuclear fields. For example, in the United States and Japan, due to greater access to health facilities like medical imaging, the artificial radiation exposure, on average, is greater than the world's annual average natural exposure, as presented in Table - 1.

Currently, the availability of different sensitive advanced nuclear technologies help in detecting minute amounts of radiation emitted by natural or man-made sources. The radiation exposure from artificial radioactive sources can be minimized through different precautionary measures such as limiting the exposure time, increasing the distance from the source, creating barriers through appropriate shielding with lead, concrete or water and suitable containment of the radioactive materials.

The radiation protection standards are set by the appropriate authorities, generally in line with the recommendations of the International Commission on Radiological Protection (ICRP).[31] The limiting occupational radiation exposure dose, as stipulated by the ICRP,is 50 mSv (5 rem) per year, and a total of 100 mSv (10 rem) in 5 yearsand for public exposure, 1 millisievert per year averaged over five years is the limit.[32] In both cases of occupational and public exposures, the stipulated dose levels are over and above the background levels and exclude medical and other beneficial exposures.

In case of radiation safety, the International Atomic Energy Agency (IAEA) has defined the background radiation as the dose or dose rate attributable to all sources other than the one(s) specified.[31]According to IAEA recommendation, 2002, the occupational exposure doses to individual public member should be 1- 2 mSv (100 mrem) per year which do not warrant regulatory scrutiny.The IAEA states: Exposure to radiation from natural sources is an inescapable feature of everyday life in both working and public environments. This exposure is in most cases of little or no concern to society, but in certain situations the introduction of health protection measures needs to be considered, for example when working with uranium and thorium ores and other Naturally Occurring Radioactive Material (NORM). These situations have become the focus of greater attention by the Agency in recent years."[33]

TABLE 1. Average Annual Human Exposure to Ionizing Radiation in mSv/y in the World, the United States and Japan[1]

Radiation source	World	USA	Japan	Remark
Inhalation of air	1.26	2.28	0.40	Mainly depends on indoor accumulated radon
Internal and Ingestion of food & water	0.29	0.28	0.40	^{40}K, ^{14}C, etc.
Terrestrial radiation from ground	0.48	0.21	0.40	Depends on soil composition and building material
Cosmic radiation from space	0.39	0.33	0.30	Depends on altitude, atmosphere and earth's magnetic field
Sub-total (natural)	2.40	3.10	1.50	Sizeable population groups receive 10-20 mSv
Medical	0.60	3.00	2.30	World-wide figure excludes radiotherapy; US figure is mostly due to CT scans and nuclear medicine.
Consumer items	-	0.13		Smoking, air travel, building materials, etc.
Atmospheric nuclear testing	0.005	-	0.01	Peak of 0.11 mSv in 1963 and declining since; higher near sites
Occupational exposure	0.005	0.005	0.01	World-wide average to workers only is 0.7 mSv, mostly due to radon in mines; US is mostly due to medical and aviation workers.
Chernobyl accident	0.002	-	0.01	peak of 0.04 mSv in 1986 and declining since; higher near site
Nuclear fuel cycle	0.0002		0.001	Up to 0.02 mSv near sites; excludes occupational exposure
Other	-	0.003		Industrial, security, medical, educational, and research
Sub-total (artificial)	0.61	3.14	2.33	
Total	**3.01**	**6.24**	**3.83**	**mSv per year**

Conclusions

Life, since its creation on earth, has been exposed to background ionizing radiation as it exists everywhere on the planet. The constant stream of cosmic radiations from the outer space, occurrence of NORM in the ground, inhalation of radioactive gases from the air and dwellings, ingestion of radiotracers through food and drinks and internal radiation by biologically essential functional components, make the human habituated to the natural background radiation as a part of life. In addition, generation of artificial ionising radiation through the creation and application of man-made radioactivity for general benefit, has enhanced the existing background radiation. The radioactive fallout from nuclear weapon testing and accidents, also have some contribution to total dose of background radiation.

The general background radiation doses world-wide vary greatly in different parts of the world depending on the existence of the naturally radioactive sources as well as beneficial applications of artificial radioactivity. Exposure from the natural background radiation is unavoidable as the concerned radioactive materials are mostly of natural origin. However, judicious choice of the man-made radionuclides and the relevant techniques applied in human benefit may sometimes help in diminishing the artificial background exposure dose to the users. Natural and artificial ionizing radiations that enter into human bodies through several pathways are not different in kind or effect and higher radiation exposure, in general, always hasthe possibility of some adverse health effect. It is surprising that in some specific areas in the world, even with a natural background radiation dose as high as ~ 260 mSv/yr, no adverse health effect has yet been attributed to this high dose of chronic background radiation. It may be due to the fact that a living system itself, in general, can develop or evolve effective repairing mechanisms that usually limit the damage caused to the body cells by undesirable pollutants. However, it is too early to draw any specific conclusion. ❒

References

1. Background Radiation, Wikipedia, free encyclopedia, retrieved on 20.09.2017
2. N. R. Das, Wonders of Radioactivity, SaileePrakasani, India, 2011
3. Images for Background Radiation, retrieved on 18.09.2017

4. P. W. Gary, N. J. David and C. Timothy, A Primer on the Detection of Nuclear and Radiological Weapons, Center for Technology and National Security Policy, National Defense University, May, 2005
5. J. E. Pattison, R. P. Hugtenburg and S. Green, Enhancement of natural background gamma-radiation dose around uranium microparticles in the human body, Jour. Royal Society Interface. **7 (45)**, 603 (2009)
6. "Background Radiation & Other Sources of Exposure". Radiation Safety Training, Miami University, retrieved on 30.09.2016
7. Health Physics Society. "Radiation exposure during commercial Air Flights," retrieved on 24.01.2013
8. Primordial Nuclide, Wikipedia, free encyclopedia, retrieved on 20. 09.2017
9. M. Ghiassi-nejad, S. M. J. Mortazavi, J.R. Cameron, A. Niroomand-rad and P. A. Karam, Very High Background Radiation Areas of Ramsar, Iran: Preliminary Biological Studies, Health Physics, **82(1),** 87 (2002).
10. United Nations Scientific Committee on the Effects of Atomic Radiation (2006). "Annex E: Sources-to-effects assessment for radon in homes and workplaces", Effects of Ionizing Radiation (PDF). **II**. New York: United Nations, 2008, retrieved on 02.12.2012
11. J. J. Thomas, B. R. Thomas, and H. M. Overeynder, Indoor Radon Concentration Data: Its Geographic and Geologic Distribution, an Example from the Capital District, NY (PDF). Int. Radon Symp., Nashville, TN (September 27–30, 1995), American Association of Radon Scientists and Technologists, retrieved on 28.11.2012.
12. K. W. Fornalski, R. Adams, W. Allison, L. E. Corrice, J. M. Cuttler, Ch. Davey, L. Dobrzyñski, V. J. Esposito, L. E. Feinendegen, L. S. Gomez, P. Lewis, J. Mahn, M. L. Miller, Ch. W. Pennington, B. Sacks, S. Sutou, and J. S Welsh, The assumption of radon-induced cancer risk, Cancer Causes & Control (Springer), **10 (26)**, 1517 (2015)
13. United Nations Scientific Committee on the Effects of Atomic Radiation (2008). Sources and effect of ionizing radiation. New York: United Nations (published 2010). p. 4. Retrieved 09. 11. 2012
14. W. M Dade, "Doses from cigarette smoking", Health Physics Society, retrieved on 24.01.2013
15. "Natural Radiation in Western Europe"
16. M. K. Nair, K. S. Nambi, N. S. Amma, P. Gangadharan, P. Jayalekshmi, S Jayadevan, V. Cherian and K. N. Reghuram, Population study in the high natural background radiation area in Kerala, India, Radiat. Research, **152 (6 Suppl),** S145 (1999).
17. J. H. Hendry, S. l. Simon, A. Wojcik, M. Sohrabi, W. Burkart, E. Cardis, D. Laurier, M. Tirmarche and I. Hayata, Human exposure to high natural background radiation: what can it teach us about radiation risks?", Jour. Radiological Protection**. 29 (2A)**, A29 (2009).
18. United Nation Scientific Committee on the Effects of Atomic Radiation (2000). "Annex B", Sources and Effects of Ionizing Radiation, Vol. 1. United Nations. p. 121, retrieved on 11.11.2012.
19. L. Dobrzyñski, K. W. Fornalski and L. E. Feinendegen, Cancer Mortality Among People Living in Areas With Various Levels of Natural Background Radiation, Dose-Response, **13 (3),** 1 (2015)
20. D. Hart and B. F Wall, (2002), Radiation Exposure of the UK Population from Medical and Dental X-ray Examinations, (PDF), National Radiological Protection Board. p. 9, retrieved on 18. 05. 2012
21. Ionizing radiation exposure of the population of the United States, Bethesda, Md: National Council on Radiation Protection and Measurements. 2009. NCRP No. 160.
22. Nuclear Fallout, Wikipedia, free encyclopedia, retrieved on 20. 09. 2017
23. "Radiocarbon dating", University of Utrecht, retrieved on 02-19. 02. 2008
24. U.S. Nuclear Regulatory Commission (August 2009), "Backgrounder on the Three Mile Island Accident", retrieved on 24. 01. 2013
25. World Health Organization (April 2006), Health effects of the Chernobyl accident: an overview", retrieved on 24. 91. 2013
26. Geoff Brumfiel (2012-05-23), "Fukushima's doses tallies", Nature, retrieved on 24. 01. 2013
27. "Radiological Consequences of the 1957 Windscale Fire", 1997-10-10, retrieved on 24. 01. 2013
28. A. Gabbard, "Coal Combustion: Nuclear Resource or Danger?"Oak Ridge National Laboratory Review. **26 (3–4)**, 18 (1993).
29. J. P. McBride, R. E. Moore, J. P. Witherspoon and R. E. Blanco, "Radiological impact of airborne effluents of coal and nuclear plants" (PDF), Science, **202**, 1045–50 (Dec 8, 1978)
30. United Nations Scientific Committee on the Effects of Atomic Radiation (1988), "Annex A", Sources, Effects and Risks of Ionizing Radiation, New York: United Nations. p. 83, retrieved on 16. 11. 2012.
31. IAEA Safety Glossary 2007
32. "The 2007 Recommendations of the International Commission on Radiological Protection", Annals of the ICRP. ICRP publication 103. **37 (2–4**). 2007, retrieved on 17. 05. 2012
33. IAEA Safety and Security website, retrieved on 20.12. 2015