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Some Aspects of the Natural Radiation Environment

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Human exposure to the natural radiation environment and the consequent radiation doses can serve as a benchmark against which different artificial radiation exposures can usefully be compared. In radiation risk communications with the public such comparisons can help the public to have an informed perspective of radiation exposures and risks. A short overview is given here of the main components of natural radiation to which humans are exposed both externally and internally. The average annual global effective dose from radiation has been estimated by UNSCEAR to be about 3.0 mSv of which approximately 80% (2.4 mSv) is due to natural radiation. At the level of the individual, however, a wide variability of doses from natural radiation exists. This is true in particular of the doses received in the indoor environment from the inhalation of airborne progeny of radon and thoron gases. This account of some aspects of natural radiation in the environment is based on the 1st IRSCC (International Radiation Science Collaboration Centre) Seminar of the Institute of Radiation Emergency Medicine, Hirosaki University, Japan which was given by the author of this paper in February 2021.

Key words: natural radiation, doses, risks

1. Introduction

When life first appeared on earth is still a matter of debate and conjecture but based on the age of the oldest fossil containing rocks life was present on earth at least 3.5 billion years ago. From the time life first appeared until the present all life forms have been continually exposed to natural radiation coming from the environment[1]. From the moment of our conception until our death exposure to natural radiation is part of our life experience. In this short account the principal sources of such natural radiation exposures, their properties and health impact will be briefly described and discussed in the following sections. This account is based on the 1st IRSCC Seminar[2]. More detailed accounts of natural radiation sources and health effects can be found, for example, in the reports of UNSCEAR and in such compendiums as the European Atlas of Natural Radiation (EARN)[3, 4].

The sources of natural radiation in the environment may for convenience be divided into two main categories: primordial radionuclides and cosmic radiation. Primordial radionuclides were principally formed by nucleosynthesis in stars and supernovae and were present in the interstellar material from which the solar system was formed. Over geological time scales and following the formation of the primeval earth the outer layers of the earth's crust became enriched in the radioactive primordial radionuclides principally those of the Uranium (^{238}U, $T_{1/2}$ = 4.47 x 10^9 y) and Thorium (^{232}Th, $T_{1/2}$ = 14 x 10^9 y) series and of Potassium-40 (^{40}K, $T_{1/2}$ =1.25 x 10^9 y). Due to geological processes which control the

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Table 1. Main sources of doses from natural radiation[4]

SOURCES OF EXPOSURE	DOSES	
	INTERNAL	EXTERNAL
COSMIC RADIATION	Cosmogenic radionuclides	Directly ionising, photon and neutron components
TERRESTRIAL RADIONUCLIDES	^{238}U and ^{232}Th Series and ^{40}K	
	Radon (^{222}Rn), Thoron (^{220}Rn) and their progenies. (For these species, the internal doses are more significant than the external doses.)	

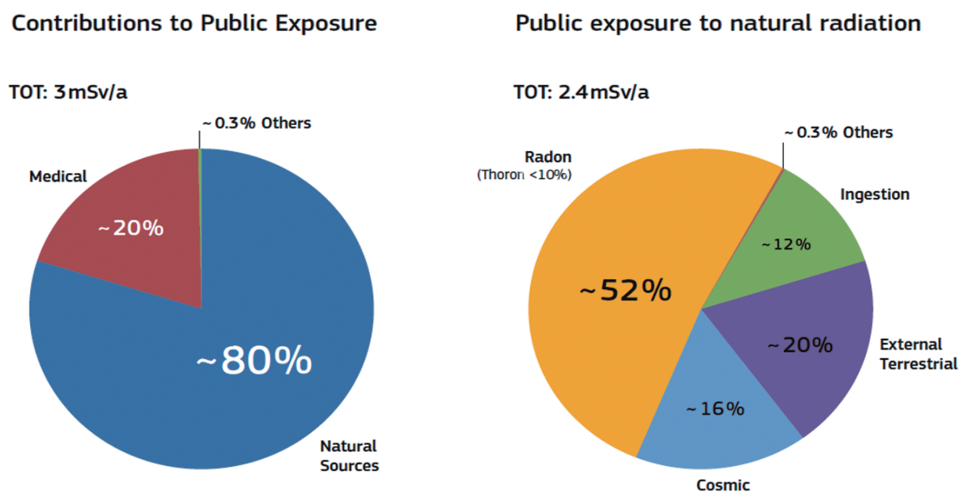

Fig. 1. Global Doses from Radiation[3, 4]

partitioning of primordial radionuclides on earth and due to radioactive decay external terrestrial dose rates today are considerably lower than at the time of the earth's formation. Due to its shorter half life compared to ^{238}U and ^{232}Th the reduction in the contribution to dose rates from ^{40}K has been more pronounced[1].

Human exposures to natural radiation take place by three main pathways. These are:

(a) By external exposure to radiation from natural radionuclides present in our surroundings such as in soil, rocks, air, building materials etc.

(b) By inhalation of natural radionuclides in the air.

(c) By ingestion of natural radionuclides in solid and liquid foods.

The partitioning of the doses received via these three pathways are given in Table 1.

UNSCEAR has over many years compiled global data on sources and doses from both natural and artificial radiation[3]. Figure 1 shows the estimated mean global effective doses from these sources based on the UNSCEAR 2008 Report to the UN General Assembly[3, 4]. In the context of this paper two features of this are most relevant to note. As shown in Figure 1 approximately 80% of the mean annual estimated dose of 3 mSv/a to the global population comes from natural sources with the remaining approximately 20% being due to medical exposures[3, 4] The second point of relevance here is that at 2.4 mSv/a approximately half of the natural doses are due to radon (^{222}Rn) and thoron (^{220}Rn) or more correctly their short-lived progeny. While the dose pie charts are being continually revised in the light of new data becoming available it must be emphasised that these estimated doses are average or mean values. At the level of an individual dose contributions can be quite variable from these mean values. This is true in particular of medical exposures where quite high doses are received during radiotherapy compared to routine x-ray procedures such as at the dentist etc. This is also the case with natural radiation where there is great variability particularly for radon exposures. Radon concentrations in air are known to range over many orders of magnitude from < 1 Bq/m^3 over the polar ice caps or mid oceanic air to many thousands of Bq/m^3 in indoor air in a minority of dwellings. In contrast to this where most people live doses from cosmic radiation have in relative terms a much lower variability. For example, while the typical cosmic radiation dose at sea level is between about 0.3 and 0.4 mSv/a in the city of La Paz at an elevation of 3900 m in the Andes it is approximately 2 mSv/a which is only about a factor of five greater.

2. Cosmic Radiation

In the period 1909 to 1912 investigators of ionisation of the air found experimental evidence which suggested the existence of an extra-terrestrial or cosmic source of ionisation. Unequivocal and quantitative evidence for this was finally obtained by the Austrian physicist Victor Hess during a series of pioneering balloon flights in 1911-1912. In these flights his measurements showed that above a height of about 1 km the rate of ionisation of the air began to steadily increase as a function of height above ground thereby verifying the existence of ionising radiation coming from the cosmos[5]. Hess together with Carl Anderson was awarded the Nobel Prize in Physics in 1936 for his discovery of cosmic radiation. It should be noted that the work of the Italian physicist Domenico Pacini in 1911 on comparing air ionisation rates in sealed chambers above and below the sea also suggested the existence of a cosmic component or source of radiation in the atmosphere[6].

It is now known that primary cosmic radiation originates in outer space both in our own galaxy and in distant galaxies and that it is composed mainly of 87% protons, 11% alpha particles (helium nuclei) and about 1% of nuclei of atomic nuclei (Z) from 4 to 26. These primary cosmic rays travel at speeds close to that of light. They are highly penetrating and their mean energy is about 10^{10} eV. Maximum energies appear to be in the region of 10^{19} eV. The typical flux of cosmic rays at the top of the earth's atmosphere is about 10^4 $m^{-2}s^{-1}$. In addition to the primary cosmic radiation there is also cosmic radiation of solar origin. Solar cosmic rays have much lower energies (<100 MeV) than the primaries but have a higher proton component (98%) and a lower alpha particle content (2%)[7]. At ground level the largest component of cosmic radiation are muons at energies generally in the range about 1 to 20 x 10^9 eV.

When cosmic radiation enters the atmosphere it interacts with molecules in the air to produce a cascade or shower of secondary particles consisting of electrons, neutrons and mesons. Cosmogenic radionuclides are also produced as a result of these interactions most notably ^{14}C[8]. Cosmic radiation globally on average accounts for about 0.4 mSv (16%) of the annual dose from all natural radiation sources. The actual dose rate from cosmic radiation is a function of altitude above sea level and geomagnetic latitude. For example, while the average dose from cosmic radiation at sea level is estimated to be in the range 0.3−0.4 mSv/year for populations living at high altitudes in the Andes or Himalayas doses are in the range 1.0−2.0 mSv/year. For example, in Japan the dose rate from the ionising component of cosmic radiation on the summit of Mount Fuji (elevation 3776m) was found to be 3.6 times that at sea level while that from its neutron component was about ten times that at sea level[9]. Various programmes are available such as the Excel based EXPACS Programme to calculate cosmic ray dose rates at any location on the surface of the earth based on input data of elevation, geomagnetic latitude, heliocentric potential and soil moisture[10]. The significance of moisture is because cosmic radiation reflected from soil is affected by its moisture content as the water molecules in wet soil will absorb neutrons.

Travelling by air increases the dose received from cosmic radiation. On a typical high altitude flight route from Tokyo to Frankfurt the return trip cosmic ray dose received is about 100 μSv while on a typical lower altitude and much shorter flight from Tokyo to Seoul it is only about 6 μSv. Therefore for members of the public these non-occupational cosmic radiation doses do not present a radiation protection problem. On the other hand for aircrew, the annual cumulative doses can be of the order of a couple of mSv and therefore require the application of radiation protection procedures in particular for pregnant aircrew[11, 12].

While it is likely only to be relevant to a small number of people there is growing scientific interest in the doses and possible consequent health effects due to cosmic radiation exposure of astronauts on long term missions in space stations and in interplanetary travel. For the Apollo and Skylab space missions it has been estimated that doses in the range 1.2–1.4 mSv/d were received by the astronauts. In longer duration missions to the International Space Station for example the dose rate would be typically about 150 mSv/a. Of particular interest are planned manned missions to Mars where the total journey time to and from Mars will be about a 1year duration followed by perhaps a comparable time on the planet. For such an exposure scenario estimated cumulative effective doses of up to 1 sievert (1000 mSv) may be experienced by astronauts. Additional exposures from solar flares or major stellar events during the mission which cannot be predicted could give rise to significant additional doses. In spite of the high doses that astronauts have in the past received there is up to the present no evidence of spaceflight radiation carcinogenesis. One reason for this lack of evidence is that estimates of the rate of cancer in astronauts and cosmonauts due to cosmic radiation is limited due to low statistics. A recently published study of cancer mortality in US astronauts, Soviet and present day Russian cosmonauts which showed no significant increase in cancer mortality when compared to the general population only approximately 320 subjects were studied[13]. In addition there are the inherent difficulties in the application of radiation risk factors largely based on low LET exposures on earth, such as from studies of the Japanese atomic bomb survivors to that of the completely different space radiation environment.

Currently (2021) the U.S space agency NASA is proposing a new space radiation health standard for astronaut[13]. NASA intends to use a mean 3 percent REID (Radiation Exposure Induced Death) as the basis for a dose-based limit. On this basis, for all astronauts, the maximum allowable space radiation exposure would be the effective-dose for a 35-year-old female astronaut whose mean REID is at 3 percent. This standard if adopted would delineate an effective-dose career limit of approximately 600 mSv that applies equally to male and female astronauts, regardless of an astronaut's age.

In the context of effects of cosmic radiation during space flight It is of some interest to note that during the Apollo lunar missions, starting with Apollo 11 astronauts reported flashes of light in their eyes which were subsequently attributed to the passage of relativistic particles though their heads. Various mechanisms were proposed for this phenomenon such as Cerenkov radiation flashes in the vitreous humour of the eye due to the passage of relativistic particles to direct action on either the visual cortex or retina[14]. To date the latter possibility is considered to be the most likely. Prior even to the Apollo missions experimental investigations at sea-level on earth showed a positive correlation between the passage of cosmic ray mesons through the human head and the detection of light flashes in the eyes of dark adapted persons[15]. As a student in the 1960s the author of this paper was a volunteer participant in investigations of this type.

3. Terrestrial Radiation

As noted in the introduction the surface of the earth contains concentrations of primordial radionuclides and their progeny. Radiation exposure of humans and associated doses from these can take place principally by (a) direct external radiation of gamma and betas outdoors either from soil or rocks or indoors from building materials derived from geological material. (b) inhalation of airborne radon, thoron and their progeny both outdoors and more significantly indoors. (c) ingestion of the primordial radionuclides and their decay products in water and foodstuffs.

In the case of outdoor exposure the external radiation component of terrestrial radiation from primordial radionuclides depends primarily on the characteristics of their specific activity in the surface material to a depth of about one metre at the point of measurement. UNSCEAR estimates that globally the mean annual dose at the surface of the earth is about 0.48 mSv corresponding to an hourly dose rate of 55 nSv/h. There are however locations on the earth where elevated concentrations of primordial radionuclides can give rise to much higher doses. Ramsar (Iran), Kerala (India), Yangjiang (China) and Guarapari (Brazil) are examples of such locations. In the case of Ramsar it is the elevated concentration of ^{226}Ra in the local geology and surface waters that is the reason for this[16]. The author has measured outdoor dose rates as high as 100 μSv/h in Ramsar and at a wall surface in one dwelling there measured the dose rate to be approximately 34 μSv/h.

In the case of indoor exposure to terrestrial radiation the primordial radionuclide concentrations in the building materials are the source of the exposure and resulting doses.

Because of this many radiation regulatory agencies control the use of building materials by means of an activity concentration index (I) for the gamma radiation emitted by building materials. In the case of Member States of the European Union the EU Basic Safety Standards uses an index value of 1 as a conservative screening tool to identify materials that may cause the reference dose level of 1mSv/a to be exceeded[11]. The index value is determined by means of the following formula:

$I = C_{Ra226}/300 + C_{Th332}/200 + C_{K40}/3000$ where C_{Ra226}, C_{Th332} and C_{K40} are in Bq/kg.

Naturally occurring radionuclides in the terrestrial environment both on land and in the oceans are incorporated into food products. Apart from the inhalation of airborne radon/thoron progeny food intake is a significant route for the intake of natural radionuclides by the public. Due to food intake the body of a 70 kg human adult contains about 140 g of the essential element Potassium of which approximately 0.017 g is the naturally occurring radioactive isotope Potassium 40 (^{40}K). This gives rise to the human body having an activity of about 5000 Bq. For adults the total annual effective dose due to the ingestion and inhalation of natural terrestrial radionuclides is estimated to be about 0.29mSv, of which 0.17mSv is due to ^{40}K and 0.12mSv is due to the long-lived radionuclides in the uranium and thorium series. In contrast to this the average annual dose contribution from the ingestion in food of the cosmogenic radionuclide ^{14}C is much smaller at about 2 μSv.

It is of interest to note that studies of representative dietary intakes for Japanese adults have shown that the committed effective doses are dominated by natural radionuclides in foodstuffs[9]. In this regard the three most significant contributions are made by ^{210}Po (0.73 mSv). ^{40}K (0.18 mSv) and ^{210}Pb (0.058 mSv). As the total committed effective dose from all radionuclides is estimated to be 0.80 mSv the ^{210}Po contribution accounts for 90% of this. On the basis of food category 80% of the total committed effective dose of 0.80 mSv is due to the consumption of fishes and shellfish which are an important though declining component of the Japanese diet[9].

4. Radon

Excluding doses from radiotherapy UNSCEAR has estimated that the largest and most variable contributor to radiation doses received by the majority of the general public during their lifetime is due to the two main isotopes of the gaseous element radon namely: ^{222}Rn ($T_{½}$ = 3.825 days) and ^{220}Rn ($T_{½}$ = 55.6 s) which are generally referred to as radon and thoron respectively[16]. Radon is a member of the ^{238}U series and its immediate parent is radium (^{226}Ra) while thoron is a member of the ^{232}Th series and its immediate parent is another radium isotope (^{224}Ra). UNSCEAR has estimated that globally radon and thoron account for more than half of the dose. Indoor radon concentrations are mainly due to radon entering buildings from the decay of radium in the soil or rocks beneath the building. Outdoor concentrations of radon are typically in the range 3 to 10 Bq/m^3 while in most countries mean indoor concentrations generally range from about 20 to 80 Bq/m^3 [3, 17]. A small percentage of buildings exist in many countries with indoor radon concentrations of many thousands of Bq/m^3. For example, the author has measured radon concentrations as high as 50000 Bq/m^3 in a dwelling built on karstic limestone above uraniferous geological strata in southwest Ireland[18].

The principal epidemiologically confirmed health effect of radon is lung cancer not only in underground miners but also in studies of the general public exposed to radon in their homes[19, 20]. The mechanism by which inhalation of radon is considered to increase the risk of lung cancer is by alpha particle damage to sensitive cells in the bronchial epithelium. When air containing radon is inhaled the radiation dose received is mainly due to alpha particles emitted by the short-lived progeny of radon such as ^{218}Po and ^{214}Po deposited on the surface of the airways rather than by radiation from the gas radon itself[21]. A detailed account of the dosimetry of radon and its progeny is given in the ICRU Report 88[19].

5. Public Perception of Natural Radiation

Most members of the public have very little knowledge of natural radiation. In recent decades due mainly to public information campaigns on health risks from indoor radon public awareness of natural radiation has been increasing in many developed countries. Even for technically educated members of the public, however, knowledge of natural radiation and its health effects are very rudimentary and it is generally thought to be of little health consequence. This is in part due to the common use of the term "background radiation" as a descriptor for natural radiation in the environment. In English, and perhaps in some other languages the word "background" used in describing a phenomenon has connotations of insignificance or of not being important such as in "background noise". An additional aspect of how the terminology used affects public perception of natural radiation arises because it is natural and in the present zeitgeist something natural is often and incorrectly taken to infer it to be safe or of little danger to health. When one considers the many life threatening natural phenomena such as earthquakes, tsunamis, volcanic eruptions, malarial carrying mosquitos etc. to uncritically view natural phenomena as safe is illogical but it is a perception held by many. Numerous studies of public perception have shown that the anxieties and fears of the public for radiation from artificial sources such as nuclear power do not seem to apply to radiation from natural sources[22, 23]. A good example of this is public apathy towards the risk from indoor radon even though the extensive body of epidemiological evidence available is unequivocal that radon is a human carcinogen and according to the WHO radon is the second known cause of lung cancer after smoking. WHO estimates that exposure to radon may be responsible for between 3% and 14% of lung cancer deaths globally[24]. Even allowing for the many uncertainties involved in such estimates it is clear that in the case of radon exposure the health effects are substantial. Here again the fact that radon and its progeny are natural radionuclides in the perception of the public means nobody is to blame for indoor radon exposures. This misconception is a significant contributing factor to apathy and inertia of the public towards controlling indoor radon. Studies have shown that even when householders are made aware that their homes have an unacceptable level of radon only a small percentage will remediate the problem[25]. The reality is that while radon is indeed natural indoor radon levels are not natural. They are a direct consequence of the way we locate, design, construct, use and maintain our dwellings. Radiation from indoor radon is in fact a form of TENR (Technologically Enhanced Natural Radiation) which is conceptually the same as the enhancement of cosmic radiation doses received by both aircrew and the travelling public due to air travel.

In the aftermath of nuclear accidents such as occurred in Chernobyl in 1986 and more recently in Fukushima in 2011 part of the reason for the fear and anxiety of the public was that they had no benchmark or yardstick against which to compare the resulting doses. Doses from natural radiation in the environment could usefully play the role of such a benchmark against which artificial doses from accidental radionuclide releases and even those from medical exposures could be compared[22)].

6. Conclusion

As described in this paper exposures, both external and internal, to radiation from the different components of the natural radiation environment are and always have been part of the human experience. UNSCEAR estimates the mean dose rate globally from natural sources to be about 2.4 mSv/year. At this dose rate level the health risks to the public from natural radiation in most exposure scenarios are considered to be insignificant. In the case, however, of long term elevated radon exposure numerous epidemiological studies both of exposed workers and of members of the public have unequivocally shown and quantified the increased risk of lung cancer related to such exposures[19, 20)]. It is considered that increased public awareness of natural radiation in all its forms can play a useful role in helping the public to compare radiation risks and to make value judgements of the risks from radiation exposures in other situations such as in accidental nuclear energy accidents and medical exposures.

Conflict of Interest

The author declares that he has no conflict of interest.

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