CND BRIEFING

A primer on radiation and radioactivity

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Following Russia's recent shelling of nuclear power plants in Ukraine in early March 2022, many people have asked for information about radiation. Below is a primer for lay people on radioactivity and radiation: it assumes a basic knowledge of physics and chemistry.

What is radiation?

Radiation is the collective term given to electromagnetic energy, including gamma rays and X-rays. However, the term also includes energetic particles such as beta particles, alpha particles and neutrons.

Conventionally, most scientific studies are concerned with ionising radiation: that is, radiation with sufficient energy to knock electrons out of their orbital shells around the centre of the atom, i.e., creating an imbalance that makes them electrically charged or 'ionised'.

It is usually thought that radiation's adverse health effects are mostly due to such ionisations, which can result in breaks in our DNA and mutations in our genes.

Such alterations to our reproductive cells result in hereditary effects in our offspring: alterations to our body cells result in cancers and cardiovascular diseases. Alterations to embryonic or fetal cells result in developmental malformations (known as teratogenic effects).

The International Agency for Research on Cancer (IARC), an agency of the United Nations' World Health Organisation (WHO), has stated that all forms of radiation, including X-rays, gamma radiation and neutrons, are carcinogenic to humans (IARC, 2018). In addition, radiation exposures to pregnant women are mutagenic to their fetuses and embryos, that is, both carcinogenic and teratogenic.[1] These effects depend on the magnitude of the exposure and the stage of fetal development.

Light waves (e.g., sunlight, infrared and ultraviolet radiation) are also forms of electromagnetic radiation but these are not considered problematic at very low doses.[2]

Ionising radiation is different from the radiation used by mobile phones, 3G, 4G, 5G networks, microwaves and radio/TV stations. These sources use radio-frequency (RF) radiation, which imparts less energy. Some authorities (IARC, 2018; PHE, 2011) consider that the evidence for health effects from exposures to RF sources is not strong. This review does not discuss this type of radiation: it merits a separate report.

External radiation and internal radiation

When most people hear the word 'radiation', they usually think of X-rays which is an external form of radiation. Another type is internal radiation, for example when we breathe in the radioactive gas radon in the air. Internal radiation is less understood and less discussed, but it is the more serious of the two kinds. For example, the radioactive fallout from nuclear accidents or from shelling nuclear reactors results mainly in internal radiation exposures from inhalation and ingestion.[3]

A good description of internal radiation risks is the report of the UK Government's Committee on the Radiation Risks of Ionising Radiation (CERRIE, 2004).

What is radioactivity?

Radioactive fallout affects us when we inhale it, or ingest it or absorb it through our skin. So what is radioactivity? Radioactivity occurs when the nucleus of an atom is unstable, i.e., it has too much energy.[4] Therefore it loses this energy at characteristic intervals to achieve more stability by emitting particles and/or energy. This process is called radioactivity and the particles and energy given off are called radiation. Atoms which are radioactive are called radionuclides, or nuclides for short. When they disintegrate, they usually emit alpha particles, beta particles, and gamma rays. Less commonly, they emit protons, positrons, X-rays and neutrons. These all come from the heart of the atom – its nucleus.

About 3,000 nuclides exist in theory: most are artificially created. It is important to realise that, before the age of nuclear weapons and its offspring nuclear energy, only a handful of nuclides existed.[5] These are the so-called primordial nuclides with extremely long half-lives as they are remnants left over from the time the earth was formed 4.6 billion years ago. These include all uranium isotopes, all thorium isotopes, and potassium-40. The reason they still exist is their immensely long half-lives.

Commonly mentioned (man-made) nuclides are caesium-137 (Cs-137), strontium-90 (Sr-90), radon-222 (Rn-222), radium-226 (Ra-226), hydrogen-3 (H-3 or tritium) and carbon-14 (C-14).

Radiation's effects

Ionising radiation has two main effects:
(a) immediate cell-killing and
(b) later probabilistic,[6] effects.

Cell-killing occurs after acute exposures to relatively high amounts of radiation, i.e., over 50 mGy[7] or so. Examples of cell-killing include skin reddening, skin burns, nausea, vomiting, dizziness - all occurring within a few hours or days. At higher doses over ~300 mGy, eye cataracts, severe skin burns, and hair loss occur. At very high doses over, ~1 Gy, loss of consciousness, coma and eventual death may occur within a few days or weeks, depending on the level of medical care.

Probabilistic effects occur much later. The cancers of leukaemia and lymphoma are usually the first to arrive within a few years followed later by solid cancers (i.e., tumours) and also cardiovascular diseases. The evidence for such effects comes partly from laboratory experiments but mostly from the observed health effects in survivors of the Hiroshima and Nagasaki atomic bombs in 1945.

Most of these effects have long latency periods lasting years or decades. The latency period is the time for the radiation's probabilistic effects to start to appear. After then, radiation's effects will continue to arise, sometimes for very long periods. For example, excess thyroid cancers are still occurring among the survivors of the Hiroshima and Nagasaki bombs in Japan in 1945, more than 60 years later (Imaizumi et al, 2006). The rate at which they arise depends on the initial dose.

These later, slower, effects result in an increased probability of cancer. Radiation is therefore like cigarette smoking: not everyone who smokes will immediately get cancer, but the more one smokes the greater one's chance of cancer. Another analogy is when you are exposed to radiation you receive a negative lottery ticket: if you are unlucky your number will come up.

Often government sources and media reports have ignored these later effects of radiation, or have found them difficult to grasp, or even to accept. However, when large numbers of people are exposed to low levels of radiation, they are by far the more significant effect of radiation. To give an example, during the nuclear catastrophe at Chornobyl in 1986, about 50 firefighters died from cell-killing effects, but tens of thousands of people were estimated to have died from cancer from radioactive fallout.[8]

Cancer

Cancer is the name for a large group of diseases which are very common and can be fatal. For example, according to the UKCRC, half of UK people born after 1960 will be diagnosed with cancer during their lifetimes. Rather worryingly, the incidence of cancer is growing slowly in Western countries, and we don't know for sure why. On the other hand, treatments for cancer are generally getting better with the result that survival rates are increasing: cancer death rates are actually declining. However, the diagnosis of cancer is still a devastating blow for patients and their families, and chemotherapy and radiotherapy regimes can often be unpleasant, indeed harrowing.

Cancer results when a single stem cell[9] is damaged so that it fails to respond to signals telling it to stop dividing. As a result, the stem cell and its descendants divide continuously producing a mass of cells, i.e., a tumour, which if untreated can be fatal. The type of cancer depends on which organ the stem cell is found. Most stem cells are in the gut lining, bone marrow and skin, but they are to be found in every organ of our bodies.

In adults, the production of new cells is closely controlled and just keeps pace with cell loss. This means that stem cells divide only when new cells are needed; if new cells are not needed, the division of stem cells is prevented by signals from nearby cells. However, sometimes this control mechanism doesn't't work and a cancer results.

For some adult cancers, as many as five or more separate DNA mutations are needed for a cancer to result, but in childhood tumours, fewer are needed. The need for several mutations explains why cancers often appear several years after the original exposure. An initial exposure to radiation causes only the first of the several mutations required, with the other mutations being caused in later years most likely by our continual exposure to background radiation. This does not occur with childhood cancers whose causes are still poorly understood, but some scientists are beginning to think that background radiation during pregnancy may cause about half of child leukemias.[10]

Cancers can also occur in white blood cells. The result is abnormal increases in their numbers and sizes. They do not result in tumours but in deformed cells which are unable to carry out their normal functions of protecting us against bacterial and viral infections.

Should we worry about radiation?

Many people fear radiation as we cannot feel, see, smell, hear or touch it. Much ignorance exists; regrettably, radiation risks are not taught in schools (e.g., they are not on national syllabuses) and few university courses exist on radiation, certainly not on its risks. But it is better to inform ourselves about it than to fear it.

Radiation affects different people in different ways. For example,

a. Adult women are approximately twice as radio-sensitive as adult men. The authoritative US BEIR VII report (BEIR, 2006) estimated that radiogenic cancer risks in adult women were 1.6 times greater than in adult men on average.

b. Children under 5 years old are estimated to be about 10 times more sensitive to radiation than adults.[11]
c. Infants under about 1 year old are estimated to be about 100 times more sensitive to radiation than adults.[12]

People might presume that the legal safety limits to radiation exposure would take these increased radio-sensitivities into account. Sadly, this is not the case. The current legal limit of 1 mSv per year applies to all persons regardless of age and gender.[13]

Background radiation

Exposures to low levels of radiation are ubiquitous. This background radiation is often thought to be safe but it is not, even though there is little we can do about it. Background radiation partly comes from low levels of radioactivity in the soil, in the air, in our bodies (e.g., potassium 40), and partly from cosmic radiation, i.e., from the sun and outer space.

Here are some basic facts about background radiation rarely mentioned in the media:

1. Background radiation is the main reason why women who wish to have families are counselled to have children before they are 40 years old. The explanation is that a girl's complete store of eggs is created at her birth. So by the time she has attained 40 years, her eggs will have been exposed to about 40 mGy of gamma radiation from background radiation. This means some of her eggs will have been killed and some of the remainder will have been damaged.
2. Some experts think that background radiation actually causes about a fifth of all childhood leukemias. Other say about a half as reported by Fairlie (2021).
3. Many scientists are now realizing that the ageing process is intimately connected with our continual exposure to background radiation. Ultimately, background radiation may be the main reason why we are not immortal. In the UK, people are exposed to about 1 mGy of background gamma radiation each year.

Nuclear facilities

A great deal of epidemiological evidence exists strongly suggesting raised levels of cancers, including childhood leukemia, near nuclear facilities around the world. (Laurier and Bard, 2008; Laurier et al, 1998; Korblein and Fairlie, 2012). The largest and most important is the German KIKK study (Kaatsch et al, 2008a and 2008b) which found a 120% increase in leukemias among children living within 5 km of all German nuclear power stations. Fairlie (2014) has proposed a hypothesis to explain these leukemia increases despite official assurances that their doses are too low. Essentially, both official dose estimates are unreliable and official risk estimates are too low. However, proponents of nuclear power contest the matter: this issue is still debated (Fairlie, 2014).

Medical procedures

We also receive radiation exposures from medical treatments for cancer and from medical diagnostic procedures such as X-rays and computed tomography (CT) scans. Although CT scans have clinical benefits for doctors and patients, some clinicians are worried about the increasing numbers of such scans especially in infants and children. Some have pressed for CT scans to be generally avoided in infants, children and in pregnant women. and for ultrasound to be used instead wherever possible (Fairlie, 2021).

Space Shuttle

Crews on the International Space Shuttle are generally only allowed to stay in space for 6 months or fewer because of the very high levels of radiation in space.

Tanning beds

In 2009, the World Health Organization's International Agency for Research on Cancer classified UV tanning beds as Class 1 human carcinogens.

Nuclear accidents

Major catastrophes have occurred at regular intervals of about every decade or so e.g., Windscale in 1957, Three Mile Island in the US in 1979, Chornobyl in 1986, and Fukushima in 2011. We should inform ourselves of the adverse effects of these accidents.

Nuclear weapons testing

In the late 1950s and early 1960s, several thousand nuclear weapons were exploded in the atmosphere mainly by the US, former USSR, UK and France giving rise to very high levels of nuclear fallout. Exposures were very high at the time, but have declined considerably since then. However high levels of relatively long-lived nuclides such as Cs-137 and Sr-90 remain in certain areas around the world (Martin et al, 2021).

Air travel

A seven-hour airplane trip from London to New York will result in a dose of about 0.02 mSv. This is because of the increased exposures to cosmic rays at high altitudes. The radiation dose rate at an of 35,000 feet is about 0.003 millisieverts per hour. Air crews receive on average an annual dose of about 3 mGy.

Conclusion

It is concluded that most people should be better informed about radiation.

Footnotes

[1] resulting in malformations in babies

[2] all doses of radiation are in fact harmful, even very low ones, but the smaller the dose the lower the risk. Sunlight has beneficial effects as well.

[3] some external radiation can also occur from semi-immersion in radioactive clouds. These result in skin doses, as occurred after the Three Mile Island nuclear accident in the US in 1979. But most radiation exposures after nuclear accidents are from the inhalation and ingestion of radioactive isotopes in fallout.

[4] imbalances of electrical charges in the nucleus give it so much energy that it is unstable

[5] in addition, a few nuclides are continually created by cosmic ray bombardment of the earth, the most important of which is hydrogen-3 (tritium)

[6] probabilistic means we cannot be certain when these effects will occur but we can judge whether or not they are likely, and act accordingly.

[7] a mGy or milligray, is one thousandth of a gray (Gy). These are the units of radiation doses.

[8] '30 Years After Chernobyl', 10 March 2016, Dr Ian Fairlie's blog https://www.ianfairlie.org/news/30-years-after-chernobyl/

[9] stem cells proliferate indefinitely to produce more of the same stem cell and other cells at the same time. For example, when a bone marrow stem cell reproduces, it creates a bone marrow cell AND another stem cell

[10] 'Radiation and Cancer in Children', 5 December 2021, Dr Ian Fairlie's blog https://www.ianfairlie.org/news/a-report-on-radiation-risks-and-on-cancer-in-children/

[11] 'Radiation and Cancer in Children', 5 December 2021, Dr Ian Fairlie's blog https://www.ianfairlie.org/news/a-report-on-radiation-risks-and-on-cancer-in-children/

[12] 'Radiation and Cancer in Children', 5 December 2021, Dr Ian Fairlie's blog https://www.ianfairlie.org/news/a-report-on-radiation-risks-and-on-cancer-in-children/

[13] For more information on this poor state of affairs, see https://beyondnuclearinternational.files.wordpress.com/2018/07/radiation-and-harm-to-human-health_27-july.pdf and https://beyondnuclearinternational.org/2018/10/08/radioactivity-harms-us-and-no-dose-is-safe/

[14] studies of disease in human populations

[15] Here is what the US Food and Drug Administration says about tanning beds https://www.fda.gov/consumers/consumer-updates/indoor-tanning-risks-ultraviolet-rays

[16] See CND info sheets https://cnduk.org/resources/?filter=no-to-nuclear-power and websites such as https://www.ianfairlie.org/

[17] For more information, please refer to https://beyondnuclearinternational.files.wordpress.com/2018/07/radiation-and-harm-to-human-health_27-july.pdf and https://beyondnuclearinternational.org/2018/10/08/radioactivity-harms-us-and-no-dose-is-safe/

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Glossary of common radiation terms

Absorbed dose Quantity of energy imparted by ionising radiation to unit mass of matter such as tissue. 1 Gy = 1 joule per kilogram.
Activity Rate at which radioactive substances decay. Unit – the becquerel (Bq). 1 Bq = 1 disintegration per second.
Beta particle An electron emitted by the nucleus of a radionuclide.
Decay The process of spontaneous transformation of a radionuclide. The decrease in the activity of a radioactive substance.
Decay product A nuclide or radionuclide produced by decay. It may be formed directly from a radionuclide or as a result of a series of successive decays through several radionuclides.
Dose General term for quantity of radiation. See absorbed dose, effective dose, equivalent dose.
Dose factor Committed effective dose resulting from the inhalation or ingestion of 1 Bq of a given radionuclide. Unit - sievert per becquerel, symbol - Sv/Bq.
Effective dose The quantity obtained by multiplying the equivalent doses to various tissues and organs by the tissue weighting factor appropriate to each and summing the products. Unit sievert, symbol Sv.
Equivalent dose The quantity obtained by multiplying the absorbed dose by the appropriate radiation weighting factor to allow for the different effectiveness of the various ionizing radiations in causing harm to tissue. Unit sievert, symbol Sv.
Gamma ray A discrete quantity of electromagnetic energy, without mass or charge.
Half-life The time taken for the activity of a radionuclide to lose half its value by decay.
Ionisation The process by which a neutral atom or molecule acquires or loses an electric charge. The production of ions.
Ionising radiation Radiation that produces ionisation in matter.
Nuclear fission The process in which a nucleus splits into two or more nuclei and energy is released.
Radionuclide An unstable nuclide that emits ionizing radiation when it decays.
Risk factor The probability of fatal cancer or leukaemia per unit effective dose.
Sievert See effective dose.

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