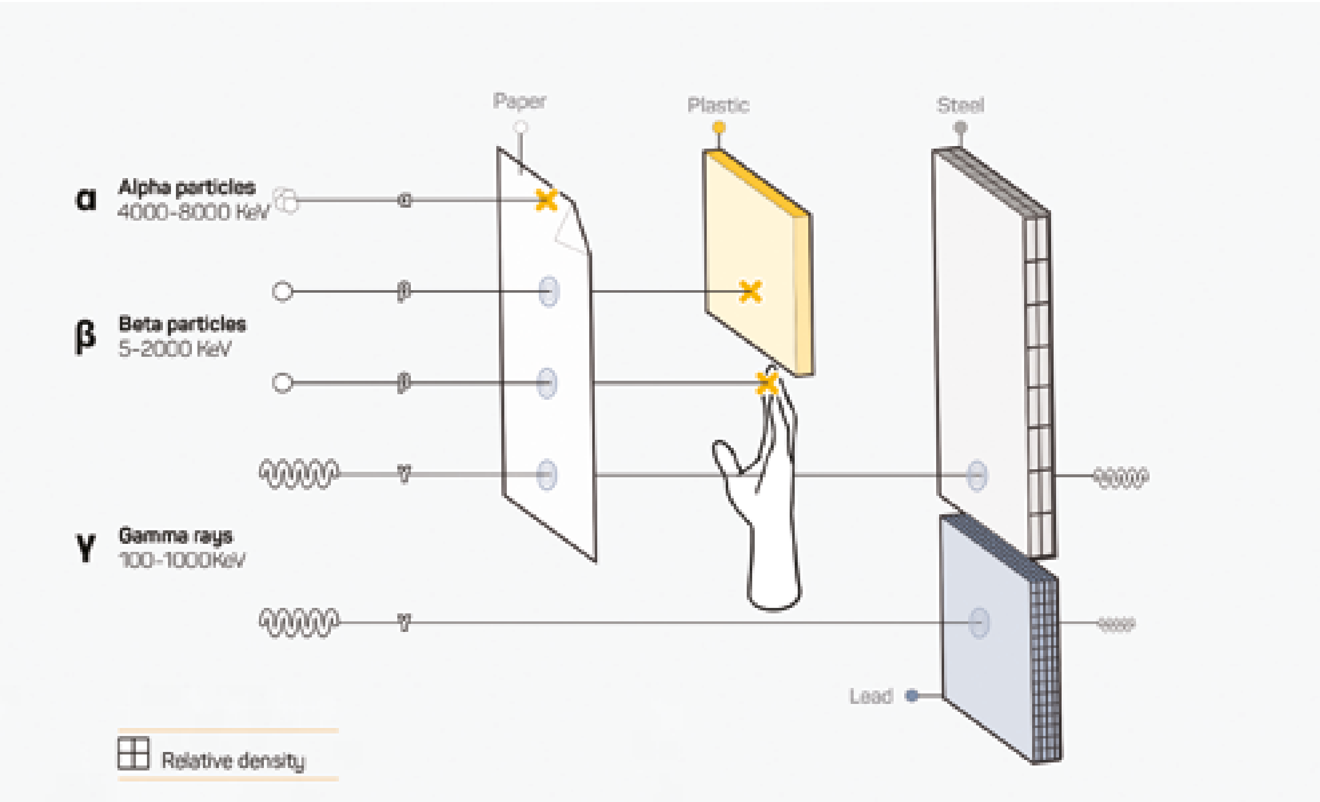
APPENDIX K: RADIATION CONCEPTS

WHAT IS RADIATION?

Radiation comprises particles and electromagnetic waves that have sufficient energy to change the composition of matter, including cells in living creatures.[1] Radiation cannot be seen or heard, and can only be detected and measured accurately and in real time using specialist equipment.

Radiation arises from the radioactive decay of elements on Earth, although it also originates from sources in space.[2] There are three different types of radiation that vary in their physical properties, as seen in Figure K.1. Those types are[3]:

- Alpha radiation: Alpha radiation consists of highly energetic, charged particles that interact with any matter with which they come into contact. As a result, they will not pass through barriers, including human skin, so they are easy to shield against and contain.
- Beta radiation: Beta radiation also consists of highly energetic, charged particles; however, they have a lower charge than alpha particles, do not interact with matter as readily and therefore penetrate further. This makes them more difficult to contain and they require increased shielding.
- Gamma radiation and x-rays: Gamma radiation is naturally occurring but is similar to manufactured x-rays and consists of highly energetic electromagnetic waves. Their high energy enables them to pass through many kinds of materials, including human tissue. Therefore, they are highly penetrative and require a significant amount of shielding.



Source: ARPANSA

Figure K.1: The penetrative ability of different forms of radiation

Neutrons are another common product of radioactive decay.[4] They have a high range of energies and can indirectly damage cells. Neutrons have a similar penetrative ability to gamma radiation.

Radioactive elements that decay can produce one or more types of radiation.[5] This has an impact on the measures that need to be in place to protect people and the environment when radioactive materials are being handled. The duration of the hazard is also affected by the speed of decay. The amount of time it takes for half of the atoms of an isotope to decay is described as a 'half-life'.[6] Some radioactive elements decay quickly—in seconds or fractions of seconds—while others can last for hundreds of thousands of years.[7]

RADIATION DOSE

The concept of a 'dose' is used to quantify the effects of radiation on living things and is the starting point when calculating the effect of radiation on humans. The 'absorbed dose' is a measure of the amount of energy that radiation delivers to a kilogram of material. Doses are measured in units known as gray (Gy).[8]

As previously described, there are a number of different types of radiation, and the impact each type has on living tissue varies. 'Weighting factors' account for the effects of radiation on living tissue when multiplied by the absorbed dose. This is known as the 'equivalent dose' and is measured in sieverts (Sv). To measure low doses, sieverts can be further broken down into millisieverts and microsieverts. One millisievert (mSv) is 0.001 Sv and one microsievert (μSv) is 0.000001 Sv.[9] Low and very low doses of radiation are understood to be below 100 mSv and 10 mSv, respectively.[10]

A weighting factor is used to define the damage caused by radiation exposure to different organs and tissues. Multiplying the tissue weighting factor by the equivalent dose to organs and tissue in humans gives the 'effective dose' to that area, also measured in Sieverts. A total effective dose to a person is the sum of the individual effective doses, which takes into account sensitivities associated with different organs.[11]

RADIOTOXICITY

'Radiotoxicity' describes the toxicity of a particular radionuclide, or combinations of radionuclides, in the event of either ingestion or inhalation. It takes into account both the biochemical (elemental) nature of the nuclide, as well as the type and energy of radiation it emits.[12] Therefore, it addresses how all the individual characteristics (rather than just radioactivity) could harm the human body in postulated scenarios that lead to ingestion or inhalation. For a single radionuclide, the radiotoxicity is obtained by multiplying the amount of the nuclide (measured in Becquerels, or Bq) by established 'dose conversion factors'.[13] For any collection or combination of radionuclides—such as those in used nuclear fuel—the radiotoxicity of the material is the sum of the radiotoxicity of all constituent nuclides. The radiotoxicity, expressed as a dose and measured in millisieverts (mSv), describes the health impact in the event of ingestion or inhalation.

HEALTH EFFECTS OF RADIATION

Exposure to radiation can have a harmful effect on human health. Radiation can damage or cause the death of human cells. Radiation also has the potential to affect the environment and other living organisms through similar mechanisms to human tissue. The effects on fauna can include increased disease, death, or reduced fertility and reproductive success.[14] The types of damage can be defined by two main categories, 'deterministic' and 'stochastic'.

DETERMINISTIC EFFECTS

Deterministic effects occur in cases of very high exposure to radiation, once a certain threshold dose has been exceeded. The severity of the effects increases as the radiation dose increases. Deterministic effects are caused by significant damage to cells or the death of a large population of cells that impact the function of human organs or tissue.[15] These effects develop soon after exposure and may occur within days or weeks of receiving a large dose of radiation. The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) defines a high dose of radiation, where acute effects of short term exposures will occur, as more than 1 Sv.[16] The most common effects are associated with bone marrow and its ability to produce blood cells. Other symptoms, such as nausea and vomiting, relate to the gastrointestinal tract.[17] Large doses can cause the central nervous system to fail and, in extreme cases, result in death. A high penetrating dose of radiation in a short period of time can cause acute radiation syndrome.[18] Depending on the dose, this syndrome is characterised by several stages of symptoms including nausea, fever, infection, diarrhoea, bleeding, cardiovascular collapse and respiratory distress, followed by either a period of recovery or death.[18] Delayed deterministic effects can also occur, such as cataracts, which take longer to develop and may not appear for many years following exposure.

STOCHASTIC EFFECTS

Stochastic effects occur as a result of damage to DNA in human cells. Due to this DNA damage, there is the possibility of long-lived mutations in cells, increasing the likelihood of cancerous growths in the future. The higher the dose of radiation received, the greater the likelihood of an effect occurring.[19] There are natural mechanisms that can repair DNA damage, although these are not always effective. Stochastic effects tend to have a longer latency period, from a few years up to tens of years. If reproductive cells are damaged, there is potential to cause hereditary effects, or gene mutations, that can affect the offspring of the exposed person.[20] This effect has been observed in experiments on mammals but no direct evidence has been shown in human populations.[21]

DOSE–RESPONSE RELATIONSHIP

The effects of radiation on biological systems are studied in two ways:

- epidemiological studies, which identify trends and patterns in health effects across a population
- biological studies, which directly observe the effects of radiation on living organisms.

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) concludes that it is not presently possible to explicitly attribute a stochastic effect in an individual to radiation exposure. This is because stochastic effects are not distinguishable from other health effects that may arise from different causes.[23] Stochastic effects are not only caused by radiation, but by other lifestyle choices, such as smoking or eating habits, which may bring about the same adverse health effects. Further, the effects may show up in some people and not in others despite their exposure to the same radiation dose. It is only possible to attribute stochastic effects to radiation through epidemiological studies that compare their incidence in an exposed population with a similar one that was not exposed.[24] This is based on the probability that radiation was responsible for an observed increase in the stochastic effects.

These difficulties are even more prominent when studying low radiation doses over long time periods. UNSCEAR recognises that when the dose of radiation decreases to low and very low amounts, the uncertainties in attributing health effects to radiation increase, and the ability to draw conclusions from epidemiological studies is significantly reduced.[25] ARPANSA considers a low dose of radiation to be from 10 to 100 mSv. A very low dose is generally below 10 mSv, which is the range of exposure any member of the public may experience annually.[26] The natural variance in human health, combined with the constant exposure people receive from natural background radiation, means that it has not been possible to establish any significant relationship between health risks and radiation exposure at low doses.

Figure K.2 illustrates the plausible dose–response relationships for health effects (such as cancer) at very low, low, and moderate doses of radiation.

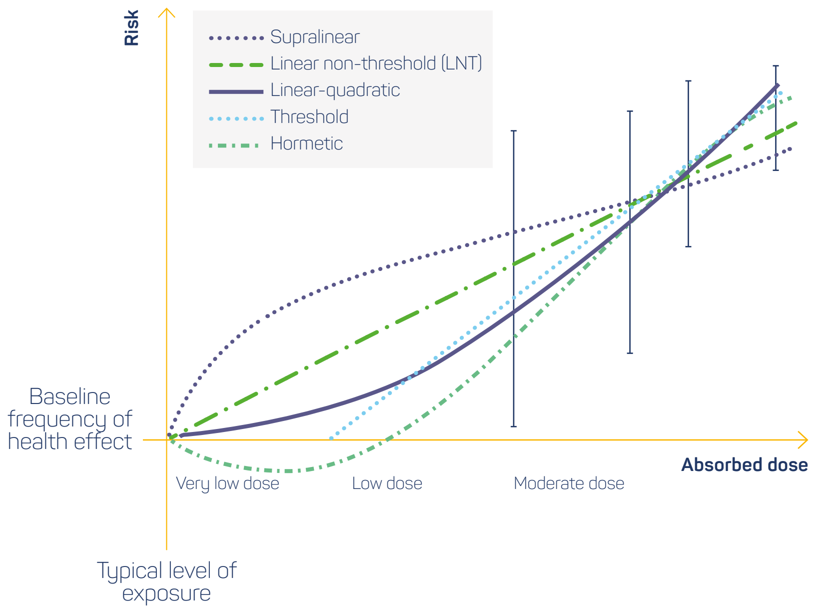


Figure K.2: Schematic plot of possible dose–response relationships (in addition to background exposure) for the risk of health effects in the ranges of very low, low, and moderate doses

Source: UNSCEAR

Given that there are five plausible relationships, there is a large degree of uncertainty in attributing health effects to moderate radiation doses or lower.

At high doses of radiation, the dose–response relationship is far more certain and stochastic effects are much more likely to arise.[27] Very high doses will lead to deterministic effects in addition to an increased risk of cancer.

NOTES

1 Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), *Fundamentals: Protection against ionising radiation*, ARPANSA, Radiation Protection Series F-1, February 2014, p. 7.

2 ARPANSA, *Fact sheet: Ionising radiation and health*, September 2015, http://www.arpansa.gov.au/RadiationProtection/Factsheets/is_ionising.cfm; World Health Organization (WHO), *Ionizing radiation, health effects and protective measures*, Fact sheet no. 371, WHO, November 2012, http://www.who.int/mediacentre/factsheets/fs371/en/; United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), *Sources, effects and risks of ionizing radiation*, UNSCEAR 2013 Report to the General Assembly with Scientific Annexes, vol. 1, scientific annex A, UNSCEAR, UN, New York, 2014, p. 1.

3 ARPANSA, 'Radiation basics – Ionising and non-ionising radiation', http://www.arpansa.gov.au/radiationprotection/Basics/ion_nonion.cfm; ARPANSA, 'Introduction to radiation basics', http://www.arpansa.gov.au/radiationprotection/Basics/index.cfm.

4 ARPANSA, 'Other types of radioactive decay', http://www.arpansa.gov.au/radiationprotection/Basics/other.cfm

5 ARPANSA, 'Radiation basics – Radioactivity', http://www.arpansa.gov.au/radiationprotection/Basics/radioactivity.cfm

6 ARPANSA, 'Radiation basics', http://www.arpansa.gov.au/radiationprotection/Basics/glossary.cfm#d1; WHO, *Ionising radiation, health effects and protective measures.*

7 WHO, *Ionising radiation, health effects and protective measures.*

8 ARPANSA, *Fundamentals: Protection*, p. 7.

9 ARPANSA, 'Units of ionising radiation measurement', http://www.arpansa.gov.au/radiationprotection/Basics/units.cfm

10 ARPANSA, *Fundamentals: Protection*, pp. 7–8.

11 ibid.

12 G Kessler, *Sustainable and safe nuclear fission energy: Technology and safety of fast and thermal nuclear reactors*, Springer-Verlag, Berlin & Heidelberg, 2012, p. 243.

13 International Commission on Radiological Protection (ICRP), *Age-dependant doses to members of the public from intake of radionuclides: Part 5 compilation of ingestion and inhalation dose coefficients*, IRCP Publication 72, Annals of the ICRP, 28(4).

14 ARPANSA, *Fundamentals: Protection*, pp. 10–11.

15 UNSCEAR, *Sources, effects and risks of ionizing radiation*, UNSCEAR 2012 Report to the General Assembly with Scientific Annexes, vol. 1, scientific annex A, UNSCEAR, UN, New York, 2012, pp. 23, 29.

16 ARPANSA, *Fundamentals: Protection*, p. 8.

17 UNSCEAR, 'Answers to frequently asked questions (FAQs)', (updated 13 February 2013), http://www.unscear.org/unscear/en/faq.html

18 ARPANSA, *Fundamentals: Protection*, p. 9.

19 ibid., p. 9.

20 ibid., p. 10.

21 ibid.

22 UNSCEAR, *Summary of low-dose radiation effects on health*, 2010 Report to the General Assembly, UN, 2010, p. 11; ARPANSA, *Fundamentals: Protection*, p. 10.

23 UNSCEAR, *Sources, effects and risks*, 2012, scientific annex A, pp. 24–25, 30.

24 ibid., p. 7.

25 ibid., pp. 8, 12, 30.

26 ARPANSA, *Fundamentals: Protection*, p. 8.

27 ibid., p. 8.

Transcripts and submissions can be found at the Nuclear Fuel Cycle Royal Commission's website: www.nuclearrc.sa.gov.au/transcripts and www.nuclearrc.sa.gov.au/submissions