BigPicture

Radiation in depth

What is the effect of radiation on astronauts? What damage can it do?

One of the biggest challenges in sending astronauts to destinations beyond the International Space Station, which orbits around the Earth, is protecting them from potentially harmful space radiation.

The types of radiation that an astronaut would be exposed to in space are different from the radiation we are all exposed to on Earth, as life on Earth is protected by the atmosphere and the Earth's magnetic field.

Space radiation is mostly made up of large subatomic particles that travel at high speeds and carry a large amount of energy. When these energetic particles pass through materials, energy can transfer from the particle to the material and break chemical bonds.

It's estimated that the amount of energy that can transfer is around six to seven times the amount needed to break the bond between two carbon atoms. Given that carbon is the basis of all (known) life, it's clear that radiation poses a substantial threat.

The International Space Station's orbit is close enough to the Earth that astronauts on it are still protected. But on missions to the Moon and other planets, astronauts will be particularly exposed.

DNA damage

Ionising radiation can damage DNA in two different ways. Either the radiation can strike and damage the DNA itself or it can ionise a water molecule in the cell to form a highly reactive molecule called a free radical, which reacts with DNA, causing secondhand damage.

DNA is a complex molecule that carries our genetic information and acts as the instructions for life. This chemical stores a record of the sequence of amino acids required to make the proteins needed by the cell and the organism. DNA is composed of two long strands on which a series of molecular structures, called bases, are attached. It is the order of the bases – of which there are four types – that dictates the amino acid sequence for proteins.

Each base is cross-linked to a complementary base on the other strand. There are four different types of bases: adenine (A), guanine (G), thymine (T) and cytosine (C). The shape of A is complementary to T, and the shape of G is complementary to C, meaning all base pairs are either A paired with T or G paired with C. These base pairs act like rungs of a ladder between the two strands. In humans, the

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strands are twisted around each other to form the distinctive double-helix shape of DNA.

There are different ways DNA can be damaged, but breaks in the long strands are the most disruptive.

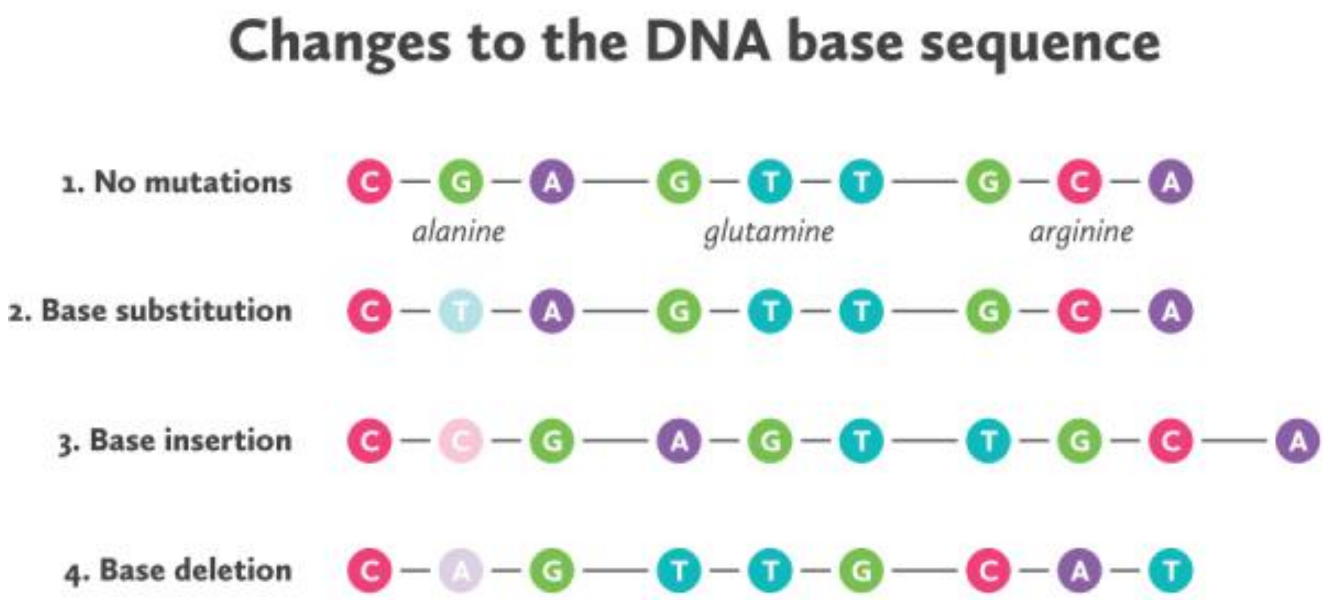
If there is a break in one of the two strands, the cell can easily repair it by using the second strand as a template and following the pairing rules A–T and G–C.

However, if there is a break in both strands, then repair becomes more difficult. The cell can make mistakes by incorrectly connecting the ends. Enzymes will sometimes 'clean' the broken ends, removing one or more of the bases before they are reconnected. If two double breaks occur, the two outer ends may be reconnected, meaning the fragment between the breaks is lost.

When the DNA damage is not correctly repaired, the base-pair sequence is permanently altered, which can change the sequence of amino acids that will be used when the cell makes a protein. This permanent change to DNA is called a mutation.

There are different types:

- base substitution (when a base changes to a different base type)
- base deletion (when a base is removed and not replaced)
- base insertion (when an extra base is added).



This diagram shows how a sample strand of DNA could be changed. For the first strand, with no mutation, the amino acids coded for are alanine, glutamine and arginine. What are the amino acids coded for if a single base is substituted? What about if a base is inserted or deleted?

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Effect on the body

Often the mutation will be so damaging that the individual cell will die. Cell death may not have a significant effect on the body, as most of our cells can be replaced.

However, if the body is exposed to a large amount of radiation over a short time and many cells are killed, this can cause acute effects, which occur soon after the exposure. Acute effects can be mild or severe, temporary or permanent – from nausea to nervous system damage or even death.

When a cell's DNA has mutated but the cell does not die, there can still be implications for health. If the mutation changes the part of DNA that provides instructions for making proteins, the cell may stop producing important proteins or start producing proteins that are damaging to the cell or the wider body.

The mutation may prevent the cell from reproducing, which usually will not have a significant effect on the body, or it may cause the cell to reproduce uncontrollably. This uncontrollable reproduction can lead to cancer.

The more radiation an organism is exposed to, the higher the risk that it will develop cancer over its lifetime, which is a primary concern when considering the effect of radiation on astronauts. This danger may seem surprising, given radiation's role in modern medicine to treat cancer. But when used as a treatment, radiation is finely controlled and targeted to try to kill only the cancerous cells.

Scientists believe that astronauts may also be at risk of other long-term health problems as a result of radiation. These include damage to the brain (possibly increasing the risk of developing Alzheimer's disease), the eyes (possibly causing cataracts), the heart, the nervous system (by accelerating the natural effects of ageing) and the digestive system. These effects are not well understood, partly due to the limited amount of data from the small number of people who have ever been to space. Research is ongoing in this field to find out more.

Radiation limits

Space agencies set limits on the amount of radiation to which they will allow their astronauts to be exposed. These figures are based on the increase in an astronaut's lifetime risk of developing fatal cancer; NASA's limit is a 3 per cent absolute increase in risk of death from cancer and ESA's is 5 per cent. (For more on absolute risk, see our article 'Are you absolutely sure?')

Space agencies also take precautions to reduce the amount of radiation astronauts are exposed to. Certain materials can be used in the construction of spacecraft to provide a shield against some types of radiation.

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On the International Space Station, astronauts are not permitted to carry out activities outside of its protection if they would be exposed to higher than normal amounts of radiation.

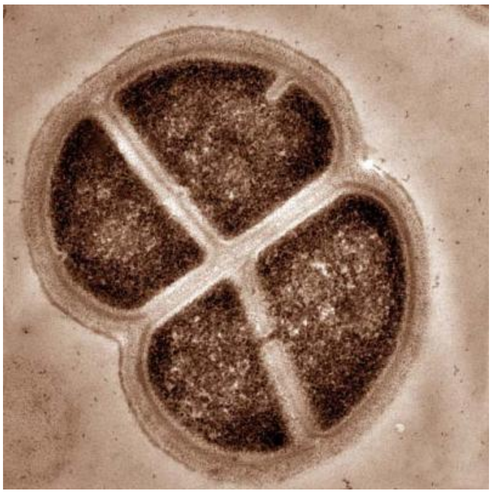
It is very difficult to design a spacecraft that can fully shield astronauts from space radiation when they are travelling beyond the protection of the Earth's magnetic field – to the Moon and other planets. All space agencies can do is to plan missions to ensure that an astronaut will not be exposed to radiation above the limit they set.

Scientists can make predictions about the amount of radiation an astronaut will be exposed to during potential missions. Using information collected by NASA's Mars rover Curiosity, scientists predict that the amount of radiation an astronaut would receive over a 180-day journey to Mars, 500 days on Mars and a 180-day return flight would increase their cancer death risk by about 5 per cent. This would exceed NASA's current limit. However, this limit was decided for missions mainly on the International Space Station. NASA could decide on a higher limit for astronauts going to Mars.

Extreme insights

Will humans or other mammals ever be able to thrive within the intense ionising radiation of space? Research into radiation-resistant microbes offers some clues.

Deinococcus radiodurans, a bacterium, can withstand 1,000 times more radiation than humans. Scientists think this is because it keeps multiple copies of its DNA in each cell – while human cells only have one – making it more likely a copy will survive when the cell is exposed to radiation.



Deinococcus radiodurans is a bacterium that can survive a thousand times more radiation exposure than a human.

There is also evidence that the bacterium can correctly join together two partial sections of DNA to form one complete copy.

Because of its ability to withstand such high amounts of radiation, as well as very dry conditions and very small amounts of food, *Deinococcus radiodurans* has been named "the world's toughest bacterium" in the 'Guinness Book of World Records'.

Its unique abilities make it an intriguing experimental subject. The experiments it is used in include simulations to help scientists predict where they might find life on Mars and tests to see whether the microbes could be used to treat sewage on long space flights.

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QUESTIONS FOR DISCUSSION

How do you decide how much additional risk of getting cancer or dying of cancer is too much?

How much of an increased lifetime cancer risk would be acceptable for astronauts?

What experiments could be performed to help us understand the effect that space radiation may have on astronauts?

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