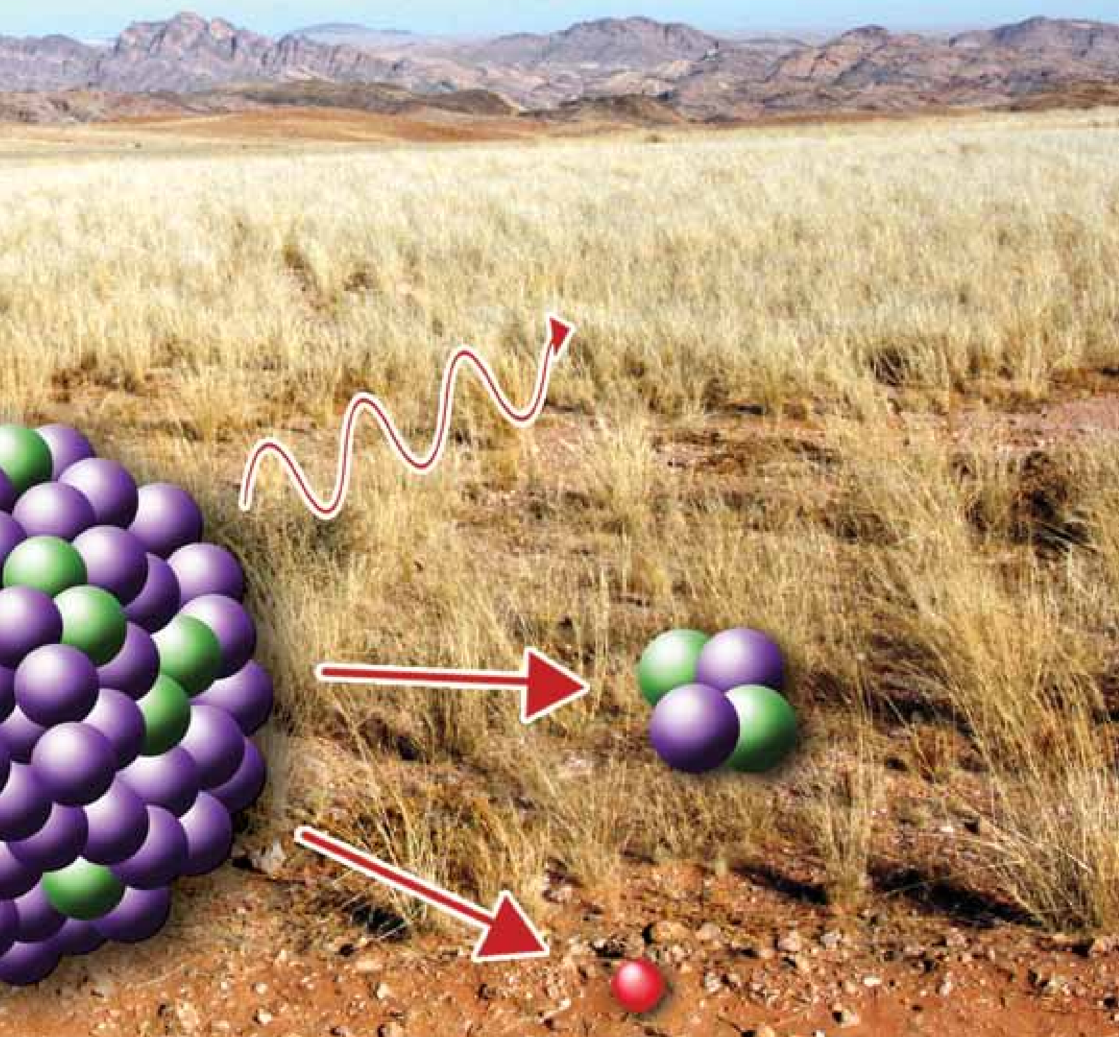
Questions Answered

about Uranium & Radiation



This booklet is intended to answer questions about uranium and radiation. It lends itself as an introductory guide for managers in the Namibian uranium exploration and mining industry, and interested members of the public alike. It was prepared by Dr Gunhild von Oertzen, Superintendent Radiation Safety at Rio Tinto Rössing Uranium Limited, and Dr Detlof von Oertzen of VO Consulting. Layout, design and illustrations by Jenny Beresford, Vocal-Motion.

This publication was sponsored by the following organisations:

The Uranium Institute
The Chamber of Mines of Namibia

AREVA

RioTinto

LANGER HEINRICH URANIUM (PTY) LTD

BANNERMAN RESOURCES

Reptile Uranium Namibia (Pty) Ltd

SWAKOP URANIUM

VALENCIA URANIUM (PTY) LIMITED

VO CONSULTING
www.voconsulting.net

Zhonghe Resources (Namibia)

Swakopmund, December 2011

ISBN: 978-99945-71-61-1

Questions Answered

about Uranium & Radiation

Safe-guarding the health and well-being of our workers, community and the environment is more than an obligation – it's the law. The Uranium Institute's (UI) commitment to the principle of "implementing best practices in the field of health, environment and radiation safety" underpins everything it does. The UI frequently draws upon considerable professional networks in academia, industry and government to remain on the leading edge of developments in the world of radiation safety. The scientists at the UI closely monitor global developments in radiation safety to ensure that our knowledge and services are up-to-date with the latest research.

Dr Wotan Swiegers
Director

Chamber of Mines Uranium Institute

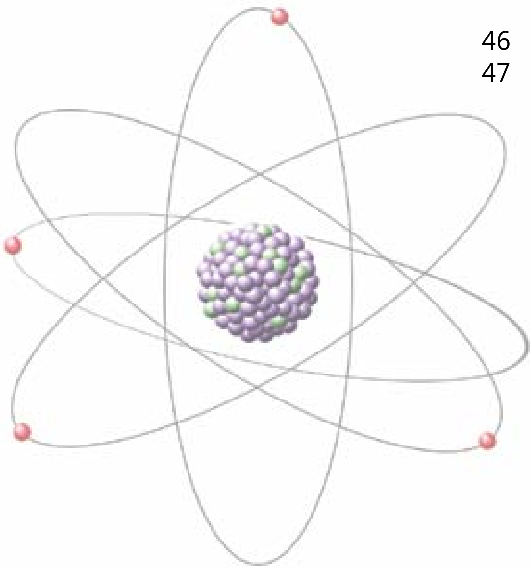
Contents

What is radiation?	6
What is electromagnetic radiation?	7
What is an atom?	8
What is radioactivity?	9
What is ionising radiation?	10
Which types of nuclear radiation are important?	11
Which external radiation is most hazardous to people?	12
Which internal radiation is most hazardous to people?	13
How can you be exposed to radiation?	14
What is uranium?	15
What are isotopes?	16
What is uranium enrichment?	17
What is a decay chain?	18
What is half-life?	20
What is secular equilibrium?	21
How is uranium used as a nuclear fuel?	22
How do we measure radioactivity?	23
What is natural background radiation?	24
How much natural background radiation is there in the Erongo Region?	25
What are man-made sources of background radiation?	26
What are the legal limits for human exposure dose from ionising radiation?	27
What is a low radiation dose?	28
What is a high radiation dose?	29
What are the biological effects of exposure to low-level radiation?	30
What are the biological effects of exposure to high-level radiation?	31
What is the linear no threshold hypothesis?	32

How can the exposure to external radiation be limited? 33
How can the intake and ingestion of radioactive materials be limited? 34
How can the exposure to radon and its decay products be limited? 35
What is the typical exposure of workers at Namibian uranium mines? 36
What is the "System of Radiological Protection"? 37
How is external occupational radiation monitored? 38
How is internal occupational radiation monitored? 39
What about pregnant workers? 40

What is radioactive contamination? 41
How is the transport of radioactive materials regulated? 42
How is radioactive waste managed? 43
What are the relative risks from exposure to radiation? 44
How is the public exposed to radiation from exploration/mining? 45

Glossary of terms 46
Literature 47



What is radiation?

Radiation is travelling energy.
Radiation can be in the form of electromagnetic waves or subatomic particles.

We live in a sea of radiation, and benefit from many forms of radiation in our everyday lives, including from radio waves, microwaves, visible light and x-rays.

Radiation can be harmful, especially when we are exposed to too high doses and/or for too long, for example to x-rays and nuclear radiation.

Many forms of radiation are beneficial and essential to our survival. Some types of radiation can be hazardous and therefore pose risks to people. Two examples of high-energy potentially hazardous radiation are x-rays and nuclear radiation emitted by radioactive materials.

Different forms of radiation are defined by the energy, i.e. how low or high the energy is, and the type, i.e. whether it is in form of electromagnetic waves or subatomic particles.

It is important to understand the different types of radiation, which types and how much of such radiation can be hazardous, and how we can protect ourselves against harmful radiation.

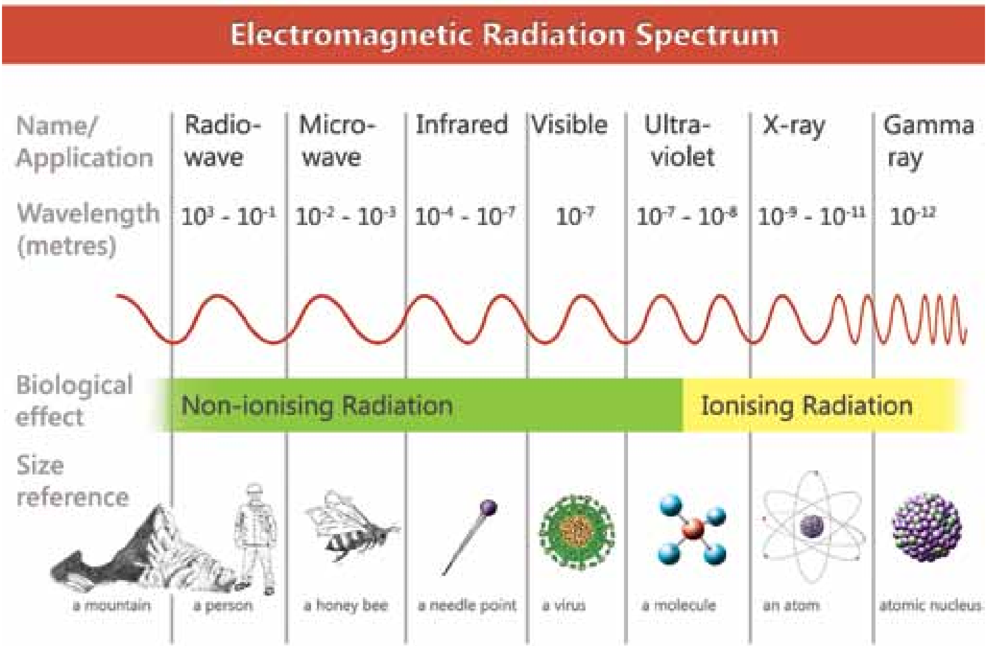
What is electromagnetic radiation?

Electromagnetic radiation is made up of coupled electric and magnetic waves.

The type of electromagnetic radiation depends on its energy and its associated frequency (how fast the waves are wiggling) and its size (how large the wavelength is).

For example, radio waves can be longer than a soccer field or as small as a soccer ball. Microwaves are about the size of a large insect, while infrared (heat) waves are the size of a needle point (fraction of a millimetre).

Low energy electromagnetic radiation is non-ionising; high energy electromagnetic radiation is ionising and is explained on page 10.



What is an atom?

The basic building block of matter is the atom.

Atoms are extremely small – if you place ten million of them next to each other, they will form a line of one millimetre, i.e. about the size of the full stop at the end of this sentence.

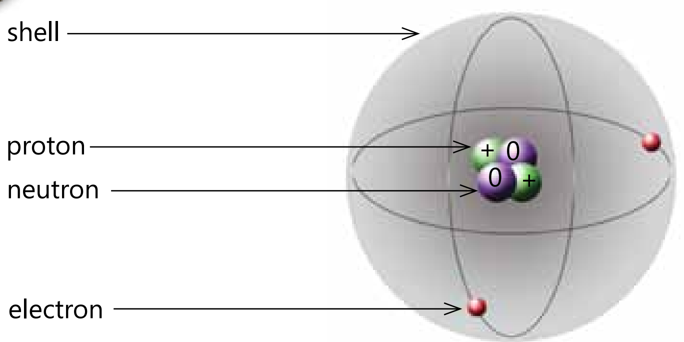
Atoms have structure, much like a peach: they consist of a very small, very dense inner nucleus (like the core of the peach) and an extended, spread out external shell (like the flesh of the peach).

The nucleus of the atom consists of ***protons*** (positive charge) and ***neutrons*** (uncharged). The shell consists of electrons. Electrons are much lighter than protons or neutrons (almost 2,000 times lighter).

Atoms have the same number of protons and electrons, so that they look electrically neutral from the outside.

Different types of atoms have different numbers of protons/electrons. For example, a hydrogen atom has one proton and one electron, and a uranium atom has 92 protons and electrons.

The same type of atom can have different numbers of neutrons, for example a hydrogen atom can have zero, one or two neutrons. The different types of the same atom are then called isotopes (see page 16).



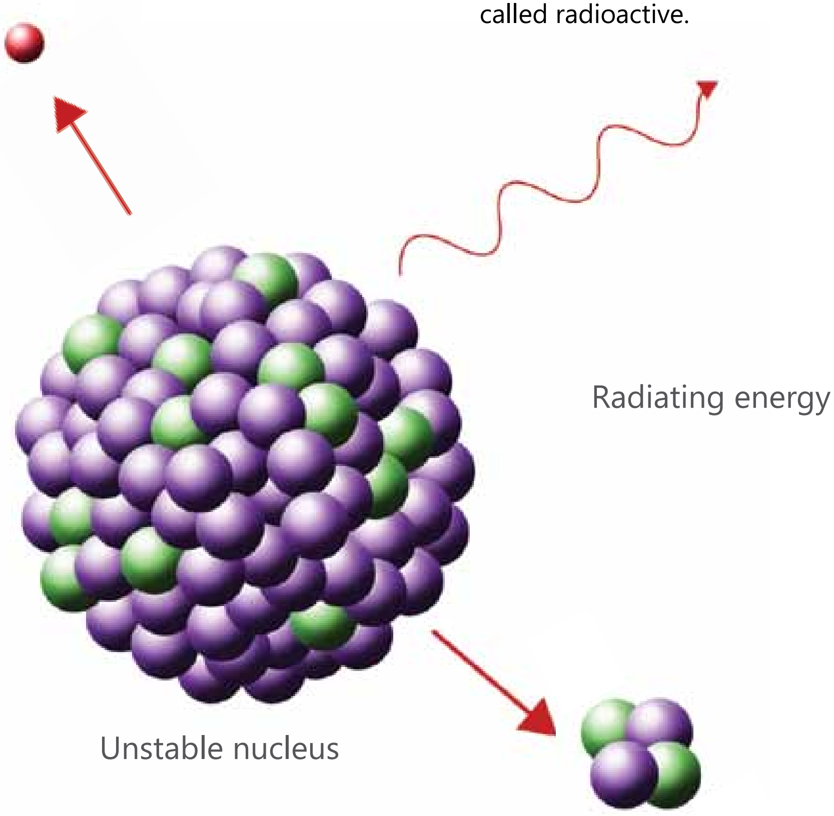
What is radioactivity?

Radioactivity is the disintegration of unstable atomic nuclei.

If an atomic nucleus is large, or has too many protons relative to the number of neutrons, it may be unstable.

Unstable nuclei emit energetic particles or electromagnetic waves. This is referred to as nuclear radiation.

Atoms with unstable nuclei are called radioactive.



Radioactive nuclei can emit three different types of radiation: alpha, beta and gamma radiation.

What is ionising radiation?

Ionising radiation is high-energy radiation.

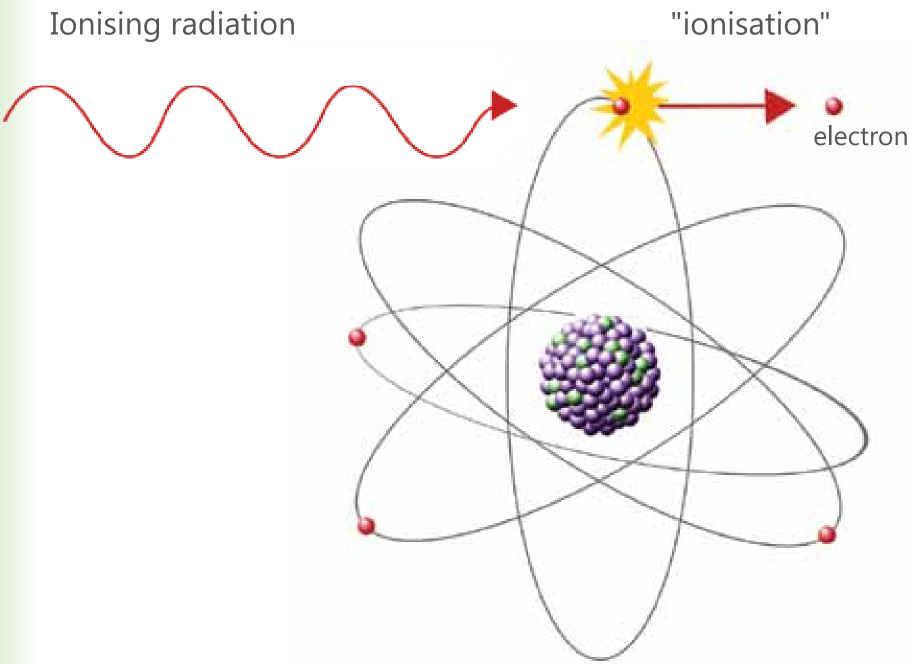
If radiation (be it subatomic particles or electromagnetic waves) is very energetic, it has the ability to strip electrons from atoms.

An atom that has lost one or more electrons is called an ion.

Radiation with the ability to rip out one or several electrons from an atom is referred to as ionising radiation.

High-energy ultra-violet radiation (UV), X-rays, gamma rays and nuclear alpha and beta radiation are different forms of ionising radiation.

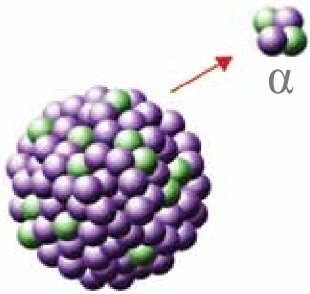
Radiation which does not have sufficient energy to damage atoms is called non-ionising radiation. Examples of non-ionising radiation are radio waves, radar, microwaves, infrared (heat) radiation and visible light.



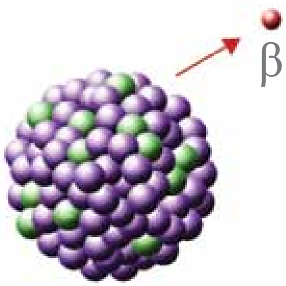
Which types of nuclear radiation are important ?

Radioactive nuclei emit three types of ionising radiation: alpha (α), beta (β) or gamma (γ) radiation.

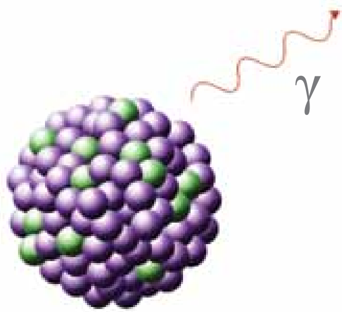
α Alpha radiation consists of 2 protons and 2 neutrons (the same as a helium nucleus). Of the three radiation types, it is the heaviest and most charged. It travels only a few centimetres in air and is easily stopped by a sheet of paper and by human skin.



β Beta radiation consists of electrons which are emitted from the nucleus. They are much lighter than alphas (almost eight thousand times lighter) and only half as charged as an α. They travel a few tens of centimetres in air or 1 to 2 cm in human tissue. Betas are easily stopped by a sheet of aluminium foil.



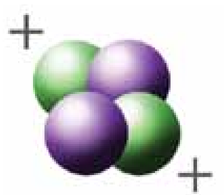
γ Gamma radiation is high energy electromagnetic radiation emitted from the nucleus. This type of radiation is emitted after an alpha or beta decay, as a result of the subatomic particles in the nucleus rearranging themselves. Gamma radiation has no charge and no mass, and travels many metres in air. It can be stopped by a thick layer of dense material, such as lead or concrete.



Which external radiation is most hazardous to people?

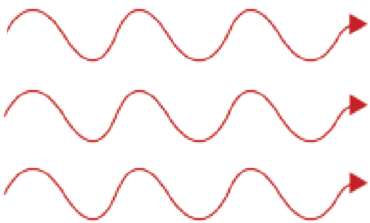
The effect of ionising radiation on humans depends on whether it is external or internal radiation. Gamma radiation is the most penetrating type of nuclear radiation and hence the most hazardous externally.

α Alpha radiation, made up of heavy (on the nuclear scale), charged particles, is stopped easily by the outer layers of human skin. These layers are dead and therefore not harmed by exposure to alpha radiation.



β Beta radiation is much lighter than alpha radiation and is therefore more penetrating than alpha radiation. It penetrates through several layers of skin, but does not penetrate to the more sensitive inner organs. The risk of exposure to external radiation from beta particles is therefore usually low except if the doses are very high.

γ Gamma radiation is the most penetrating of the three nuclear radiation types. It is able to penetrate the human body, and is therefore the primary type of radiation which contributes to the external radiation hazard. Thick layers of lead or concrete are needed to reduce the intensity of gamma radiation emitted by radioactive materials.



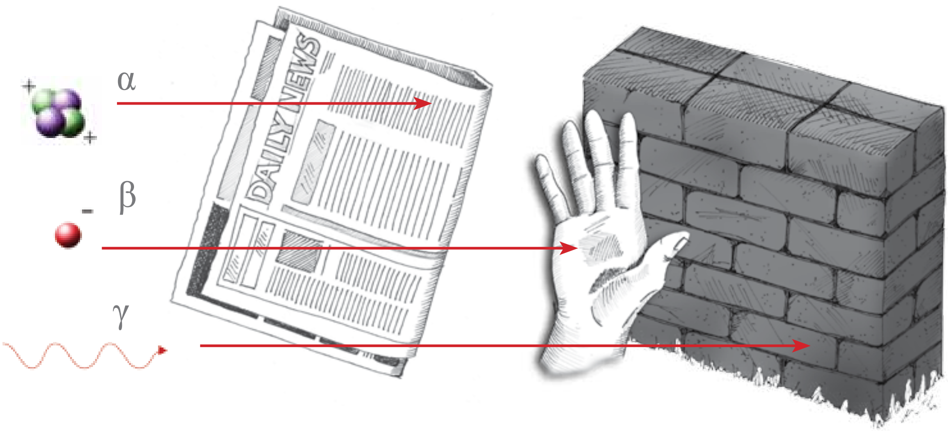
Which internal radiation is most hazardous to people?

Alpha radiation is the most ionising type of nuclear radiation, and hence is the largest internal radiation hazard.

Alpha particles are charged and heavy. Internally, e.g. when inhaled into the lungs, an alpha particle deposits a large amount of energy into a small volume (just like a rhino running into a crowd of people will damage a few people severely). Alpha radiation is therefore the primary contributor to internal radiation damage.

Beta particles are much less ionising than alphas. They are therefore less significant in terms of their contribution to internal radiation damage relative to alphas.

The internal hazard from gamma radiation is relatively minor, because the quantities of radioactive materials inhaled or ingested are almost always small.

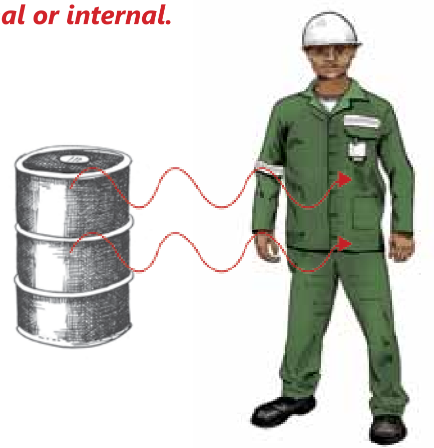


Neutrons as generated in nuclear fission are not relevant in uranium exploration and mining.

How can you be exposed to radiation?

Radiation exposure can be external or internal.

External exposure is mainly from gamma radiation, and typically occurs from radioactive ores, stockpiles of uranium-bearing waste rock, or filled uranium oxide drums and containers packed with such drums.



Inhalation of uranium-bearing ore dust or uranium dust leads to internal exposure, mainly from alpha radiation.

Inhalation of radon gas and its decay products leads to internal exposure to alpha radiation.

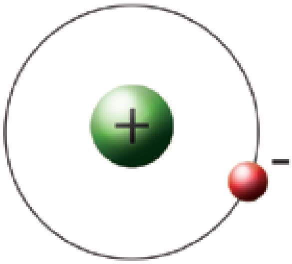
Ingestion (swallowing) of uranium-bearing ore dust or uranium dust leads to internal exposure, mainly from alpha and gamma radiation.

What is uranium?

Uranium is a heavy radioactive metal.

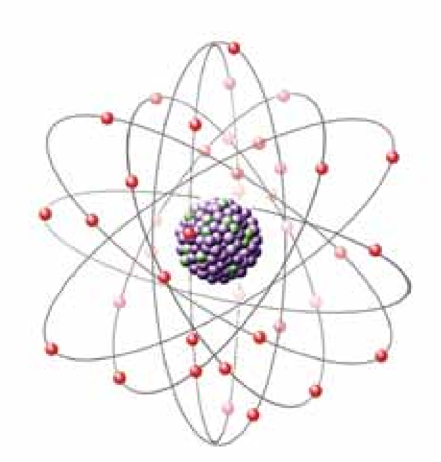
The world around us is made up of atoms. There are 92 different types of naturally occurring atoms in nature.

The simplest atom is hydrogen, having 1 proton and 1 electron.



Next in the series is helium, with 2 protons and 2 electrons, and so on.

The heaviest of the naturally occurring atoms is uranium, with 92 protons and 92 electrons.



A uranium atom with 146 neutrons is called U-238, one with 143 neutrons is called U-235 and one with 142 neutrons is U-234. These different types of uranium atoms are called isotopes (refer to page 16).

1 litre of water (one water molecule consists of 2 hydrogen atoms combined with 1 oxygen atom, H_20) weighs 1 kg.

1 litre of uranium metal weighs almost 19 kg, and 1 litre of uranium oxide (U_3O_8) weighs approximately 16 kg.

What are isotopes?

Atoms having the same number of protons/electrons but with different numbers of neutrons are called isotopes.

The number of electrons in the shell of an atom determines what kind of atom it is: Hydrogen, for example, has only one electron, and only one proton. The number of neutrons does not make a difference to the type of atom, so atoms of the same type can have different numbers of neutrons. Atoms with different numbers of neutrons but the same number of protons/electrons are called isotopes.

Uranium has three natural isotopes:

U-238 (146 neutrons, 99.3%),

U-235 (143 neutrons, 0.7%),

and U-234 (142 neutrons, 0.005%).

The above uranium isotopes have 92 protons, and are all radioactive. This is the reason why they are also called radio-isotopes.

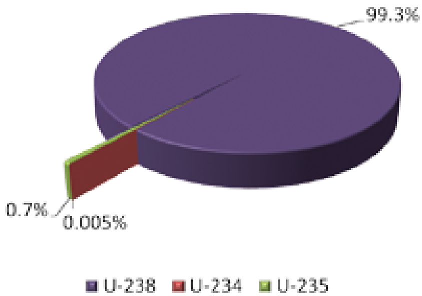
Hydrogen has three isotopes:

Hydrogen $^{1}_{1}H$ nucleus

Deuterium $^{1}_{2}H$ nucleus

Tritium $^{1}_{3}H$ nucleus

Composition of natural uranium



What is uranium enrichment?

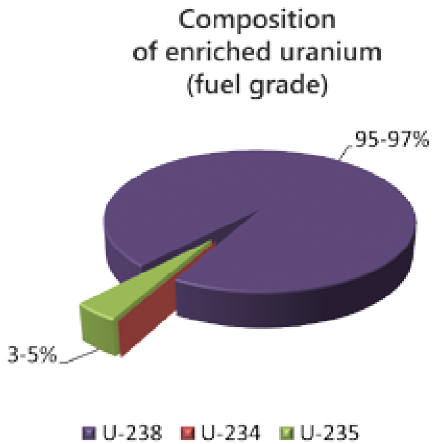
Enrichment is the modification of uranium's natural isotope ratio to increase the percentage of U-235.

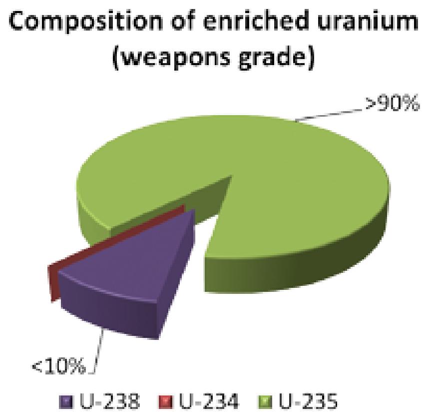
Natural uranium consists of 99.3% U-238 and only 0.7% U-235, which is the fissile isotope needed as a nuclear fuel.

U-238 has 146 neutrons, whereas U-235 has only 143 – it is therefore lighter. In enrichment plants, this mass difference is used to enrich the natural uranium to fuel grade uranium, which has a content of 3–5% of the sought-after U-235 isotope.

Enrichment plants that produce enriched uranium for nuclear reactors will not usually produce weapons grade uranium, which is enriched to 90% or more of U-235!

The enrichment of natural uranium requires a sophisticated technical plant on an industrial scale. Enrichment is also very energy intensive.





What is a decay chain?

A decay chain is the sequence of radioactive decay processes in which the decay of one element creates a new element that may itself be radioactive and decay in time.

When a radioactive element decays, it does this by emitting an alpha (α) or beta (β) particle from its nucleus.

The nucleus is irrevocably changed in this process – the element transforms into a different chemical element.

When uranium-238 decays, it emits an alpha particle and becomes thorium-234. Thorium-234 itself is also radioactive and therefore unstable, and decays by emitting a beta particle, transforming into protactinium-234m. The process continues until a stable element is reached, in this case lead-206 (Pb-206). This is called the uranium decay chain.

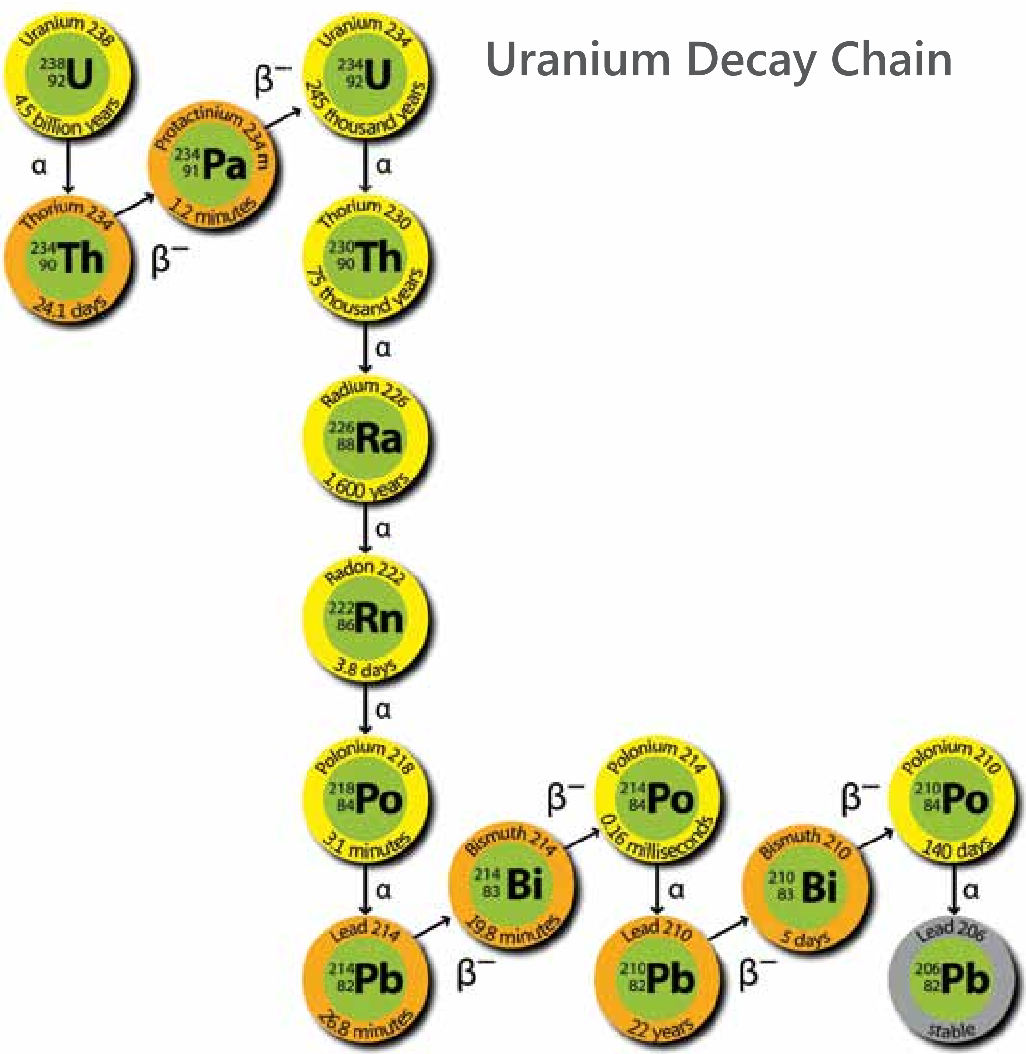
Uranium-235 is the head of an entirely independent decay chain, which is also called the actinium chain.

A third chain is headed by thorium-232 and is called the thorium chain.

Naturally occuring radioactive materials therefore consist of the parent element plus all its decay products, which are also called daughters. All the daughters in a decay chain are radioactive except the final element in the chain which is stable.

The decay chain starting with U-238 is called the uranium decay chain.

Uranium Decay Chain



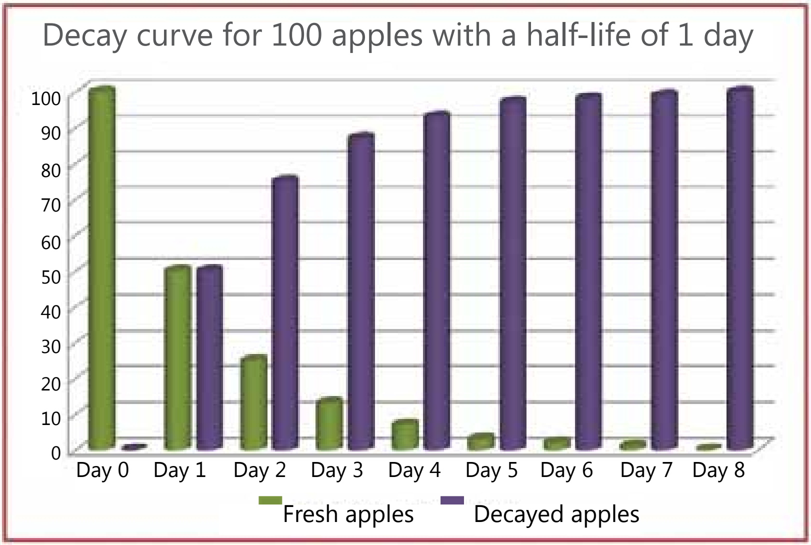
What is half-life?

Radioactive half-life is the amount of time it takes for one-half of a given material to undergo radioactive decay.

A long half-life means the element decays slowly, so is weakly radioactive.
A short half-life means the element decays quickly, so is strongly radioactive.

To illustrate: for 100 apples with a half-life of 1 day,

- after 1 day, 50 apples have decayed,
- after 2 days, another 25 apples have decayed,
- after 3 days, another 12 (or 13) have decayed, and so on.



Examples:

Element	Half-life
U-238	4.5 billion years
U-235	703 million years
U-234	245 thousand years
Radon (Rn-222)	3.8 days

What is secular equilibrium?

Secular equilibrium occurs if the quantity of a radioactive isotope remains constant because the rate at which it is produced is equal to the rate at which it decays.

Secular equilibrium is a stable state where the quantity of a radioactive nuclide remains constant because its production rate is equal to its decay rate. It occurs when the half-life of the daughters in a decay chain is much shorter than the half-life of the parent.

This can be compared to a series of buckets overflowing into each other. Here, the rate of water flowing from each of the buckets will be exactly the same, equal to the amount which overflows from the first bucket in the series.

In the case of uranium in ore, this means that the activity of U-238 and all of its decay products is essentially the same in the ore. The same holds for the U-235 and the Th-232 decay chains.

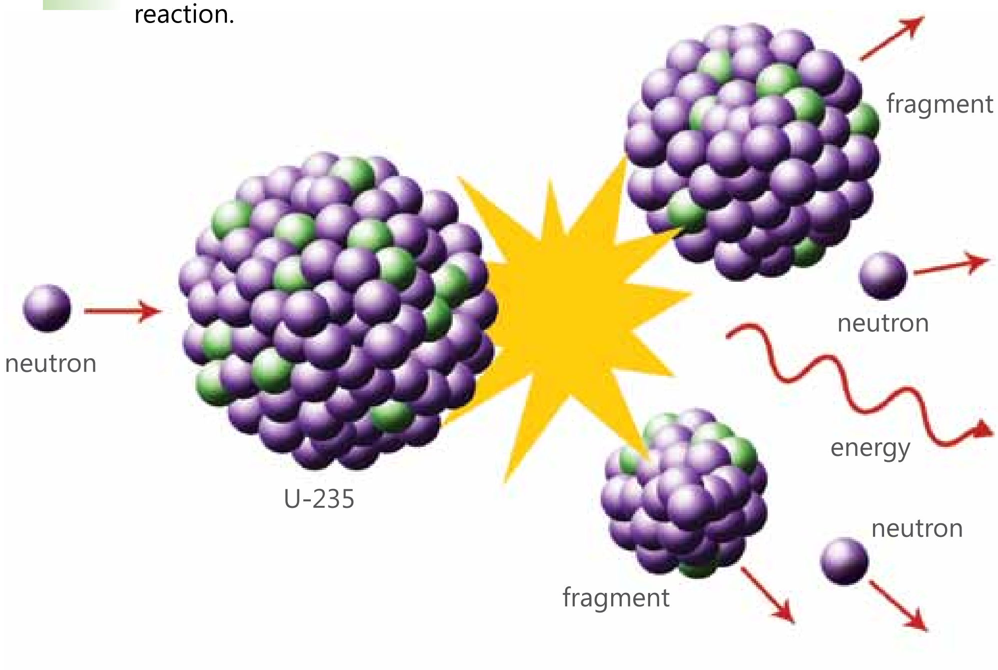
Uranium in the ore body is in approximate secular equilibrium with its decay products. The (radio)activity of ore containing U-238 in secular equilibrium with its progeny is 14 times the activity of U-238 alone.

How is uranium used as a nuclear fuel?

Uranium-235 is fissile – this means its nucleus can split into two parts, and thereby release a large amount of energy, which can be used to generate electricity.

Uranium-235 nuclei can be easily split by activating them with slow neutrons. Neutron activation splits the uranium-235 nucleus, and releases multiple neutrons and gamma radiation. The neutrons continue to activate further uranium-235 nuclei. This is called a nuclear fission chain reaction.

Nuclear reactors are based on the process of nuclear fission, where the nuclei of atoms are split, causing energy to be released. The element uranium-235 is the main fuel used to undergo nuclear fission to produce energy in nuclear power plants.



The large amounts of energy released in a controlled nuclear fission chain reaction are used to produce steam. The pressurised steam then drives a turbine, which generates electricity.

How do we measure radioactivity?

Radioactivity is measured in Becquerel (Bq).

Equivalent dose is measured in Sievert (Sv).

Radioactivity is measured in decays per second, or counts per second. The unit "decays per second" is called the Becquerel, which is abbreviated Bq.

1 Bq = 1 decay per second.

One thousand Becquerel can be abbreviated as 1 kBq.

For example, 1 g of granite has an activity of about 2 Bq.

1 g of pure natural uranium has an activity of about 25,000 Bq.

1 g of uranium oxide (U_3O_8) has an activity of about 21,000 Bq.

Human exposure to ionising radiation is measured in Sievert (Sv) and indicates the biological effect of ionising radiation.

One Sievert is equal to an energy of 1 Joule deposited into 1 kilogram of tissue, which is also referred to as the equivalent dose to the affected body or tissue.

Because the Sievert is a large unit, we often use the milli-Sievert (mSv), which is a thousandth of a Sievert, or the micro-Sievert (µSv), which is a millionth of a Sievert.

1 Sv = 1,000 mSv
1 mSv = 1,000 µSv
1 µSv = 1,000 nSv

The Sievert measures the biological effect of ionising radiation.

What is natural background radiation?

Naturally occurring radiation in our environment is called natural background radiation.

Our environment is filled with a "sea" of radiation from various natural sources.

Our soils, rocks, and water contain radioactive materials, such as uranium, thorium and potassium (and many more). This leads to direct external radiation and to internal radiation by way of inhalation and ingestion.

Natural background radiation is a natural phenomenon, and occurs everywhere around us. Every second of our lives we are exposed to natural background radiation emitted from the ground, outer space, the air and water.

Plants, animals and people also take up radioactive materials with food and drink, and the air they breathe.

We distinguish the following types of background radiation: terrestrial, cosmic, internal (food and drink), internal (dust) and internal (radon and its decay products).

How much natural background radiation is there in the Erongo Region?

Natural background radiation in the Erongo Region causes an average exposure dose of approximately 1.8 mSv per annum.

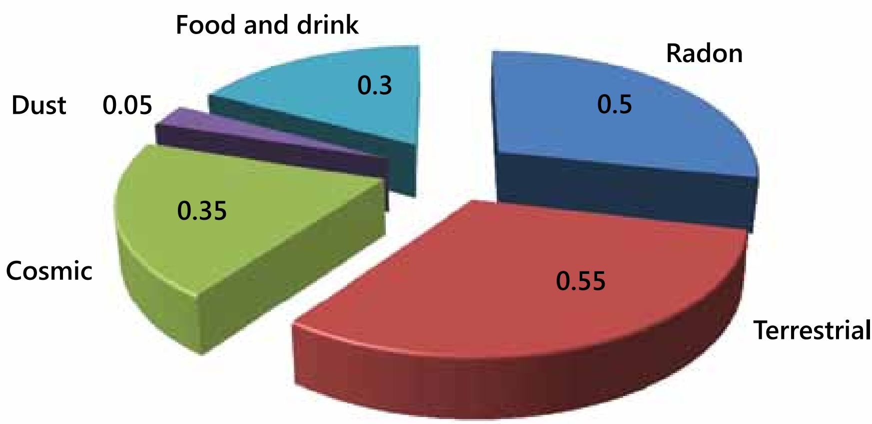
Terrestrial radiation is external radiation from the physical environment such as soils, rocks, dust clouds and water.

Cosmic radiation originates from outer space and consists of very high energy charged particles and gamma radiation. The atmosphere shields us from cosmic radiation. Its impact is therefore more pronounced at high altitudes and less so at sea level, where we have a thicker layer of atmosphere above our heads.

Internal radiation arises from the inhalation of radioactive materials in dust, and from eating or otherwise swallowing radioactive materials contained in food and drinks.

Radon is a radioactive gas which is a part of the decay chain of uranium. Its decay products, which are solids, attach themselves to aerosols and are inhaled with the air we breathe. The inhalation of radon and its progeny causes internal radiation exposure.

Natural background radiation exposure per person in the Erongo Region, in mSv per year



What are man-made sources of background radiation?

Many man-made radioactive sources contribute to our exposure to radiation. Smoking is by far the largest contributor of exposures from man-made sources.

Man-made sources of background radiation include the following:

1. Smoking is a major contributor to exposures from man-made sources. For example, smoking 1 pack of cigarettes a day leads to an exposure of more than 10 mSv per annum.

2. Consumer products, such as smoke detectors (using small amounts of Americium), ceramic glazing (using small amounts of zircon for gloss), salt replacement using potassium (which is slightly radioactive), lead to an average exposure of 0.06 mSv per annum in the U.S.

The equivalent annual exposure in Namibia is not known.

3. Security and medical x-rays lead to extra exposures; the exposure from one chest x-ray is about 0.04 mSv.

4. Fallout from past nuclear tests (open air testing was discontinued in the 1980s), contributes about 0.0017 mSv per annum.

5. The nuclear fuel cycle contributes on average about 0.0002 mSv per annum for each person living on Earth.

6. The production of radio-nuclides for medical applications leads to no measurable dose on average.

7. Frequent flying increases the exposure to cosmic radiation. A flight from Windhoek to Frankfurt contributes approximately 0.4 mSv.

What are the legal limits for human exposure dose from ionising radiation?

The Namibian occupational dose limit is 20 mSv per year. The annual dose limit for members of the public is 1 mSv, excluding the exposure dose from background radiation.

Workers are assumed to be fit and healthy adults between 18 and 65 years of age.

In addition to adults and children, members of the public include unborn babies, infants, the elderly and infirm, who may be especially sensitive to the effects of ionising radiation on the body.

The legal limit for exposure to ionising radiation is different for workers and for members of the public.

Workers are assumed to be in a working environment for some 2,000 hours per year, while members of the public spend the whole year (8,760 hours) in a particular environment.

The above dose limits are prescribed by the International Atomic Energy Agency, and also form part of the Namibian Radiation Protection Regulations (refer to the reference section on page 47).

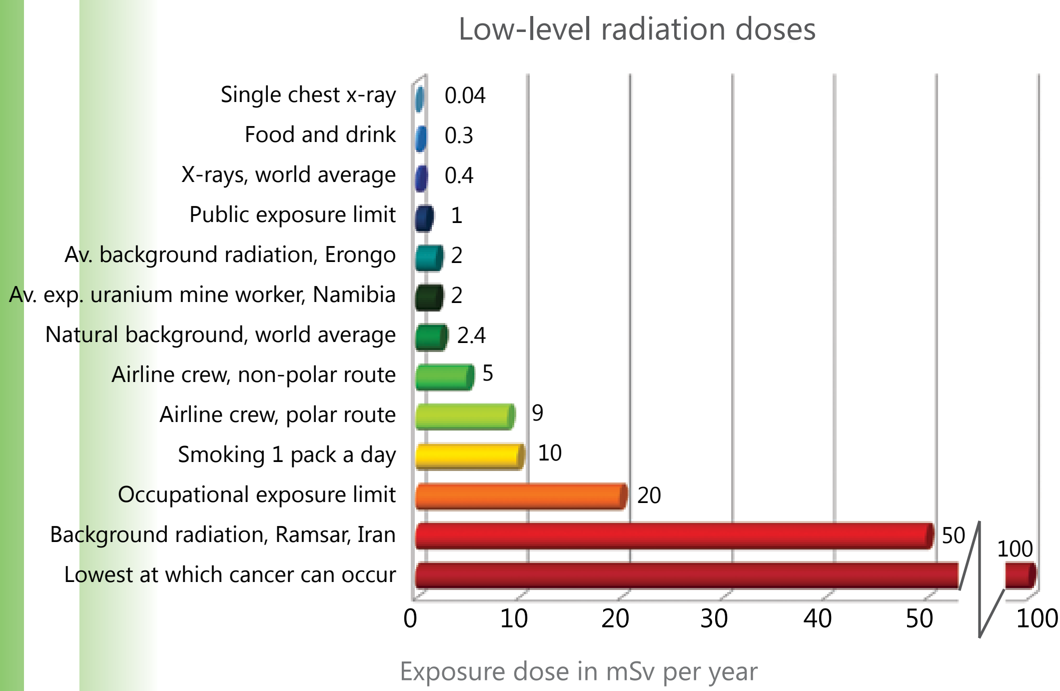
What is a low radiation dose?

Annual radiation exposure levels of up to 100 mSv are regarded as low.

Exposure to radiation resulting in a dose below 100 mSv per year is considered to be low.

This is because the lowest annual exposure dose at which there is scientific evidence for increased cancer rates is 100 mSv.

Examples of low-level radiation doses are shown below.



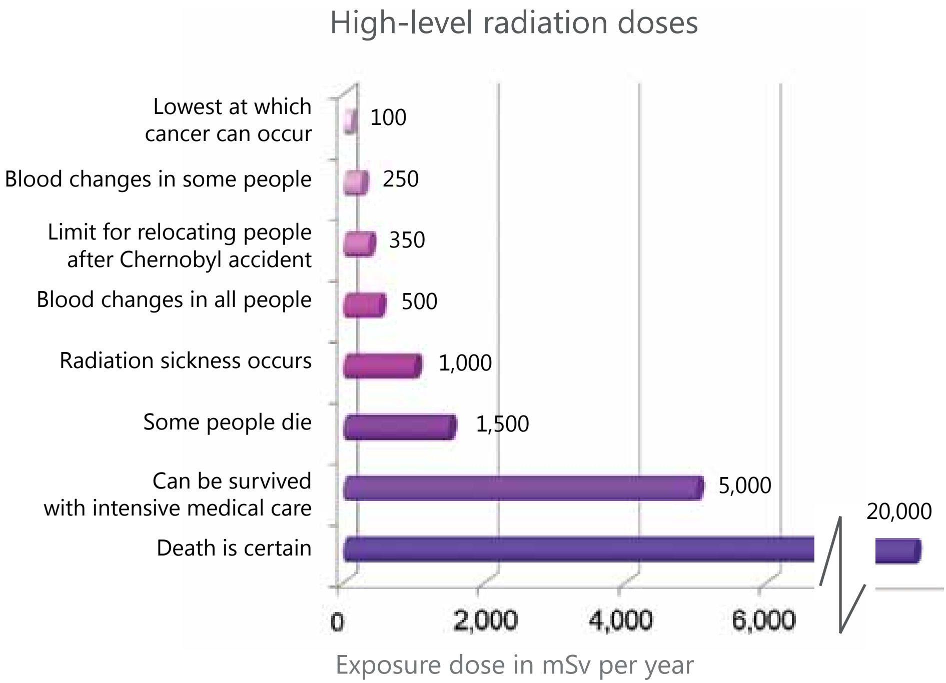
What is a high radiation dose?

Annual radiation exposures exceeding 100 mSv are regarded as high level radiation exposures.

High radiation doses are almost never experienced in everyday life. They may however occur during explosions of nuclear devices or during accidents at nuclear power plants.

Acute radiation effects, such as skin burns, temporary sterility and blood changes occur from 500 mSv, when exposure occurs in a short period of time.

Some typical examples are shown in the graph below.



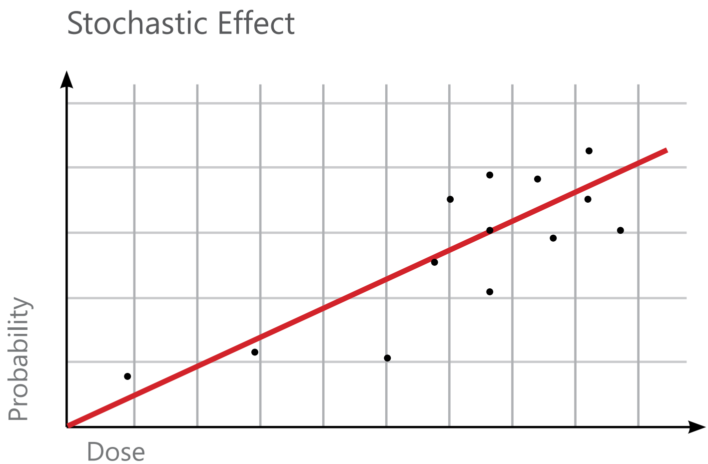
What are the biological effects of exposure to low-level radiation?

Biological effects as a result of exposure to low-level radiation are called stochastic effects, because they may occur by chance and cannot be predicted with certainty.

It is very difficult to determine the effects of exposure to low levels of radiation because of the presence of background radiation and a large number of other environmental factors which may also lead to similar effects.

However, the assumption is generally made that exposure to any amount of ionising radiation, no matter how low, will lead to some effect.

Such effects are called stochastic effects, and include cancer and chromosome aberrations. The likelihood of stochastic effects occurring increases with an increase in radiation dose. For this reason, exposure to radiation must at all times be kept ***A***s ***L***ow ***A***s ***R***easonably ***A***chievable. This internationally accepted principle of radiation protection is called the principle of optimization, also referred to as the ***ALARA*** principle.



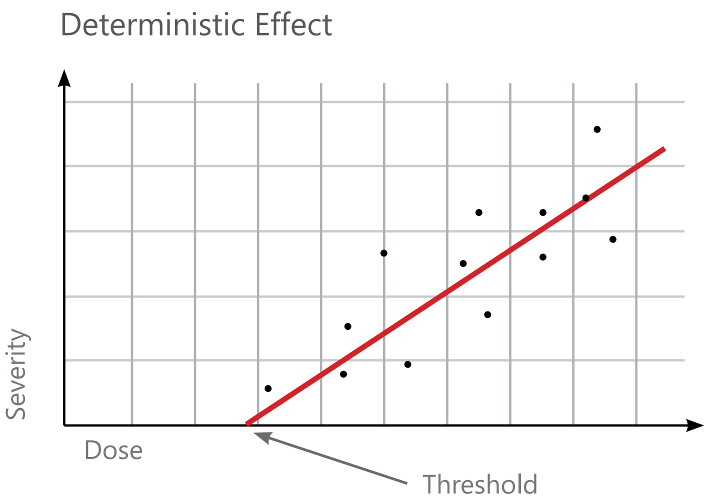
Exposure to low-level radiation leads to stochastic effects. There is no threshold dose for stochastic effects, but the probability for stochastic effects to occur increases with increasing radiation dose.

What are the biological effects of exposure to high-level radiation?

Biological effects as a result of exposure to high-level radiation are called deterministic, because they are definite to occur above a determined threshold dose.

Deterministic effects do not occur as a result of exposure to low levels of ionising radiation. However, they occur above a determined cut-off or threshold, and include effects such as skin burns, bone marrow changes, hair loss, cataract induction, tissue swelling, radiation sickness, and in the extreme case, death.

The threshold differs from one effect to the next, for example the threshold for skin burns is approximately 500 mSv.



Exposure to high-level radiation leads to deterministic effects. There is a determined threshold dose for each deterministic effect to occur, and the severity of the effect increases if the radiation dose is increased beyond the threshold dose.

What is the linear no threshold hypothesis?

The linear no threshold hypothesis (LNT) is a model of the effect of exposure to radiation which assumes that the observations of high dose effects can be extrapolated to predict low dose effects.

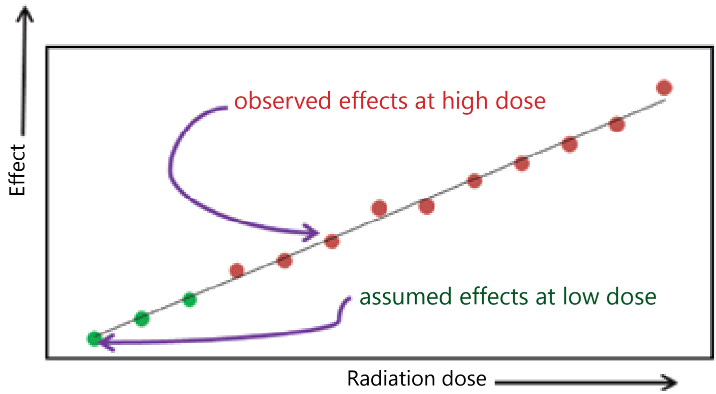
How do we know what the risks from exposure to low levels of ionising radiation are? The fact is – we do not know what they are.

What we do know is what the effects are from exposure to high levels of radiation, such as those from nuclear bombs (Hiroshima, Nagasaki) or nuclear accidents (Chernobyl).

From this the LNT infers the possible risk from exposure to much lower levels of ionising radiation, such as those at uranium mines or during medical investigations (x-rays).

The argument goes like this:

- Any amount of ionising radiation, no matter how low, has some health risk, i.e. there is NO THRESHOLD for risk.
- The amount of risk is directly proportional to the dose, i.e. the relationship between dose and effect is LINEAR.
- It does not matter over which length of time the dose was received.

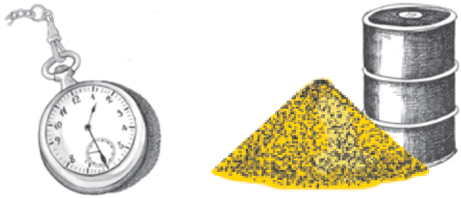


The LNT remains a hypothesis because there is no irrefutable proof for it. In fact, many scientists argue that at low exposure doses, there is NO effect due to exposure to ionising radiation. But, the linear hypothesis is still used because it is a conservative estimate of the risk of exposure to low levels of ionising radiation.

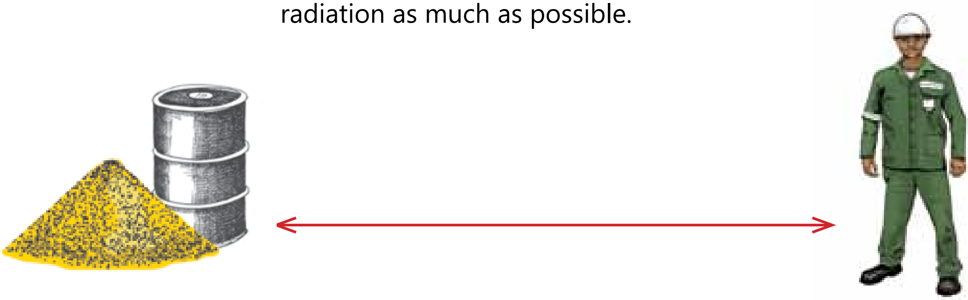
How can the exposure to external radiation be limited?

Time, distance and shielding are the main tools to limit external exposure.

1. Time: Keep the time spent in areas known to result in exposure to radiation to the essential minimum.



2. Distance: Increase the distance between yourself and a source of radiation as much as possible.



3. Shielding: Shield sources of radiation with lead, concrete, steel

How can the intake and ingestion of radioactive materials be limited?

Regularly wash your hands, and only eat in clean uncontaminated areas.

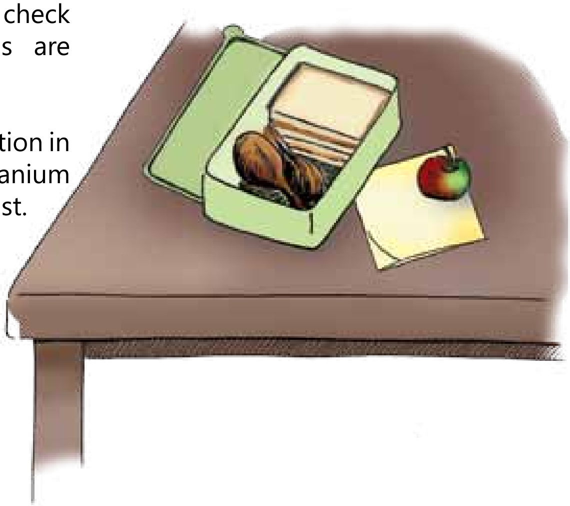
The intake and ingestion of radionuclides such as uranium, thorium and their decay products can be prevented by good hygiene practices:

1. Always wash your hands before eating, smoking and drinking.

2. Only eat in clean uncontaminated areas, and store your food in a clean area and in clean containers.

3. Undertake regular urine sampling of workers in those areas where the ingestion of uranium may occur. This is an effective indicator to check whether hygiene controls are working properly.

4. Use respiratory protection in areas with high levels of uranium or uranium-bearing ore dust.



How can the exposure to radon and its decay products be limited?

Good ventilation is the most effective radon control measure.

Radon is a radioactive gas, and is part of the decay chain of uranium.

The decay products of radon are highly radioactive solids. They readily attach themselves to aerosols in the air we breathe.

Above-ground uranium mines usually do not need active control measures in open air workplaces, because ventilation in outdoor situations is normally adequate.

When inhaled, these radon decay products stick onto the inner lining of the lung, where they continue to undergo radioactive decay, thereby leading to internal exposure to radiation.

Good ventilation ensures that radon decay products do not accumulate in the air.

However, in order to determine the risk of exposure to radon progeny, regular radon monitoring is advisable. The ambient atmospheric concentration of radon in the air is a good indicator for the potential risk of exposure to radon and its progeny.

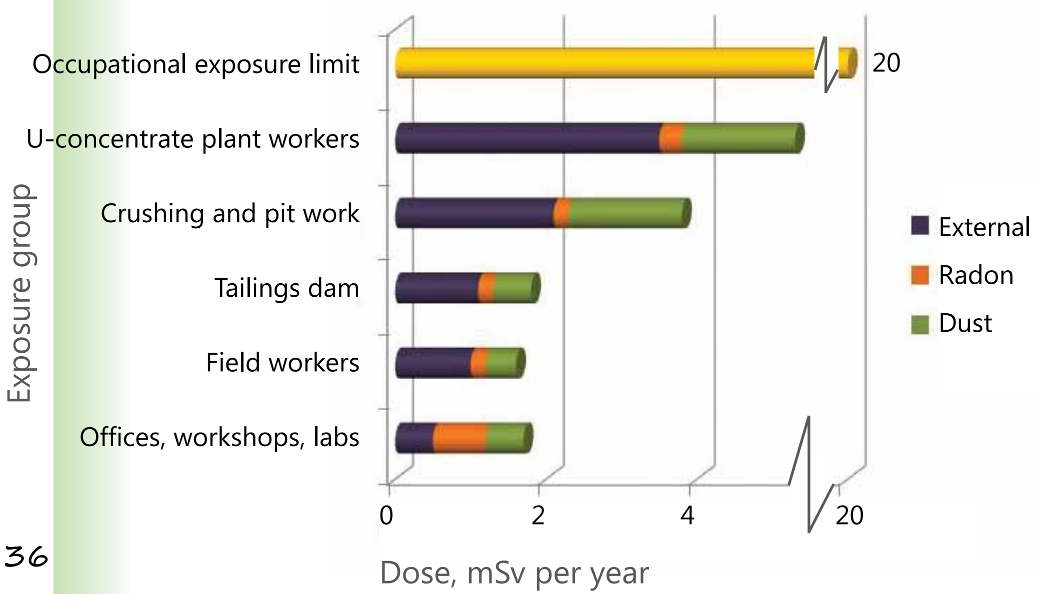
What is the typical exposure of workers at Namibian uranium mines?

The average radiation exposure of workers at Namibian uranium mines is approximately 2 mSv per year. Workers handling concentrated uranium can be exposed to higher radiation levels, but in most cases to less than 8 mSv per year.

Ore grades in Namibian uranium mines are low. Radiation exposures of mine workers are therefore usually relatively low. Situations which need regular monitoring and control are external exposures of plant workers and exposures to long-lived radioactive dust in dusty areas such as crushers and open pits.

The graph below gives some typical exposures for representative exposure groups at a Namibian uranium mine.

Typical annual radiation doses at uranium mines in mSv



What is the "System of Radiological Protection"?

Limitation, Optimisation and Justification form the so-called "system of radiological protection" proposed by the International Commission on Radiological Protection (ICRP).

The ICRP has formulated a system of radiological protection, based on three pillars:

Justification
No practice involving exposure to radiation should be adopted unless it produces a net benefit to those exposed or to society generally.

Optimisation
Radiation doses and risks should be kept as low as reasonably achievable (ALARA), economic and social factors being taken into account.

Limitation
The exposure of individuals should be subject to dose or risk limits, above which the radiation risk would be deemed unacceptable.

How is external occupational radiation monitored?

External radiation can be monitored with badge dosimeters or with electronic dosimeters.

External radiation for radiation workers is measured directly with personal dosimeters. Two types are commonly used:

1. Thermo-luminescent dosimeters (TLD), also called badge dosimeters, are worn continuously for extended periods (1–3 months) before being returned to the supplier for analysis and resetting.

A wearing period of one month ensures an optimal response time in work areas where radiation levels are higher than average.

2. Electronic dosimeters can be worn for short periods (a few hours to several days), and the dose and dose rate can be read off directly from the instrument.

This method is convenient for random sampling, but also in special situations requiring short term supervision.

The risk of exposure to external radiation can best be quantified if such exposure is regularly monitored. Management decisions should be based on actual measured data. Trivialising or guessing potential exposure doses leads to poor risk control actions.

How is internal occupational radiation monitored?

Internal radiation is often measured with pump-and-filter devices.

Internal radiation from the inhalation of long-lived radioactive dust (LLRD) can be measured with a personal pump-and-filter device, which pumps air through a filter. The filter is then analysed for its radioactivity, either directly in the instrument, or separately in a dedicated instrument used for filter analysis.

Internal radiation from the inhalation of radon decay products can be measured in two ways:

1. A personal pumping device similar to the one used for LLRD is used, and the filter is analysed for the activity due to short-lived radon decay products. Results are known immediately after the monitoring period, which minimises the risk of exposure to high ambient radon concentrations.

2. A track-etch device can be used, which records the activity due to radon gas. The device is usually placed out for extended periods (1–3 months), and afterwards sent to a lab for analysis. The exposure from radon progeny is calculated following analysis.

What about pregnant workers?

An unborn baby is considered to be a member of the public. A pregnant worker therefore has to be protected like a member of the public, not like a worker.

Namibian and international radiation protection standards specify the following dose limits:

1. An annual dose limit of 20 mSv for occupationally exposed workers.

2. An annual dose limit of 1 mSv for members of the public.

In the case of a pregnant worker, she carries a member of the public inside her, for whom the radiation protection standard of 1 mSv per year applies.

It is therefore essential to know the pregnancy status of female workers, so that they can be re-assigned to non-radiation working areas in case of pregnancy.

What is radioactive contamination?

Contamination is the unwanted presence of radioactive substances, usually on surfaces, in liquids or in solids.

The International Atomic Energy Agency (IAEA) defines radioactive contamination as follows:

Contamination means the presence of a radioactive substance on a surface in quantities in excess of 0.4 Bq/cm^2 for beta and gamma emitters and low toxicity alpha emitters, or 0.04 Bq/cm^2 for all other alpha emitters.

Natural uranium and thorium are low toxicity alpha emitters, and hence the contamination limit for uranium ores and process residues is 0.4 Bq/cm^2 for both alpha and beta radiation respectively.

Beta contamination is much more difficult to measure than alpha contamination because beta probes often cannot distinguish between ambient gamma radiation and beta radiation.

However, there are an equal number of alpha and beta emitters in the uranium decay chain. This means that the presence of a given quantity of alpha contamination implies an equal quantity of beta contamination. Hence it is often practical to measure alpha contamination only, as the beta contamination will be of similar magnitude.

How is the transport of radioactive materials regulated?

Natural uranium is exempt from licensing for transport if the activity concentration of a consignment is less than 1 Bq/g, or the activity of the consignment is less than 1,000 Bq.

If radioactive materials are to be transported, the IAEA Transport Regulations (IAEA, 2009) apply, which prescribe how radioactive materials are to be licensed, packaged, labelled and monitored before, during and after transporting them.

In the case of natural uranium, its ores and concentrates, the threshold activity concentration of 1 Bq/g and activity of 1,000 Bq apply to the head-of-chain element only, i.e. only the activity of U-238 is considered.

Any consignment in excess of these limits must be accompanied by a permit obtained from the National Radiation Protection Authority (NRPA), and must be labelled according to the IAEA Transport Regulations.

The Radiation Management Plan (RMP) has to describe the transport plan, and methods and procedures to be applied during the transport of radioactive materials.

The RMP has to be approved by the NRPA.

How is radioactive waste managed?

Each operation must have an approved waste management facility for the radioactive waste it produces. Radioactive waste is any mineral or non-mineral waste, which has an activity concentration exceeding 1 Bq/g or an activity exceeding 1,000 Bq (as determined from head-of-chain only).

Mineral radioactive waste comprises the tailings material from the uranium extraction process, uranium-bearing samples and some of the waste rock dumps.

Non-mineral radioactive waste comprises contaminated materials such as pipes, tanks, tools, radioactive scales and other waste materials which were radioactively contaminated during the exploration, mining or milling process.

The waste facility must be constructed in such a way that radiation exposure to workers and the public is limited and minimised according to the ICRP principles of radiation protection (ICRP, 2007).

What are the relative risks from exposure to radiation?

Relative risk expresses the probability that a member of an exposed group will develop a disease relative to the probability that a member of an unexposed group will develop that same disease.

The majority of scientists and regulatory agencies agree that even small doses of ionising radiation increase the risk of developing cancer. In general, the risk of cancer from exposure to radiation increases as the dose of radiation increases, refer to page 32.

It is most challenging to accurately measure the actual increase in cancer risk that may arise as a result of exposure to low-level ionising radiation. Most studies have not been able to detect an increased risk of cancer among people exposed to low and very low levels of ionising radiation.

The ICRP estimates the cancer risk from exposure to radiation to be approximately 5% per Sievert (1 Sv = 1,000 mSv) for adults. The estimate of the relative risk for exposure to low-level radiation is based on the linear no-threshold hypothesis, and is not irrefutably proven scientifically.

Health Risk	***Number per 10,000 people per year***
HIV/AIDS mortalities in Namibia	25
Smoking mortalities	min 8, max 31 (smokers only), not exactly known in Namibia
Cancer mortalities from all causes (Namibia)	7
Road deaths (Namibia)	2
Cancer due to exposure to natural background radiation of 2 mSv per year	1
Cancer due to an average occupational radiation dose of 2 mSv per year	1

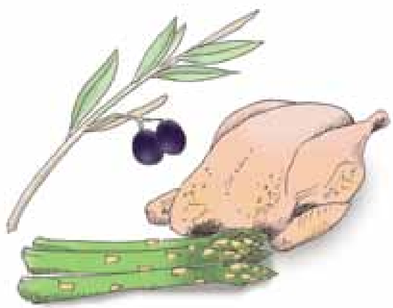
How is the public exposed to radiation from exploration/mining?

Public exposure is possible from direct external exposure to radiation sources, internal exposure from inhalation of dust and radon and internal exposure from ingestion of radioactive materials.

External exposure of the public from uranium exploration and mining activities is very low, as members of the public do not spend time at mining sites, or container stacking sites where uranium products may be stored.

Internal exposure from inhalation of dust can result if dust blows from the mine to inhabited areas. Dust control measures such as wetting of roads, road stabilisation and dust enclosures are advisable, and concentration of mining dust in inhabited areas must be monitored continuously.

Internal exposure from inhalation of radon decay products can result from exposed tailings, ore and waste rock materials. Preventive measures include covering exposed sources with soil, and monitoring of radon concentrations in air.



Internal exposure from the ingestion of radioactive materials can result if water or food is contaminated.

Contamination of water sources must be prevented, e.g. by retrieval of tailings seepage. Continuous monitoring of the water quality is recommended.

Glossary of terms

ALARA: as low as reasonably achievable
Alpha particle: subatomic particle emitted from radioactive nucleus, made up of 2 protons and 2 neutrons
Beta particle: subatomic particle emitted from radioactive nucleus, an electron
Cosmic radiation: radiation originating from outside the Earth, i.e. from the Sun and sources outside the Solar System
Daughter: decay product of nuclear decay, also called progeny
Deterministic radiation effect: effect due to high radiation dose within short period of time
Electron: negatively charged particle which forms the atomic shell
EPD: electronic personal dosimeter, used to monitor external radiation
Fission: process whereby a nucleus splits into two parts and releases energy and neutrons
Fissile: capable of sustaining a chain reaction of nuclear fission
Gamma radiation: high energy electromagnetic radiation emitted from radioactive nucleus as a result of radioactive decay
Hydrogen: chemical element whose atom has one proton and one electron
IAEA: International Atomic Energy Agency
ICRP: International Commission on Radiological Protection
Ingestion: intake and swallowing
Ionising radiation: radiation with sufficient energy to ionise an atom
LLRD: long-lived radioactive dust
mSv/a: milli-Sievert per year, 0.001 Sv per year
Neutron: neutral particle inside atomic nucleus
Nuclear fuel: material used as fuel (source of energy) in nuclear reactors
Nucleon: collective expression for protons and neutrons
Nucleus: central part of atom, contains protons and neutrons
Occupational exposure: exposure incurred while at work
Parent: radionuclide whose radioactive decay gives rise to a decay product
Probabilistic radiation effect: chance effect due to low radiation doses over extended periods of time, see stochastic effect
Proton: positively charged particle inside atomic nucleus
Progeny: radioactive decay product
Public exposure: exposure incurred by members of the public, i.e. persons not working for the operation under consideration
Radon: radioactive gas from the uranium decay chain
Radioactivity: atomic nucleus undergoing decay
Stochastic radiation effect: chance effect due to low radiation doses over extended periods of time
TLD: thermo-luminescent dosimeter, used to monitor external radiation
UV: ultraviolet radiation

Literature

Atomic Energy and Radiation Protection Act, No. 5 of 2005, Government Gazette of the Republic of Namibia, Windhoek.

Radiation Protection and Waste Disposal Regulations: Atomic Energy and Radiation Protection Act, 2005 (Act No. 5 of 2005), Government Gazette of the Republic of Namibia, 2011.

IAEA, 1996: International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115, Vienna.

IAEA, 2004: Occupational Radiation Protection in the Mining and Processing of Raw Materials, Safety Series No. RS-G-1.6, IAEA, Vienna.

IAEA, 2009: Regulations for the Safe Transport of Radioactive Material, Safety Series No. TS-R-1, IAEA, Vienna.

ICRP, 1993: Protection Against Radon-222 at Home and at Work, ICRP Publication 63, Pergamon.

ICRP, 2007: The 2007 Recommendations of the International Commission on Radiological Protection, ICRP Publication 103.

ICRP, 2009, ICRP Statement on Radon, ICRP.

UNSCEAR, 2000, Report of the United Nations Scientific Committee on the Effects of Atomic Radiation to the General Assembly, United Nations, New York.

UNSCEAR, 2006, Effects of Ionising Radiation, Report to the General Assembly, United Nations, New York.

UNSCEAR, 2008, Sources of Ionising Radiation, Report to the General Assembly, United Nations, New York.

Chamber of Mines Uranium Institute

Cottage Avenue, Swakopmund, Namibia
e-mail: director@u-institute.com
website: www.namibiauraniuminstitute.com