Radiation and Health

factsheet 12

Author: Dr Bill Williams

energyscience.org.au

There is no ‘safe’ dose of ionising radiation.

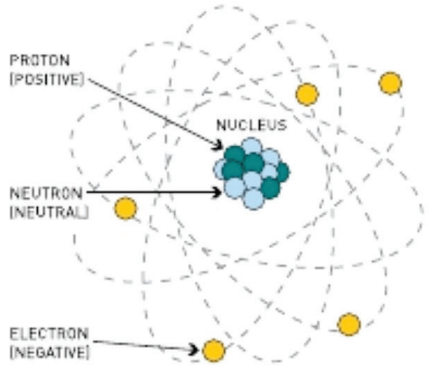
New investigative techniques reveal increasing detail about the health impacts of ionising radiation.

Expanding the nuclear fuel chain – uranium mines, reactor programs, nuclear waste – increases the threat to plant, animal and human gene pools.

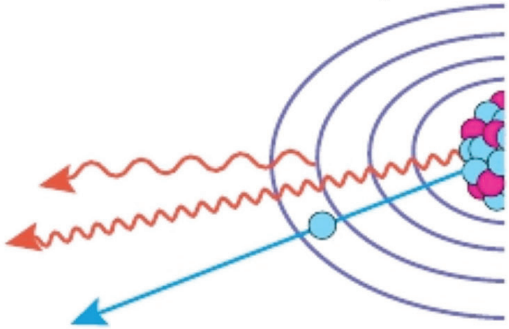
RADIATION

Radiation is energy travelling through space: the earth is bathed in this energy: it is a part of our habitat.

an atom



energy emitted from an atom or nucleus in the form of waves or particles



There is a spectrum of electromagnetic radiation energies, from radio waves, through microwaves and visible light waves, to ionizing radiation: the radiation emitted by the 'building blocks' of matter, or *atoms*.

Certain atoms (such as uranium) are said to be 'unstable' or *radioactive*: they have excess internal energy which they release in the form of *gamma rays* or fast-moving sub-atomic (alpha and beta) particles.

Through these spontaneous emissions (*decay*), the radioactive atom eventually disintegrates into a totally new atom. All the time, the atom is progressing in one or more steps towards a stable state where it is no longer radioactive. The radiation is referred to as *ionising* because electrically-charged particles called *ions* are produced in the materials it strikes.

How Radiation Hurts Us

- **all humans are made of cells**

- **every cell contains DNA**

- **DNA carries the 'story' for the cell**

- **radiation injures the DNA-story**

- **the injured DNA-story can be passed on to other cells and to your future generations.**

Uranium 238 (U238) Radioactive Decay

TYPE OF RADIATON	NUCLIDE	HALF-LIFE
	uranium-238	4.47 billion years
α	thorium-234	24.1 days
β	protactinum-234m	1.17 minutes
β	uranium-234	245000 years
α	thorium-230	8000 years
α	radium-226	1600 years
α	radon-222	3.823 days
α	polonium-218	3.05 minutes
α	lead-214	26.8 minutes
β	bismuth-214	19.7 minutes
β	polonium-214	0.000164 seconds
α	lead-210	22.3 years
β	bismuth-210	5.01 days
β	polonium-210	138.4 days
α	lead-206	stable

TYPES OF IONISING RADIATION

Electromagnetic (or 'photon') radiation

- *Gamma rays* (similar to X-rays) represent energy transmitted in a wave without the movement of material but they have great penetrating power and can pass through the human body. Thick barriers of concrete, lead or water are used as protection from them.

Subatomic particles

- *Alpha particles* have a positive electrical charge and are emitted from naturally occurring heavy elements such as uranium and radium, as well as from some man-made elements, such as plutonium. Because of their relatively large size, alpha particles collide readily with matter and lose their energy quickly. They therefore have little penetrating power and can be stopped by the first layer of skin or a sheet of paper. However, if alpha sources are taken into the body, for example by breathing or swallowing radioactive dust, they can inflict more severe biological damage than other radiations.

- *Beta particles* are fast-moving electrons (negatively charged) and are much smaller than alpha particles and can penetrate up to 2 centimetres of human flesh.

- *Neutrons* and *protons* are particles from the nucleus of atoms, much heavier than electrons

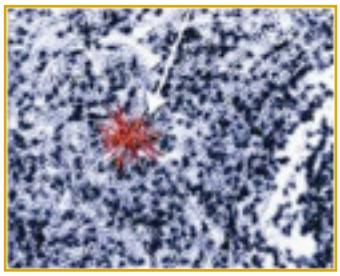
Sub-atomic particles are generally high-linear energy transfer (high-LET) radiations, which transfer more energy per unit length (more densely ionising) and are more destructive as they traverse cells.

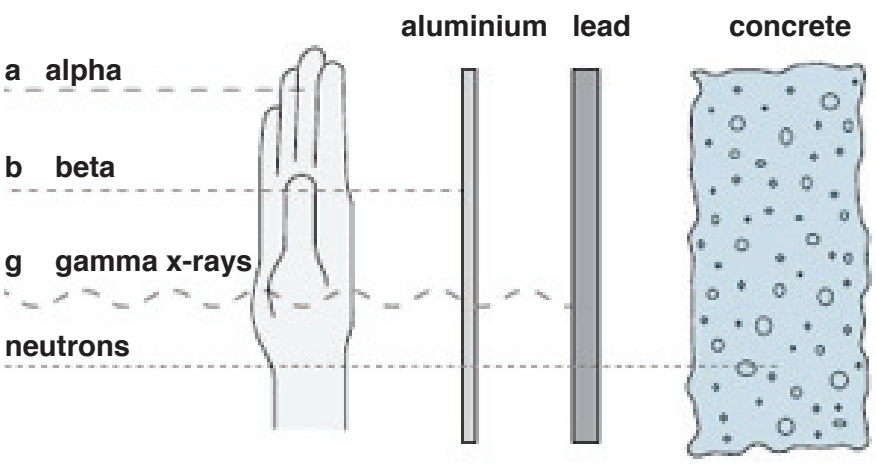
Equal doses of different types of radiation produce different biological effects – expressed as relative biological effectiveness (RBE). The RBE varies with radiation type (its LET), the dose and dose rate, and biological system. The heavy subatomic particles (alpha particles, neutrons) are most biologically damaging.

Radiation track in dog lung

The image below is a micro-radiograph depicting alpha-particle tracks from a plutonium particle in the lung tissue of a beagle dog.

If the alpha-particle hits the DNA inside a lung cell, it may trigger abnormal cell growth and lead to lung cancer.



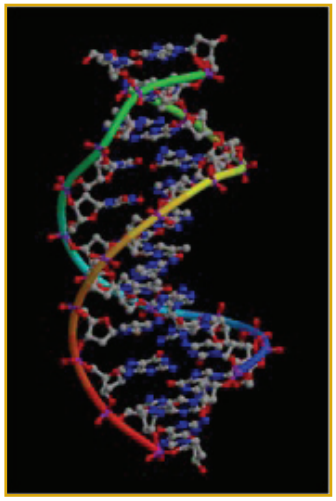


HEALTH IMPACTS

Even low doses of ionising radiation can cause damage to the DNA in living cells. Atoms and molecules become excited or ionised , which can:

- produce free radicals
- break chemical bonds
- produce new chemical bonds and cross-linkage between macromolecules
- damage molecules that regulate vital cell processes (e.g. DNA, RNA, proteins).

In recent years biologists have identified specific radiation-induced damage at the molecular level to base sequences on chromosomal DNA, including double-strand breaks, large deletions and sister chromatid exchange.



DNA damage and repair

Ionising radiation injures DNA through two mechanisms:

- transference of its energy to atoms in biological tissue which then becomes electrically charged leading to the formation of free radicals which then damage the cell's genetic blueprint (DNA) leading to genetic mutations; and
- direct DNA disruption along the track the ionising radiation traverses through the cell's nucleus

Double-stranded breaks occur where both strands of the double helix DNA molecule are simultaneously disrupted resulting in a high likelihood of mutations. They are most likely mechanism to cause genetic mutations. This predisposes to the initiation of cancer when the regulatory mechanisms of the cell fail. Cancer may not appear for 10-40 years, although this 'latent period' can be as short as 5 years for leukaemia.

The cell can repair certain levels of damage in its chromosomal DNA. At low doses cellular damage is usually repaired. However, faulty repairs may lead to cell death or to proliferation of abnormal cells which form a cancer.

At higher radiation levels, cell death results. At extremely high doses, cells cannot be replaced quickly enough, and tissues fail to function; this can result in massive cell death, organ (particularly bone marrow and gut) damage and death to the individual.

No 'safe' dose

We exist in a naturally radioactive environment: the rocks and mountains, the sun in particular, produce a *background level*. Average exposure to background ionising radiation worldwide is measured at 2.4 *millisievert* (mSv) per year. About half of this is from radon and its decay products.

However, human activities in the past century have greatly increased our exposure to ionising radiation, through atomic weapons development, testing and use, as well as uranium-mining and nuclear electricity generation and through medical diagnostic and therapeutic procedures. The on-going atmospheric fallout from the the nuclear weapons testing in the 50s and 60s adds an average extra dose to us all of 0.02 mSv per year.

Unfortunately there is no level of radiation exposure below which we are at zero risk: even low-level medical exposures such as chest X-rays (0.04 mSv per test) carry a quantifiable risk of harm. While high doses of ionising radiation will cause greater health damage, even low doses are associated with adverse environmental and human consequences.

RESEARCH REPORT #1: Hiroshima and Nagasaki Survivors

This report from 2012 covers deaths 1950-2003, so represents very long term follow up of events in 1945. 86,611 people are included in this cohort. There were 17% more cancer deaths in those exposed, and these were especially in those aged less than 10 at the time of the bombing with 58% more deaths in that group.

This study shows there is an increased risk of dying of cancer throughout life, and this risk increases proportional to radiation dose as the group ages. The dose response is approximately linear – i.e. twice the exposure dose = twice the risk, four times the exposure dose = four time the risk.

The risk of cancer mortality increased significantly for most major sites, including stomach, lung, liver, colon, breast, gallbladder, oesophagus, bladder and ovary. An increased risk of other diseases including the circulatory, respiratory and digestive systems was observed, but more research is needed to show this is from radiation.

Most significantly is that there is no safe lower dose – even low dose exposure showed increased risk.

See page 14 for all research report references

In 2006, a comprehensive review of the effects of exposure to low levels of ionising radiation, the *Biological Effects of Ionising Radiation VII* reports (BEIR) was published by the National Academy of Sciences in the USA. The BEIR committee reviewed recent epidemiologic studies of the atomic bomb survivors, as well as recent studies of populations exposed to radiation from medical studies, from occupational exposures and from exposure due to releases of radioactive materials into the environment.

RESEARCH REPORT #2: Biological Effects of Ionising Radiation VII (NAS-2006)

BEIR VII reconfirmed that the *Linear No Threshold* (LNT) model: there is no safe lower dose, and the higher the dose the higher the risk of adverse health effects. This the most practical model to estimate radiation risks, especially for radiation protection purposes:

"The balance of evidence from epidemiologic, animal and mechanistic studies tend to favour a simple proportionate relationship at low doses between radiation dose and cancer risk. ... [T]he risk of cancer proceeds in a linear fashion at lower doses without a threshold and ... the smallest dose has the potential to cause a small increase in risk to humans."

Using the LNT risk model, the BEIR VII estimated:

- Over a lifetime, a dose of 1 mSv creates an excess risk of cancer of approximately 1 in 10,000. Higher doses are associated with proportionately higher risk, eg a dose of 100 mSv would cause 1 in 100 people to develop cancer.
- Approximately 1 individual in 100 persons would be expected to develop cancer from a lifetime (70 years) exposure just to background x and gamma rays (excluding radon and other high LET radiations).

Ionising radiation effects on humans

Radiation effects can be categorised by when they appear.

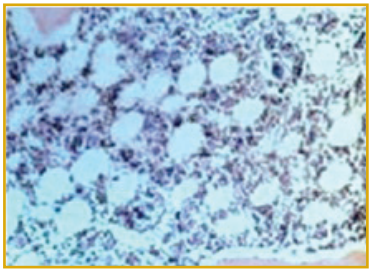
Prompt effects: including radiation sickness and radiation burns.

High doses delivered to the whole body within short periods of time can produce effects such as blood cell changes, fatigue, diarrhoea, nausea, fitting, coma and death.

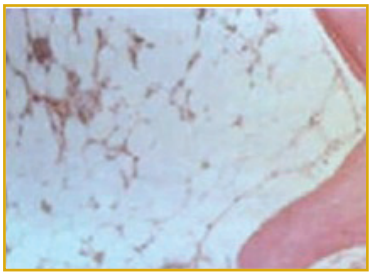
These effects will develop within hours, days or weeks, depending on the size of the dose. The larger the dose, the sooner a given effect will occur.

Doses over 100 millisievert (mSv) cause a variety of both reversible and persistent effects in different organs – particularly the blood-forming organs, the gastrointestinal system and the central nervous system. Doses over 250 mSv cause acute effects detectable by common blood testing, and symptoms of 'acute radiation sickness' develop at higher doses.

The magnified image below is a slide of normal human bone marrow. The second image is *aplastic*: damage to the DNA in the bone marrow cell nuclei has been passed on from one cell generation to the next and led to marrow failure. The resulting anaemia, immune collapse and bleeding tendency are likely to be fatal if untreated.



normal



aplastic

Delayed effects:

Cancer: If DNA abnormalities are passed on to subsequent generations of cells, the abnormal coding can lead to tissue abnormalities, including cancers. Cancer development is a multistage process, and is similar for radiation-associated cancers as for spontaneous cancers or those associated with exposure to other carcinogens.

RESEARCH REPORT 3: Medical Tests in Children (CT Scans)

In May 2013 a study in the British Medical Journal examined the cancer risk in children and adolescents following exposure to low dose ionising radiation from computerised tomography (CT) scans. The records of 10.9 million children and adolescents were identified between 1985 and 2005. Of these, 680,211 individuals had a CT scan at least one year before a cancer diagnosis.

Overall cancer incidence was 24% greater for exposed than for unexposed people. These included brain tumours, many solid tumours (eg bowel, melanoma, female genital and thyroid), leukaemia and lymphoid cancers. The risks increased for those exposed at younger ages. The increased rates of cancer were continuing in the later years of follow up. There was no follow up after the trial concluded, so the total lifetime risk of cancer cannot be determined.

The average dose of radiation per person was 4.5 mSv, and the average follow up after exposure was 9.5 years. This large study confirms that low dose ionising radiation has significant adverse health effects. The follow up time is short- more cancers are likely as these children and adolescents get older.

At all doses, including doses too low to cause any short-term effects or symptoms, radiation exposure increases the long-term risk of cancer and chronic disease for the rest of the life of those exposed.

Such cancers and other illnesses will take many cell generations to develop, so it may be several decades before they are detected. The delay in a cancer manifesting makes identification of the initiating radiation exposure event – the 'trigger' - very difficult.

This difficulty is amplified by the fact that leukemia and other cancers induced by radiation are indistinguishable from those that result from other causes, such as tobacco or other environmental toxins.

RESEARCH REPORT #4: Nuclear Industry Workers

In June 2005, the British Medical Journal published a review of the risk of cancer from low doses of ionising radiation to workers in the nuclear industry in 15 countries. This report demonstrated a definite excess risk of cancer.

407,391 workers were individually monitored for external radiation with a total follow-up of 5.2 million person years. The excess relative risk for cancers other than leukaemia was 0.97 per Sv (i.e. 97% increase – almost double per seivert). The excess relative risk for leukaemia excluding chronic lymphocytic leukaemia was 1.93 per Sv (i.e.193% or almost triple per Sievert).

On the basis of these estimates, 1-2% of deaths from cancer among workers in this cohort may be attributable to radiation. These estimates, from the largest study of nuclear workers ever conducted, are higher than the risk estimates used for current radiation protection standards. The results suggest that there is a small excess risk of cancer, even at the low doses and dose rates typically received by nuclear workers in this study (90% of workers received cumulative doses less than 50 mSv).

These results indicate that a cumulative exposure for adult workers of 100 mSv – the current recommended 5 y occupational dose limit – would lead to a 10% increase in mortality from all cancers, and a 19% increased mortality from leukemia (of types other than chronic lymphatic leukemia). While the fact that the risk from low-level radiation exposure may be 'small' in any particular individual, when this risk is translated across populations, the increase in numbers of cancers can be considerable.

Non-cancer diseases

Ionising radiation is also known to increase the risk of occurrence and death from some non-cancer diseases, including heart and lung disease. Recent evidence strongly indicates that circulatory disease mortality also increases at low doses, such as occur in many nuclear industry workers. The increased risk of death from heart and other circulatory diseases is comparable in magnitude to the radiation cancer risk.

For cardiovascular disease risk, a recent study indicates that the increased lifetime risk of death from circulatory disease estimated for the British population is about ten times higher for a child exposed to radiation before ten years of age compared with exposure occurring after age seventy. These differences relate to both increased sensitivity in the young and the generally longer remaining years of life for effects to become manifest.

RESEARCH REPORT #5: Vascular Disease (mostly strokes and heart attacks)

A 2012 review drew on eligible research papers published since 1990 looking at cardiovascular disease.

It looked at individuals who had low dose whole body exposures (cumulative average less than 0.5 Sv whole-body exposure, or exposures at a low dose rate (i.e. less than 10 mSv/day).

They were all either atomic bomb survivors or occupationally exposed. The estimates of risk of increased deaths from circulatory disease are similar to those for radiation-induced cancer.

The overall excess risk of dying after exposure to low doses or low dose rates of radiation may be about twice that currently assumed due to radiation-induced cancers alone.

Reproductive effects

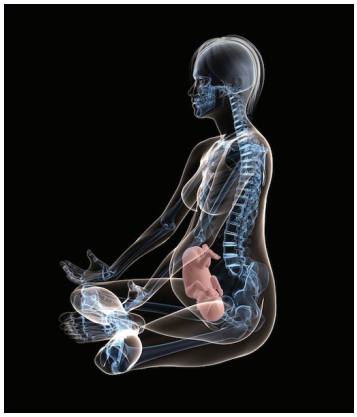
Rapidly proliferating and differentiating tissues are most sensitive to radiation damage.

Consequently, radiation exposure can produce developmental problems, particularly in the developing brain, when an embryo/foetus is exposed in the womb. The developmental conditions most commonly associated with prenatal radiation exposure include low birth weight, microcephaly, mental retardation and other neurological problems.

RESEARCH REPORT #6: Risk of childhood cancer from X-ray before birth

Initially reported in 1956, many studies have since confirmed that low dose ionising radiation increases risk of childhood cancer. This 1996 paper by Doll and Wakeford reviewed the evidence and found that one abdominal X-ray of a foetus increased the risk of childhood cancer by 40%.

More recently doses of radiation from X-rays have reduced. However there was no lower dose threshold that has been shown to be safe. The evidence has been supported by both a dose response relationship (i.e. as the exposure increases the risk of cancer increases) and by animal models.



Genetic effects

Ionising radiation is a powerful cause of genetic damage. If the damage to the DNA code occurs in a reproductive cell (egg or sperm) the coding error may be passed onto offspring, resulting potentially in birth defects and cancers in the children. While many plant and animal experiments leave no doubt that radiation exposure can alter genetic material and cause disease, and human data also show DNA and chromosomal damage associated with exposure to ionising radiation, a resultant effect on genetic diseases has not yet been observed in the case of the Hiroshima and Nagasaki survivors. This does not mean that there is no such effect in humans. It may be that there were genetic abnormalities produced that were incompatible with life and those pregnancies therefore ended in miscarriage. It may also be that an increased rate of genetic abnormalities will be found in future generations, that is, the changes will skip one or more generations.

There is no reason to believe humans are immune to such harm. Evidence is emerging of an increased risk of leukemia in children whose parents were both exposed to the atomic bombings in Japan.[i]

Evidence has also emerged recently that the cell may exhibit the phenomenon of *genomic instability*, where the progeny of an irradiated cell may unexpectedly become highly susceptible to general mutation and damage is detected only after several cell divisions. This may also occur in the progeny of cells close to the cell which is traversed by the radiation track but which themselves are not directly hit (*bystander effect*). This phenomenon has been reproduced several times in laboratory studies of human cells but has not been confirmed in living humans and its significance for human disease is yet to be confirmed.

i Goto, Y. 2012. 'High Leukemia Rate Noted Among Kids of 2 A-bomb Survivors.' *Asahi Shimbun*, June 4, http://ajw.asahi.com

High risk individuals

Infants are about four times as sensitive to radiation cancer-inducing effects as middle-aged adults (2). Recent research suggests that the increased lifetime risk of death from circulatory disease estimated for the British population is about ten times higher for a child exposed to radiation before ten years of age compared with exposure occurring after age seventy.[i] This study estimates the risk of death from solid cancer following radiation exposure before age ten was estimated at more than twenty times the risk for exposures occurring above age seventy. Although yet to be confirmed, these differences are believed to relate to both increased sensitivity in the young and the longer remaining years of life for the effects to manifest.

Adult females are overall at close to 40 percent greater cancer risk as males for the same dose of radiation. Moreover, women who are carriers of BRCA1/2 gene mutations, which put them at high risk of developing breast cancer, have recently been shown to have heightened sensitivity to increased cancer risk from exposure to radiation.[ii]

i Little, et al, 2012. 'Systematic Review and Meta-Analysis of Circulatory Disease from Exposure to Low-level Ionizing Radiation and Estimates of Potential Population Mortality Risks.' *Environmental Health Perspectives*, vol. 120, no. 11 (November), pp. 1503–1511.

ii Pijpe et al, 2012. 'Exposure to Diagnostic Radiation and Risk of Breast Cancer Among Carriers of BRCA1/2 Mutations: Retrospective Cohort Study (GENE-RAD-RISK)' *British Medical Journal*, Sept vol. 345.

RESEARCH REPORT #7: Nuclear veterans

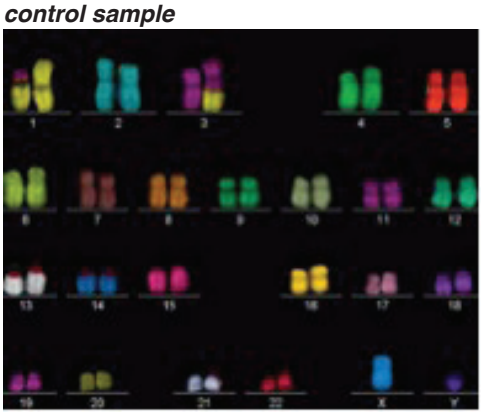
In 1957/58 the British Government conducted a series of nuclear tests in the mid-Pacific codenamed Operation Grapple, which involved several naval vessels from Britain and New Zealand.

Two New Zealand frigates with 551 personnel onboard were stationed at various distances between 20 and 150 nautical miles from ground zero.

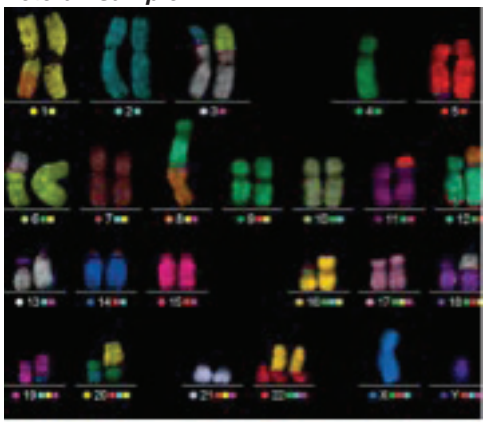
A team of researchers based in NZ applied the cytomolecular technique mFISH (multicolour fluorescent in situ hybridisation) to investigate a potential link between chromosome abnormalities and possible past radiation exposure in New Zealand nuclear test veterans who participated in Operation Grapple.

Compared to age matched controls, the veterans showed significantly higher frequencies of chromosomal abnormalities (translocations and dicentrics) and complex chromosomal rearrangements in the nuclear veterans.

control sample



veteran sample



Recommended exposure levels

Radiation health authorities use scientific modelling to calculate and set 'permissible limits' for ionising radiation exposure. As the scientific techniques have become more sophisticated, the recommended exposures for the public and the workforce have steadily been reduced: levels once regarded as 'safe' are now known to be associated with cancers, bone marrow malignancies and genetic effects.

The dose limits recommended in 1991 by the International Commission on Radiological Protection (ICRP) which are most widely used internationally are[ii]:

- for occupational exposures, 20 mSv/y averaged over 5 y, with no more than 50 mSv in any 1 y
- for the public, 1 mSv/y

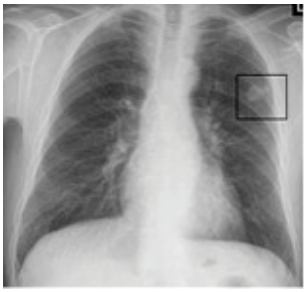
These recommended occupational limits are more than 12 times lower that those recommended in the early 1950s at the time of the first British nuclear test explosions in Australia.

ii International Committee on Radiological Protection ICRP, 1991. 'Recommendations of the ICRP'. Oxford, Pergamon Press, 1991 (ICRP publication 60).

RECENT RESEARCH FINDINGS on lower level ionising radiation effects on humans

Summary:

- Even at low doses of radiation there is clear evidence of increased risk of cancer and cardiovascular disease. There is no safe lower dose.
- The risk of increased cancers has been clearly shown in studies with very large numbers of people: workers in the nuclear industry, children having CT Scans, survivors of Nagasaki and Hiroshima, mine workers and householders exposed to raised levels of radon gas and in unborn children when their mothers had had abdominal X-rays.
- The risk of death from cardiovascular diseases is similar to that of dying of cancer, and the role of radiation causing other types of illness is currently being researched. As a result the overall excess risk of dying from exposure to low doses of radiation may be twice (or more) than that currently assumed from cancer alone.
- The trend in research over the last couple of decades, as each bit of new evidence emerges, is that the risks are greater than previously thought. There is now clear evidence that low dose exposures are harmful. The greater the exposure, the greater the risk.



RESEARCH REPORT #8: Radon gas exposure

Worldwide everyone is exposed to radon gas naturally, but levels vary widely from place to place. Radon is known as a lung carcinogen (causes cancer). Radon is a naturally occurring radioactive gas which can accumulate in enclosed places, including houses and other buildings. Uranium ore releases radon gas. Protective gear and ventilation reduces exposure in mines.

In 2006, studies found direct evidence of a lung cancer risk from the presence of radon gas in many homes, prompting a revision of safety levels, according to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).

UNSCEAR reports ample evidence of carcinogenic effects of radiation not only in the occupational dose range (up to 20mSv/annum) but also in the overall lesser residential dose range (of 1-10mSv per annum depending on where in the world you live). In fact, for the first time, studies have measured increases in lung cancer in the general public from radon mainly in their homes (previously, the risk was extrapolated from the old data from uranium mining where the doses were very high).

The UNSCEAR paper predates the doubling of the radon lung cancer risk that the ICRP (International Commission on Radiological Protection) has recommended. The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) is currently surveying workers' exposures at Olympic Dam uranium mine to update previous studies done in 1990.

With the new radon risk levels, it is possible that some of the highest exposures might even exceed the occupational limits even in open pits, if weather conditions (inversion layers which keep gas close to the surface) occur to trap the radon.

Current levels of recommended exposure are again under challenge as the techniques of molecular and radiation biology become increasingly refined, revealing micro-damage to intracellular structures.

So, current 'permissible' levels of exposure are not inherently safe and are likely to undergo further downward revision.

IMPORTANT CONTRIBUTING SOURCES

EXAMPLE 1: Uranium mining

What is uranium?

Uranium is a naturally occurring radioactive heavy metal, present in extremely low concentrations all over the world, in soil, rock and water. It exists in several configurations, known as *isotopes*. The commonest isotope is U-238 (over 99% in nature), but the isotope prized by the nuclear industry is U-235. When the U-235 form is sufficiently concentrated – via an industrial process called *enrichment* – a fission chain reaction can be achieved and sustained. *Nuclear fission* is the energy source of atomic weapons and nuclear reactors. From the 1940s to the 1960s, uranium was mined primarily to fuel nuclear weapons, but since the 1970s most of the mined uranium is processed into fuel for nuclear reactors.

How is it mined?

Uranium is widespread across the planet in extremely low concentrations but seldom sufficiently concentrated to be economically recoverable. Uranium ore can be mined by underground or open-cut methods, depending on its depth. The extracted ore is crushed and ground up, then treated with acid to dissolve the uranium, which is then recovered from solution. Uranium may also be mined by in situ leaching (ISL), where it is dissolved from the ore-body and pumped to the surface for further processing.

Exposure pathways

Humans and their habitat are exposed to uranium and its decay progeny through mining and processing and disposal of the uranium-bearing ore:

- Miners are exposed to radiation from the radon gas which is present in elevated concentrations in mines – especially underground mines.
- Workers in the processing mills where the uranium is extracted from the excavated ore are exposed to radioactive dust.
- Workers and members of the general public are exposed to radiation from the waste stream, especially the waste rock, known as *tailings*.
- Uranium and its progeny leach into groundwater and expose surrounding populations to the chemical and radio-toxicity, particularly when drinking water supplies are affected.

Radioactive decay

Uranium, like all radioactive elements, undergoes a process of decay. Over long time-spans, the uranium releases energy and changes its form to produce other, distinct, elements in a continuous cascade. The U-238 isotope takes 4.5 billion years to decay by fifty percent – known as one *half-life* – all the while producing other radioactive materials. Important decay products in the uranium cascade – known as *progeny* – include thorium, radium, radon gas, polonium and bismuth. All of these are radioactive wave or particle emitters.

Health effects

Uranium is important both as:

- a *chemical toxin* – it is a heavy metal, just like nickel or chromium, and
- as a *radioactive toxin* - via its decay progeny.

Cancer

Radon gas is regarded as the second most potent cause of lung-cancers globally, after tobacco, and its hazardous nature has been well documented over decades, in multiple studies in many countries. The decay products of the gas of particular note are radioactive lead, bismuth and polonium – alpha and/or beta emitters – which are deposited in lung tissue as they decay from inhaled gaseous radon.

Uranium waste hazards

Although the uranium is extracted from the mined ore for further processing, most of the radioactivity (from uranium progeny) remains in the waste rock. This waste rock – the tailings – is then disposed of, usually in the vicinity of the minesite.

The tailings can constitute enormous volumes of radioactive material over the life of a mine: the Olympic Dam mine in South Australia has already generated well over one million tonnes of tailing waste after over twenty years in operation. The residual radioactive progeny includes thorium-230 which decays to produce radon gas: with a half-life of 76 000 years, thorium 230 will produce radon for many millennia.

In the atmosphere, radon decays into the radioactive solids polonium, bismuth, and lead, which enter water, crops, trees, soil, and animals, including humans.

In intact rock formations, radon gas is largely trapped within the rock. In the finely ground tailings, radon gas has multiple access routes, particularly through wind and water, to the surface and the atmosphere.

Depending on the quality of tailings management, the people living in the surrounding environment will be exposed to the radiation from radon gas and radium-contaminated dust over succeeding generations.

EXAMPLE 2: Atomic weapons

In 1947 the US National Academy of Sciences set up the Atomic Bomb Casualty Commission, now known as the Radiation Effects Research Foundation, which conducts health and on-going mortality studies in the cohort of Hiroshima and Nagasaki atomic bomb survivors. There were 9,335 deaths from solid cancer and 31,881 deaths from non-cancer diseases during the 47-year follow-up.[i]

The excess risk of leukemia, seen especially among those exposed as children, was highest during the first 10 years after exposure and has continued to decrease throughout the study period. However, the excess risk for cancers other than leukemia continues today, and it seems likely that this excess risk will persist throughout the lifetime of the survivors.

Excess rates for radiation-related cancers increased throughout the study period and relative risk is highest for those exposed as children.

The evidence for radiation effects on non-cancer mortality remains strong, with risks elevated by about 14% per sievert during the last 30 years of follow-up. Statistically significant increases are seen for heart disease, stroke, digestive diseases, respiratory and blood diseases.

Among the approximately 3,000 atomic-bomb survivors exposed *in utero*, the following results have been observed: a reduction in IQ as radiation dose increases, a higher incidence of mental retardation among the heavily exposed, and impairment in the rate of growth and development on average.

See also research report #1.

i Preston DL et al. Studies of mortality of atomic bomb survivors. Report 13: Solid cancer and noncancer disease mortality: 1950-1997. Radiat Res 2003; 160(4): 381-407

EXAMPLE 3: Atmospheric nuclear test explosions

From 1945 to 1980, 423 announced nuclear weapons test explosions were conducted in the atmosphere, resulting in radioactive fallout distributed globally. By the year 2000, this had resulted in an estimated global collective dose of 5.4 million person-sievert, or 1.4 mSv for every inhabitant of the planet.

Assuming a world population of 10 billion over millennia to come, the total radiation dose the world's population is committed to as a result of these explosions is estimated at 30.4 million person-sievert.

These doses are estimated to have already resulted in 430,000 additional fatal cancers worldwide by the year 2000, and a total of 2.4 million extra cancer deaths long-term.[ii]

While this is a substantial health cost all of us pay for atmospheric nuclear tests, it represents only a small increase in global cancer rates – too small to be detected by epidemiological studies, except for test workers and downwind communities more highly exposed.

This example highlights how even small increases in risk, when applied to very large numbers of people over a long period of time, can result is substantial numbers of people suffering from radiation-related diseases.

ii International Physicians for the Prevention of Nuclear War and Institute for Energy and Environmental Research. Radioactive heaven and earth. London, Zed Books, 1991.

EXAMPLE 4: Chernobyl

'For the first time, we confront the real force of nuclear energy, out of control'
Mikhail Gorbachev

The accident at the Chernobyl Nuclear Power Plant on April 26, 1986 consisted of an explosion at the plant and subsequent radioactive contamination of the surrounding geographic area.

A plume of radioactive fallout drifted over parts of the western Soviet Union, Eastern and Western Europe, Scandinavia, the UK, Ireland and eastern North America. Large areas of Ukraine, Belarus, and Russia were badly contaminated, resulting in the evacuation and resettlement of over 336,000 people.

Reports by the UN Chernobyl Forum and the World Health Organisation in 2005-06 estimated up to 4,000 eventual deaths among the higher-exposed Chernobyl populations and an additional 5,000 deaths among populations exposed to lower doses in Belarus, the Russian Federation and Ukraine.

A study by Elizabeth Cardis and her colleagues published in 2006 in the International Journal of Cancer estimates 16,000 deaths.[i] Research published in 2006 by UK radiation scientists Ian Fairlie and David Sumner estimated 30,000 to 60,000 deaths.[ii] A 2006 report commissioned by Greenpeace estimates a death toll of about 93,000. The variation in these figures reflects the inevitable difficulty of calculating illness and death rates from statistical formulae, rather than actual cases. Such prediction-hazards are even more complex in the case of Fukushima.

i Cardis E., 2006. 'Estimates of the cancer burden in Europe from radioactive fallout from the Chernobyl accident.' *International Journal of Cancer*, Sep 15; 119(6):1224-35.

ii Fairlie I, Sumner D., 2006. 'The other report on Chernobyl (TORCH)'. Berlin, April 2006. Available at www.nirs.org.

RADIOACTIVE FALLOUT AFTER CHERNOBYL

- Predicted excess cases of thyroid cancer range between 18,000 and 66,000 in Belarus alone depending on the risk projection model.
- Other solid cancers with long latency periods are beginning to appear over 20 years after the accident.
- Belarus, Ukraine and Russia were heavily contaminated, but more than half of Chernobyl's fallout was deposited outside these countries.
- Fallout from Chernobyl contaminated about 40% of Europe's surface area. The International Atomic Energy Agency (IAEA) estimates a total collective dose of 600,000 person-sieverts over 50 years from Chernobyl fallout. Applying the *Linear No Threshold (*LNT) risk estimate of 0.10 fatal cancers per sievert gives an estimate of 60,000 deaths.

EXAMPLE 5: Fukushima – unfolding radioactive injury

On 11 March 2011, an earthquake followed by a series of tsunami waves devastated the east coast of Tohoku, the north-eastern region of Honshu, Japan's main island. The earthquake and tsunami hit 14 reactors in 4 nuclear power stations on the Pacific coast. Units One to Four of the six Fukushima Daiichi units were devastated, resulting in massive release of radioactivity into the environment. The other 10 reactors escaped meltdown and radioactive release by a series of lucky circumstances, but they were nevertheless damaged considerably.

The impacts of the nuclear disaster have been enormous. More than 100,000 people are still homeless and some will never be able to return. Preliminary scientific estimates of the long-term cancer death toll range from hundreds to around 1000. The death toll could rise significantly if many people resettle in contaminated areas. Contamination with long-lived radionuclides will persist for many generations — caesium-137 will be a concern for about 300 years. Direct and indirect economic costs

of the disaster will amount to several hundred billion dollars. It will be decades before the ruined reactors are decommissioned and decades before the legal battles have concluded.

Concerns over the health of firemen, site workers, and some general public inside and outside of the exclusion zone and other scheduled zones are addressed comprehensively in a further *energyscience* factsheet.

CASE STUDY 1: Marie Curie (1867-1934)

Marie Curie studied radioactive materials, particularly pitchblende, the ore from which uranium was extracted, which had the curious property of being more radioactive than the uranium extracted from it. Over several years of unceasing labour she refined several tons of pitchblende, progressively concentrating the radioactive components, and eventually isolating two new chemical elements. The first was named polonium after Marie's native country Poland, and the other was named radium from its intense radioactivity.

Much of her work was carried out in a shed with no safety measures. She carried test tubes containing radioactive isotopes in her pocket and stored them in her desk drawer, resulting in massive exposure to radiation. She remarked on the pretty blue-green light the substances gave off in the dark.

She died in 1934 after decades of ill health from aplastic anemia (bone marrow failure).

Her daughter Irene won the Nobel Prize in Chemistry in 1935. In 1938 her research on the action of neutrons on the heavy elements, was an important step in the discovery of nuclear fission.

She died in Paris in 1956 from leukemia almost certainly contracted as a result of her work.

CASE STUDY 2: Alice Stewart (1906-2002)

British epidemiologist Alice Stewart's first major work on the health effects of radiation was a study she co-authored while at Oxford about increasing rates of leukemia among children.

Called the Oxford Study of Childhood Cancer, the work was published in The Lancet in 1956.

The study was a landmark in the history of radiation science: the first epidemiological study to examine the health effects of small doses of radiation. Using detailed questionnaires administered to the mothers of study subjects, Stewart compared prenatal exposures among children who had died of leukemia with those of children who had died of other forms of cancer. She then compared these data to results from living controls matched for age, sex, and region. Children from both cancer groups had received twice the amount of prenatal X-rays as had the living children.

Stewart and her colleagues concluded that the effect of a single diagnostic X-ray, which was a mere fraction of what was considered a "safe" dose at that time, doubled the risk of childhood cancer.

This finding was a surprise to Stewart and was not welcome in the scientific community. Enthusiasm for nuclear technology was at a high point in the 1950s, and radiography was being used for everything from treating acne and menstrual disorders to ascertaining shoe fit. X-rays, as Stewart put it, "were the favourite toy of the medical profession". The British and American governments were investing heavily in the arms race and promoting nuclear energy, and there was little willingness to recognise that radiation was as dangerous as Stewart claimed. She never again received a major grant in England.

For the next two decades, however, she and her statistician, George Kneale, extended, elaborated and refined their database and a second report appeared in the British Medical Journal in 1958. This analysis – which tracked 80 percent of all childhood cancers occurring in Britain between 1953 and 1955 – confirmed the earlier findings.

Subsequent expansion of the number of children studied up to the age of 15 years confirmed that exposure to prenatal x-rays was associated with a statistically significant leukemia risk, and a 40% increase in risk of childhood cancer at low doses of 10-20 mGy (see Case Study #6).

In the 1970s major medical bodies recommended that pregnant women should not be X-rayed, and the practice virtually ceased throughout the world.

Meanwhile, the single largest source of ionising radiation comes from medical procedures (48%) – such as plain X-rays, nuclear medicine procedures like bone scans and computerised axial tomography – or CT scans.

Having a CT scan of the abdomen (dose 12mSv) adds one chance in a thousand to our risk of developing fatal cancer. We already face a one-in-four chance of developing fatal cancer in our lifetime. But the risk adds up across our life, so any additional radiation dose adds to the risk (double the dose means double the risk).

Reducing our dose of radiation lessens the risk of radiation causing cancer but does not remove it.

No dose is absolutely 'safe'. Radiation protection is all about avoiding exposure, or minimising it.

'Permissible' exposure levels are a last resort, if avoidance and minimisation procedures fail. Just meeting permissible thresholds is not good safety practice.

GLOSSARY OF TERMS

- **alpha particles** a highly ionising form of particle radiation
- **aplastic** the bone marrow cannot generate mature blood cells.
- **atom** a basic unit of matter consisting of a nucleus, made up of protons (positive charge) and neutrons (neutral) and surrounded by a cloud of electrons (negative)
- **beta particles** high-energy, high-speed electrons or positrons, 100 times more penetrating than alpha particles.
- **DNA** a molecule that encodes the genetic instructions for the development and functioning of living organisms
- **uranium enrichment** the concentration of the U-235 isotope by removing other isotopes
- **gamma rays** extremely high frequency / high energy, wave-form ionising radiation
- **genomic instability** a high frequency of mutations within the gene sequence of a particular cell-line
- **half life** the time required for half of the radioactive atoms in a sample to undergo decay
- **insitu leach (iSL)** mining through boreholes drilled into a deposit
- **ions** electrically-charged particles
- **ionisation** radiation which produces ions in the materials it strikes
- **isotope** variants of a particular element, with the same number of protons, but a different number of neutrons in the nucleus
- **neutrons** neutral charge particles in the atomic nucleus
- **millisievert (mSv)/ sivert (Sv)** a measure of the health effect of low levels of radiation on the human body
- **progeny** decay products
- **protons** positive charge particles in the atomic nucleus
- **radioactive decay** a nucleus of an unstable atom loses energy by emitting ionising radiation
- **tailings** the materials left over after separating the valuable fraction from an ore-body

RESEARCH REPORT References

1. Ozasa, K., et al, 2012. 'Studies of the Mortality of Atomic Bomb Survivors, Report 14, 1950–2003: An Overview of Cancer and Non-Cancer Diseases.' *Radiation Research*, vol. 177, no. 3 (March) pp. 229–243.
2. BEIR, 2006. 'BEIR VII-Phase 2: Health Risks From Exposure to Low Levels of Ionising Radiation' Committee to Assess Health Risks from Exposure to Low Levels of Ionising Radiation, *National Research Council*. www.nap.edu/catalog/11340.html.
3. Mathews, J. et al, 2013. 'Cancer Risk in 680,000 People Exposed to Computed Tomography Scans in Childhood or Adolescence: Data Linkage Study of 11 Million Australians.' *British Medical Journal*, vol. 346 (May), f2360. www.ncbi.nlm.nih.gov.
4. Cardis et al, 2005. 'Risk of cancer after low doses of ionising radiation: retrospective cohort study in 15 countries'. *British Medical Journal*. (June) 331(7508): 77.
5. Little, M. P., et al, 2012. 'Systematic Review and Meta-Analysis of Circulatory Disease from Exposure to Low-level Ion-izing Radiation and Estimates of Potential Population Mortality Risks.' *Environmental Health Perspectives*, vol. 120, no. 11 (November), pp. 1503–151.
6. Doll, R, et al,1997. 'Risk of childhood cancer from fetal irradiation'. *The British Journal of Radiology,* Vol 70 (February) pp 130-139.
7. R.E. Rowland et al, 2008. 'Elevated chromosome translocation frequencies in New Zealand nuclear test veterans'. Cytogenet Genome Res 121:79–87 DOI: 10.1159/000125832.
8. BEIR, 2006. 'BEIR VII-Phase 2: Health Risks From Exposure to Low Levels of Ionizing Radiation'. Committee to Assess Health Risks from Exposure to Low Levels of Ionizing Radiation, *National Research Council*. 2006 www.nap.edu/catalog/11340.html.

Credits: the author, whilst taking responsibility for any inaccuracies, wishes to thank A/Prof Tilman Ruff, Dr Peter Karamoskos, Dr Margaret Beavis, Dr Cath Keaney and Ms Dimity Hawkins for suggestions and contributions.

This energyscience factsheet was updated in July 2014

ABOUT THE AUTHOR

Dr. Bill Williams, is a General Practitioner on Victoria's Surfcoast with over thirty years experience in community medicine, including clinical and public health responsibilities in urban, rural & remote locations. He is a former president of the Medical Association for Prevention of War (Australia) and current president of the International Campaign to Abolish Nuclear weapons (ICAN) Australia. He has written and studied extensively on the human health consequences of ionising radiation for many years, and worked with affected communities around Australia.

Contact details: via our website: www.energyscience.org.au

ABOUT OUR ORGANISATION

energyscience.org.au is a cooperative production by a group of concerned scientists, engineers and policy experts that seek to promote a balanced and informed discussion on the future energy options for Australia.

With increasing concern over the looming impact of global climate change the community needs to be aware of the issues involved. *energyscience* aims to provide reliable and evidence based information to our whole community.