

Radiation and Health

fact sheet
12

Author: Bill Williams energyscience.org.au



There is no safe dose of ionising radiation.

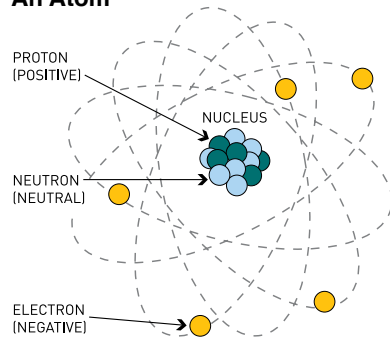
New scientific investigative techniques reveal increasing detail about the pathogenic properties of ionising radiation.

Expanding nuclear reactor programs means increasing the threat to plant, animal and human gene pools.

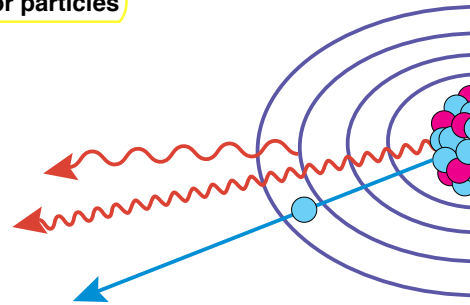
Radiation

Radiation is energy traveling 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 'ionizing' because electrically-charged particles called 'ions' are produced in the materials it strikes.

Uranium 238 (U238) Radioactive Decay

Type of Radiation	Nuclide	Half-life
	 uranium-238	4.47 billion years
α	 thorium-234	24.1 days
β	 protactinium-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 Ionizing Radiation

Electromagnetic (or 'photon') radiation

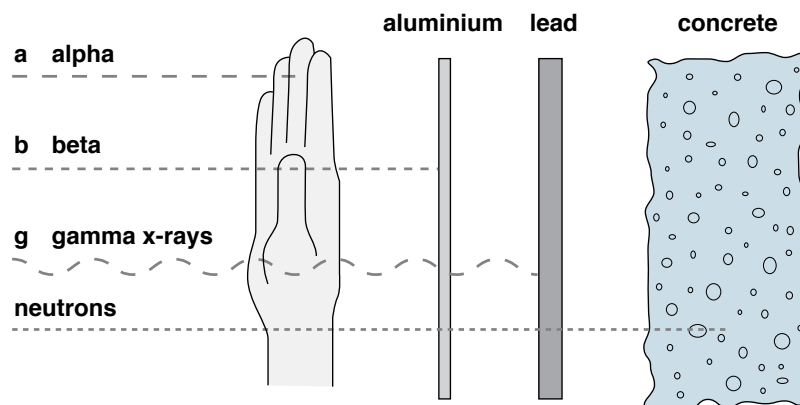
- Gamma rays (similar to X-rays) represent energy transmitted in a wave without the movement of material but they have great penetrating power and can pass through the human body. Thick barriers of concrete, lead or water are used as protection from them.

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 ionizing) and are more destructive as they traverse cells.

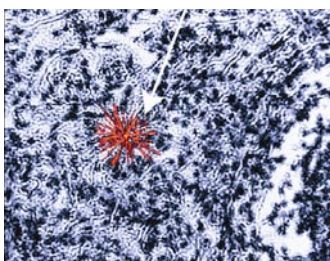
Equal doses of different types of radiation produce different biological effects – expressed as relative biological effectiveness (RBE). The RBE varies with radiation type (its LET), the dose and dose rate, and biological system. The heavy subatomic particles (alpha particles, neutrons) are most biologically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



How Radiation Hurts Us

- all humans are made of cells
- every cell contains DNA
- DNA carries the story for the cell
- radiation breaks the DNA-story
- the broken DNA-story can spread
 - to other cells
 - to your kids

Radiation Track in Dog Lung



Health Impacts: Even low doses of ionizing radiation can cause damage to the DNA in living cells. Atoms and molecules become ionized or excited, 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 nucleotide sequences on chromosomal DNA, including double-strand breaks, large deletions and sister chromatid exchange.

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

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 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.

Radiation effects can be categorized 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 component changes, fatigue, diarrhea, nausea 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.

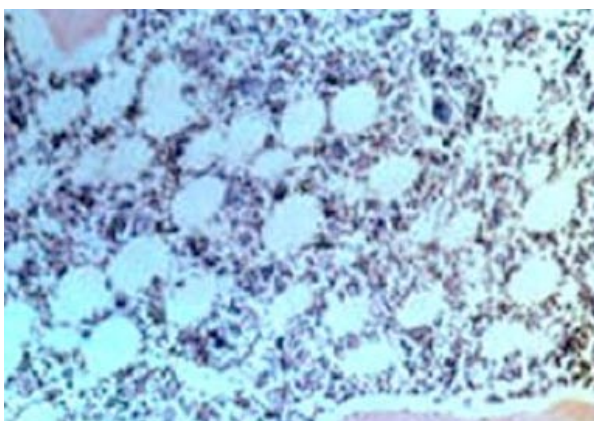
Delayed Effects: If DNA abnormalities are passed on to subsequent generations of cells, the abnormal coding can lead to tissue abnormalities, including cancers. Cancer development is a multistage process, and is similar for radiation-associated cancers as for spontaneous cancers or those associated with exposure to other carcinogens. Low dose radiation appears to act principally on the early stages of cancer initiation, whereas for high doses effects on later stages of cancer promotion and progression are also likely. Genetic disorders associated with deficiencies in ability to repair DNA damage and in tumour-suppressor type genes (which normally suppress cancer development) increase the radiation cancer risk.

Mutational events at key points such as 'proto-oncogene' or 'suppressor gene' sites provide a credible mechanism for radiation-induced malignant (cancerous) transformation.

Such cancers will take many cell generations to develop, so it may be several decades before they are detected. The delay enables polluters to avoid responsibility for the disease-promoting properties of radiation. This avoidance is amplified by the fact that leukemia and other cancers induced by radiation are indistinguishable from those that result from other causes.

The magnified image on the left below is normal human bone marrow. That on the right 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.

Normal



Aplastic



Reproductive Effects:

Prenatal radiation exposure: 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/fetus 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.



Natasha (12) and Vadim (8) from Belarus, suffering the effects of the Chernobyl nuclear disaster nearly twenty years after the reactor's core exploded releasing clouds of radioactive material into the environment. Natasha was born with microcephaly, Vadim has a bone disease and is mentally retarded.

Genetic effects: 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 ionizing 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.

Radiation-induced genetic damage is likely to manifest mainly as multisystem developmental abnormalities. The most authoritative current estimates for radiation-induced genetic damage in humans are that for 1 Gy of low LET, low dose radiation, there would be an increase of 3000-4700 cases of genetic diseases per million progeny in the first generation, and 4000-6700 in the second generation.¹ This represents a 0.4-0.9% increase over baseline per Gy of radiation dose.

Evidence has emerged recently that the cell may also 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. Such studies would necessarily need to be extraordinarily long. However if the theory of induced genetic instability is correct, then the human gene pool could be permanently altered.

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’ ionizing 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 ionizing radiation, through atomic weapons development, testing and use, as well as uranium-mining and nuclear electricity generation. The ongoing atmospheric fallout from the nuclear weapons testing in the 50’s and 60’s 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 ionizing radiation will cause greater health damage, even low doses are associated with adverse environmental and human consequences.

Using the “linear no-threshold” risk model, the 2005 U.S. National Academy of Sciences Committee on the Biological Effects of Ionizing Radiation (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)

It should be noted that while these are average risks, the risks in vulnerable groups of the population may be considerably higher. BEIR VII assessed women as having about twice the radiation risk for solid cancer incidence as men, and 38% higher cancer mortality risk than men. Children are at even greater risk – radiation during infancy for boys results in 3-4 times the cancer risk as between 20-50 y, and female infants have double the risk of boys.

Radiation health authorities use scientific modeling to calculate and set 'permissible limits' for ionizing 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:²

- 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 than those recommended in the early 1950s at the time of the first British nuclear test explosions in Australia.

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.

Case Study 1:

Marie Curie (1867-1934) 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 (low LET).³

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

Case 3: **Depleted Uranium**

Depleted uranium is the ‘waste’-product of the uranium ‘enrichment’ process: the manufacture of uranium with a sufficient concentration of the highly radioactive U-235 isotope to fuel (“fission”) nuclear weapons and nuclear power plants. DU, thus “depleted” of its U-235 (now containing ~0.2%) and U-234, is mostly U-238: the non-fissionable uranium residue, which still retains about 60% of the radioactivity of natural uranium.

Most of the radiation from U-238 - about 95% - is emitted as alpha particles at 4.2 Mev and 4.15 Mev - high in energy but travelling only a few millimetres in air, as well as the β -particles and γ -rays from its daughter products.

One milligram of U-238 emits per year the equivalent of over one billion high energy, ionizing particles and rays that can produce extensive biological damage. The mass of ‘breathe-able’ particles is typically a few nanograms (one billionth of a gram), so a typical one may emit about a thousand alpha particles per year, or one every few hours. Alpha-emitters cause very high doses to local cells in the 40-micron range of their disintegration tracks. Cells will be hit again and again since the particle will continue to emit radiation: a lifetime of alpha-particle bombardment of surrounding cellular microenvironments ensues.

Inhaled particles of less than 2.5 microns diameter can enter deep into the lungs and may move from the lung to the lymph nodes and bone. Embedded fragments in wounds may solubilise and redistribute to the brain, lymph nodes, gonads, liver, kidney, and spleen, with the highest concentrations in skeletal tissue.

Miller and co-workers discovered the first direct evidence that radiation from DU damages chromosomes within cultured cells. Chromosomes break, and the fragments reform in a way that results in abnormal joins. Both the breaks and the joins are commonly found in tumour cells.⁴

Case 4: **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 have been 9,335 deaths from solid cancer and 31,881 deaths from non-cancer diseases during the 47-year follow-up.⁵

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.

Case 5:

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.⁶ 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 in substantial numbers of people suffering from radiation-related diseases.

Case 6:

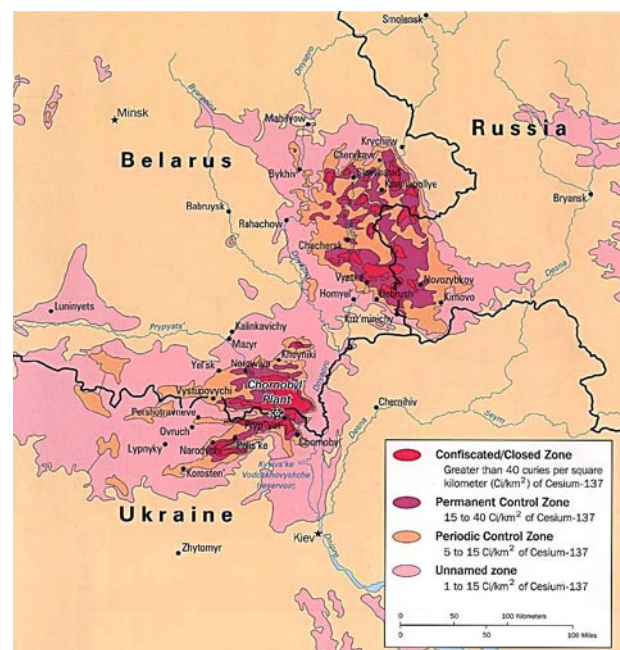
Chernobyl

'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.

- about 30,000 to 60,000 excess cancer deaths are predicted.⁷
- 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 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 most credible published collective dose is estimated to be about 600,000 person sievert, more than 10 times greater than the 55,000 estimate by the IAEA/WHO in 2005.
- about 2/3rds of Chernobyl's collective dose was distributed to populations outside Belarus, Ukraine and Russia, especially to western Europe.

Radiation hotspots resulting from the Chernobyl Nuclear Power Plant accident



Case 6:

Nuclear Industry

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 which 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 (95% confidence interval 0.14 to 1.97). The excess relative risk for leukaemia excluding chronic lymphocytic leukaemia was 1.93 per Sv (< 0 to 8.47). 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.

References:

- 1 Committee to Assess Health Risks from Exposure to Low Levels of Ionising Radiation. BEIR VII: Health risks from exposure to low levels of ionizing radiation.. Washington DC, National Academies Press, 2005, summarized on pp 22 and 202-6. Available at www.nap.edu
- 2 International Committee on Radiological Protection ICRP. Recommendations of the ICRP. Oxford, Pergamon Press, 1991 (ICRP publication 60).
- 3 Committee to Assess Health Risks from Exposure to Low Levels of Ionising Radiation. BEIR VII: Health risks from exposure to low levels of ionizing radiation.. Washington DC, National Academies Press, 2005:303. Available at www.nap.edu
- 4 Miller AC et al. Potential late health effects of depleted uranium and tungsten used in armour-piercing munitions: a comparison of neoplastic transformation and genotoxicity with the known carcinogen nickel. *Milit Med* 200; 167(2 Suppl):120-2
- 5 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
- 6 International Physicians for the Prevention of Nuclear War and Institute for Energy and Environmental Research. *Radioactive heaven and earth*. London, Zed Books, 1991.
- 7 Fairlie I, Sumner D. The other report on Chernobyl (TORCH). Berlin, April 2006. Available at www.nirs.org.

About the author:

Dr. Bill Williams, a General Practitioner on Victoria’s Surfcoast, is Vice-president of the Medical Association for Prevention of War (Australia).

About our organisation:

energyscience.org.au is a co-operative 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](http://energyscience.org.au) aims to provide reliable and evidence based information to our whole community

Contact details:

via our website: www.energyscience.org.au