Submission
No 12

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>
> **Professor John O'Connor, President**
> **Austraiian Institute of Physics**
>
> **"Keay lists (anti-nuclear) myth after myth and neatly disposes of them all..."**
>
> **Padraic P McGuiness, Sydney Morning Herald**

The booklets "*Nuclear Energy Fallacies*" and "*Nuclear Radiation Exposed*" are directly available from the Enlightenment Press for Seven dollars per single copy including postage and handling [redacted]. Further titles are in preparation.

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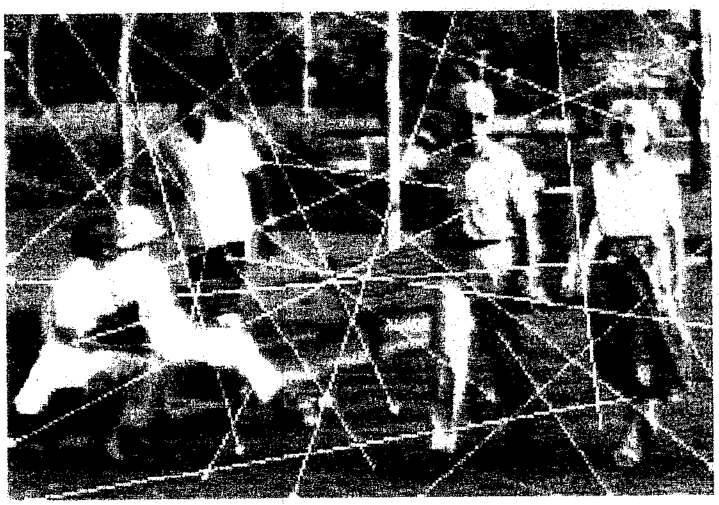
Nuclear Radiation Exposed
-
A Guide to Better Understanding

Colin Keay



The Enlightenment Press

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2001

Acknowledgements

I can hardly begin to thank the colleagues and friends who have encouraged me to write this booklet. Those familiar with the subject see a need for an up-to-date treatment and those not so familiar see a need for an accurate, readable and reliable source of information. It is my hope that these objectives are being met.

Some useful reference sources:

Eisenbud, M and Gesell, T, "Environmental Radioactivity" Fourth edition, Academic Press, San Diego CA 1997, ISBN 0-12-235154-1

Hore-Lacy, I, "Nuclear Electricity" Sixth edition, Uranium Information Centre, Melbourne VIC 1999, ISBN 1-875551-01-8

Jaworowski, Z, "Beneficial Ionising Radiation", Chapter 6 of "What Risk?" R Bate (ed.), Butterworth-Heinemann, Oxford 1997. ISBN 0-7506-3810-9

UNSCEAR 2000 Report, Sources and Effects of Ionising Radiation", United Nations Scientific Committee on the Effects of Atomic Radiation, Vol. 2, Annex J. ISBN 92-1-422396

Every effort has been made to ensure the accuracy of the material presented in this booklet. If an error is detected the author would be pleased for it to be drawn to attention and advised of a more authentic source. Should the error be verified the author will be grateful and an amendment incorporated in future reprints.

ABOUT THE AUTHOR

The author is a retired physicist and astronomer who, as an associate professor at the University of Newcastle for 24 years, taught nuclear and reactor physics to senior classes.

During his professional career as a university scientist he encountered under laboratory and research conditions both radioactive substances and high-voltage electricity, learning to respect each for their lethal dangers. He considers it paradoxical that people are comfortable with electricity, happily harbouring its deadly dangers in every home, while on the other hand nuclear radiation usually sends chills up the spine of some folk notwithstanding the fact that radioactivity and nuclear radiations are present all around us. There can be no such thing as a truly nuclear-free zone anywhere in the known universe. This booklet has been written with the aim of throwing light on the actual hazards of nuclear radiation and not the exaggerated scares so often presented by the media and various irresponsible organisations.

The author has no past or present connection with the nuclear industry.

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Introduction

There exists in the public mind a completely unjustified fear of low-level nuclear radiation. It is irrational, because the risk of death or injury from such radiation is exceedingly low on the scale of risk from other sources such as comet or asteroid strikes, earthquakes, lightning, mowing the lawn or even sitting in a sofa to watch TV. All of these are potentially hazardous, some more so than others, however we accept them with optimism and go about our lives regardless.

But similarly harmless whiffs of nuclear radiation send the media and anti-nuclear activists into hysterics, spreading doom and gloom wherever they reach. When the Three Mile Island power reactor in Pennsylvania suffered a meltdown in 1979 the minor release of radioactive gas caused no casualties. But a rise was noted in the death rate from strokes and heart attacks in the surrounding population. These were purely psychosomatic illnesses induced by media scaremongering.

The same thing is happening in the falsely alarmed suburban shire of Sutherland, near the Lucas Heights nuclear research establishment south of Sydney. There the shire council has imported "experts" carefully chosen to pronounce a proposed new research reactor as unsafe. Similar reactors have existed without harm to their neighbours for decades in the heart of large cities like London, Boston and Munich.

The so-called "experts" rely on the fact that most citizens know very little about nuclear radiation. This book has been written to bring facts of the matter to light and dispel unjustified fears.

Shoot-Out on Main Street

It was lunch-break. Kate stepped out onto the footpath and collided with a man walking close to the building.

"Pardon me," she murmured as she zapped him with a few dozen shots.

The man responded with a greater number, because he was bigger, and went on his way.

All along the footpath Kate traded volleys of shots with the passers by and, feeling invigorated, headed for the bank to get some spending money. As she entered the solid granite portals of the bank she was subject to a hail of crossfire coming and going.

At the kerbside stand where she bought coffee, a ham sandwich and a banana for lunch, the crowd was close and hundreds if not thousands of rounds were exchanged.

Finding a seat in a park she read a magazine while she ate the trigger-happy ham. The banana and coffee also took pot shots at her. But these were nothing compared to the swarm of shots and missiles hurtling at her from the sky while the solid ground beneath her responded with a bombardment of its own.

Returning to her cosy office in the basement of the building she worked in, Kate received a fusillade of grenades from the very air she breathed.

And so it went on, day in, day out, at work and at home, until Kate died of a stroke at the age of 97, unaware of the battering her body had been receiving, and delivering, since the day she was conceived.

So you think this is fantasy. Star Wars stuff. Not at all. It is happening to you, too, affecting the atoms and molecules and cells throughout your body all the time.

The bombardment is real, it is nuclear, yet we would know nothing about it but for the discoveries of nuclear science. And there was Kate, firmly believing she dwelt in a nuclear-free city!

What exactly is this bombardment? Where does it come from? Is there any chance of escape? Is it a health hazard? What can we do to lessen its effects? These and many other leading questions will be answered in this presentation.

Nuclear Shots, Shrapnel and Grenades

The sub-atomic world, the realm of nuclear physics, is a hive of ceaseless activity on an energy scale where chemical and biological processes are insignificant. As we shall see, however, biological systems have a magic of their own that enables them to cope with much of the damage caused by nuclear radiations. Just as well, or we humans would not be here today.

What we described as "shots" in the previous section are gamma rays, which are like high energy x-rays. In our bodies they arise from the radioactivity of carbon and potassium. An average adult generates about two hundred gamma rays every second. Ham, being meat, is also a source as well as bananas, which, being rich in potassium, are more radioactive than most fruits.

Because gamma rays are very penetrating, most of them escape the body in all directions to irradiate everything in the vicinity. Because we presumed Kate to be lighter than the man she collided with, she received more gamma rays from him than he from her. At the bank, the granite structure gave off so much gamma radiation that it would not be granted a licence to operate if it functioned as a nuclear power station!

The "shrapnel" from the sky that zapped Kate while she lunched (and at all other times too) came from cosmic rays. At sea level these are a mixed bag of high-energy neutrons, protons[1], muon particles and gamma rays. The neutrons and protons are debris from the nucleii of atmospheric gas atoms shattered by the impact of the incident high energy cosmic rays from space.

The neutrons and protons disrupt chemical bonds, wrecking molecules, when they collide with atoms in the body. Muons do the same and are like electrons, negatively charged but about three hundred times heavier. That means they are like beta radiation with a much greater punch. Cosmic-ray muons easily penetrate a human body and leave a trail of damage as they tear through flesh and bone at nearly the speed of light. One has to go down in a very deep mine to avoid them.

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[1] The number of protons in the nucleus of an atom defines the kind of chemical element. For example an atom of carbon is defined by having six protons in its nucleus. Except for the lightest element, hydrogen, all nucleii contain some neutrons as well as protons.

Cosmic rays increase with altitude, giving jet aircraft crews two or three times the cosmic radiation dose they would receive if they were not flying.

The "grenades" we spoke of are radon atoms. These result from the decay of radioactive elements in the ground. Radon is a gas that seeps upwards and tends to gather in basements and poorly ventilated dwellings. When inhaled, some of the radon atoms decay in the lungs and release energetic alpha particles. Alpha radiation deposits all of its energy very close to the point of decay and causes severe cell damage within a tiny region less than the thickness of a thin piece of paper. Then, given other predisposing factors, a lung cancer might result. The chances of this are extremely small but would have been much greater had Kate been a heavy cigarette smoker, for then the alpha particles from the decay of polonium in the cigarette smoke would have added considerably to the effects of the radon.

There is no escape from nuclear radiation of one kind or another. Going down a deep mine to escape cosmic rays exposes a person to higher concentrations of radon. You can't win!

Now you might wonder how Kate could possibly survive having her body riddled with so much unfriendly fire. If she believed the nonsense spouted by highly unqualified "experts" in the news media she might just as well surrender, turn up her toes and die. And the rest of the human race would be in peril as well.

Fortunately, the self-proclaimed "experts" are wrong. Over eons of time, living creatures learned to live with nuclear radiation, so everyone may now relax. Shortly we will explain more about this happier state of affairs, but first we should become more familiar with the properties of each type of nuclear radiation and the effects that various amounts really have on living organisms.

Properties and Effects of Nuclear Radiations

The three main kinds of radiation released by radioactivity were historically called alpha, beta and gamma rays. Later, other kinds were recognised. All of them are frequently referred to as ionising radiation because they carry enough energy to knock electrons out of atoms (ionising them) and thereby break chemical bonds.

Alpha rays are particles, comprising a pair of protons bound together with a pair of neutrons to form a helium nucleus. That means they are quite heavy on the sub-atomic scale. Despite their weight their double positive charge makes them interact strongly with atoms in their path, so they dump all their energy very quickly whenever they encounter matter. That is why they cannot even penetrate a sheet of paper or, for that matter human skin. But, as we have said, once inside the body they can be very damaging to living cells in their close vicinity.

As alpha particles lose energy and slow to a stop their positive charge attracts a couple of stray electrons to achieve neutrality and they then become harmless helium atoms. Most of the helium on this planet originated from the alpha particles emitted by radioactive decays deep underground.

Very heavy atoms like uranium and thorium are alpha radioactive simply because they act to improve their stability and reduce their high positive nuclear charge through the emission of alpha particles. A good example of an alpha particle emitter is polonium-210, which is inhaled in cigarette smoke.

Beta rays are simply fast electrons, like those that occupy the inner orbits of an atom or comprise the scanning beam in a TV tube. Electrons, being negatively charged, are ejected by a radioactive nucleus seeking to increase its positive charge for better stability. Beta decay therefore complements alpha decay.

Betas are more penetrating than alphas. Because of their much lighter mass they lose less energy per collision with matter and therefore travel further, dispersing the damage they cause. However a thin sheet of metal or a few millimetres of flesh will stop them. "Beta burns", while not common, were suffered by some of the casualties close to the destroyed Chernobyl reactor.

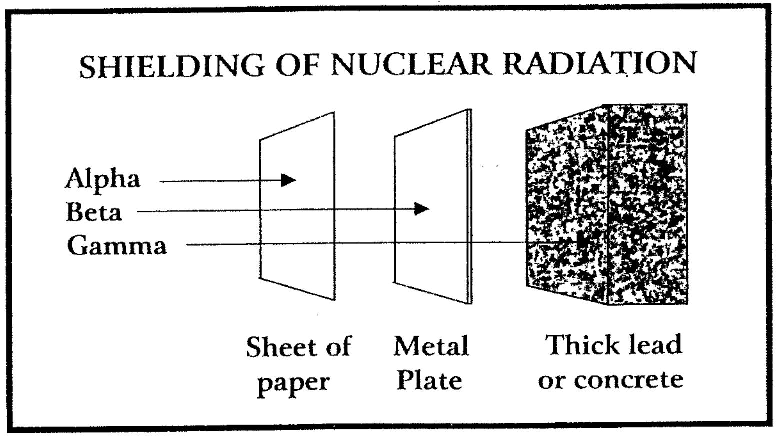
The major internal beta emitter in the body is carbon-14.

Electrons are "mirrored", if you like, by an oppositely charged anti-particle called a positron. You guessed right: it has a positive charge. A nucleus seeking to lose excess positive charge, without losing the weight of an alpha particle, may emit a positron, which in this instance is also referred to as a beta ray. When a positron meets an electron the pair annihilate to create two oppositely directed gamma rays. This is the principle behind the medical physics marvel of PET - Positron Emission Tomography - that can pinpoint the location of processes in a living brain.

Gamma rays are simply highly energetic electromagnetic waves like x-rays. They are emitted by radioactive nucleii possessing too much energy for their long-term stability.

Being pure radiation, gamma rays carry no electric charge and, like x-rays, are very penetrating. Several centimetres of lead or metres of concrete are needed to shield it. Excessive exposure to gamma rays can overwhelm the body's defences, although normal levels are readily dealt with.

Gamma rays come from many sources. A good example of a gamma emitter is the radioisotope technetium-99 used in body scans for medical diagnostics.


SHIELDING OF NUCLEAR RADIATION

Another important kind of nuclear radiation is neutron radiation, mainly found near nuclear reactors and also in cosmic rays. It is very penetrating and intense doses are extremely harmful to human tissue. However neutrons are themselves radioactive and decay with a half-life of twelve minutes when they are outside an atomic nucleus.

We have already mentioned muons, which are also radioactive. They decay in a matter of microseconds into beta particles.

The Decay of Radioactivity

Radioactive decay is a chancy business, like winning the lottery. Every radioactive atom has a ticket for a win. It might win this instant, or next, or in a century or more. It is a statistical problem and the time it takes for a decay to occur varies from one radioactive species to another and is characterised by what is called a half-life. If a certain radioactive element (more precisely an isotope[2] of an element) has a half-life of one hour that means there will be approximately half of the original amount remaining after an hour has passed. Suppose we have 1000 atoms of it to start with, then after one hour there will be close to 500 remaining. Maybe 499, or 501, or even 502 or 498 because radioactivity is a process governed by chance. After two hours about half of those will have decayed, leaving around 250 intact. After three hours about125 will remain. And so on until ten hours later there will be none, or one, possibly two, or improbably three left.

Now consider a second isotope with a half-life of half an hour. Obviously it will decay more rapidly than the first isotope, so its radioactivity will be twice as great. This, then leads to the rule that "**the activity of a radioactive element is inversely proportional to its half-life**".

Consider the two most important radioactive isotopes in the human body, carbon-14 and potassium-40. The former has a half-life of 5,730 years while the latter has a half-life of 1.28 billion years, over 400,000 times greater. This means that the potassium-40 is that much less active than the carbon-14, which is why the tiny amount of carbon-14 present in the body has a level of activity comparable to that of the vastly greater quantity of potassium-40 in the human body.

In an adult carbon and potassium produce about five thousand beta particles every second, while about a tenth of the potassium

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[2] All elements exist in a variety of forms called isotopes. Every isotope of a given element is identical chemically but their nucleii carry differing numbers of neutrons so their nuclear properties and stabilities differ. For example carbon-12 is the normal stable isotope of carbon while carbon-14 is unstable and therefore radioactive. The number 12 is the sum of the number of protons and neutrons in the nucleus, which tells us that carbon-14 possesses two too many neutrons and will be beta radioactive.

betas are accompanied by gamma rays. Because gamma rays deliver their damage at any point where there is enough matter to absorb them some will affect the source person and the remainder will escape to irradiate others nearby.

The Human Nuclear Defence System

As we have already indicated, nuclear radiations destroy chemical bonds, which means they cause breaks in DNA strands, let loose highly reactive fragments of organic molecules and disrupt cellular microstructures.

Scaremongers love to claim that a single nuclear particle "may" cause a cancer. If this were true, everyone on the planet would be riddled with radiation-induced cancers. Considering that our bodies are zapped by billions of particles of radiation every day it is surprising that cancer rates are as low as they are. Hence the use of the weasel-word "may" in the activist's claim.

Since the dawn of life on Earth, living creatures have evolved through eons of time when radiation levels were considerably greater than at present. The first unicellular organisms coped with their radioactively hot environment by developing strong defences. These are evident today in bacteria like *micrococcus radiophilus* found thriving in the cooling water subject to intense radiation within the cores of nuclear power reactors. As well there is the most radiation resistant organism on Earth, another bacteria called *deinococcus radiodurans.*

Moving up the evolutionary tree there are the cockroaches that have been around for hundreds of millions of years and can tolerate very high doses of radiation, as can a number of other species of insects.

Human beings, at the top of the evolutionary tree, are able to thrive in the most radioactive localities on this planet. Inhabited areas with high levels of natural radioactivity are Kerala in India, Morro do Ferro near Pocos de Caldas in Brazil and Yangjiang in China. But the settled area where the natural background radiation is greater than anywhere else in the world is the coastal city of Ramsar, in northern Iran overlooking the Caspian Sea. Ramsar citizens are continually exposed to levels up to forty times higher than the world average background radiation and well over the dose limits to workers in the nuclear industry. At the four places we have named, the inhabitants receive a 70-year lifetime dose considerably exceeding that adopted as the criterion for evacuation of Chernobyl victims.

Epidemiological studies have consistently indicated that the high levels of natural background radiation in these regions are not harmful to the inhabitants. People living in the highest background areas of Ramsar do not show any increased incidence of cancer or leukaemia or evidence of chromosomal damage. There is in fact much evidence that inhabitants of areas with high backgrounds of natural radiation are healthier than similar populations in low background areas. We will return to this startling finding later when we discuss radiation hormesis - the health-giving properties of radiation. Sufficient at this stage to comment that it makes nonsense of the claims that there is no safe level of exposure to nuclear radiation.

Returning to our highly evolved nuclear radiation defence mechanisms we first of all should note that the DNA in each cell of the trillions in a human body undergoes more than 100,000 spontaneous alterations per day from metabolic and other bodily functions. These are mainly single-strand breaks and lesions to the coding molecules. A daily radiation dose of four times the average annual exposure adds only 20 additional events per day per cell. These are well within the capabilities of the repair mechanisms associated with the body's immune system.

The worst DNA damage comes from double-strand breaks, of which there are very few spontaneous ones and the above mentioned radiation dose produces about forty times more than normal. In such cases the damage is difficult to repair and a mammalian cell becomes disfunctional. Amazingly it is then self-programmed to die; a process called apoptosis, whereupon it is discarded along with millions of other cell deaths every day. It is nature's clever - not to say, ruthless - technique for getting rid of cells with badly damaged DNA before they can turn cancerous or pass on a mutation. These benefits are supported by studies of the Japanese atomic bomb survivors who display no greater incidence of lifetime cancers compared with the unexposed population. Or with their children where there is little evidence of greater than normal genetic damage.

In the light of these research findings it becomes clear why there is a threshold level of nuclear radiation below which there is no evidence for increased tumour rates. Before going on to discuss thresholds and health benefits we need to look at the units for measuring nuclear radiation. Then we can appreciate more clearly where harmlessness ends and danger begins.

Measuring Nuclear Radiation

Each click of a geiger counter signals the decay of a radioactive atom. Until fairly recently the counting of decays was the only way individual atoms could be monitored. Consider a tiny grain of salt - let's make it potassium salt because, as we mentioned, it is slightly radioactive. It will contain about a thousand billion billion atoms. Or, if you prefer, about a million million billion atoms. Either way that's a whale of a lot of atoms in that tiny grain of salt. Imagine picking out just one among all those atoms. Yet a geiger counter tells when just one decays with the emission of a beta ray and special counting equipment can also tell when one in ten of them emits a gamma ray as well! Fantastic!

This process is measured in units of bequerels, honouring Henri Bequerel, the discoverer of radioactivity. An activity of one bequerel corresponds to one decay per second. Our tiny grain of salt has an activity of about 2.5 bequerels, remembering that only one in ten thousand potassium atoms is of its radioactive isotope. Just as well. Our bodies would be dangerously radioactive if every atom of potassium was of the radioactive potassium-40 isotope.

Radioactive decays, of whatever type, release particles carrying an amount of energy that can be measured. The emitted particles deposit their energy over distances corresponding to their degree of penetration. Alpha particles, as mentioned earlier, are stoppable by a thin sheet of paper, which means that all of their energy is deposited in a number of collisions within a short distance until they are brought to a halt. This means the damage they cause is highly concentrated near their source. On the other hand gamma rays are deeply penetrating and they deposit their energy in single collisions with atoms they encounter at some point within their range. This means that their damage is spread throughout whatever material lies in their path, up to the range at which all of the gamma rays are absorbed.

The total energy deposited is given by the source activity in bequerels times the energy of each gamma ray emitted. It is measured in grays[3], a unit named after Stephen Gray, discoverer of electrical conduction. But grays relate more to the strength of the source rather than the effect on whatever is receiving it. As we have noted, the energy deposited is highly concentrated for alpha particles and diffuse for gamma rays.

These variations are taken into account through Radiation Weighting Factors that vary from one to twenty. Multiplying the energy deposit in grays by an appropriate RWF yields the effective dose of radiation. Effective doses are measured in sieverts, named after a pioneer in the study of radiation dosimetry.

Radiation Weighting Factors

Gammas, betas and muons	1
Neutrons	energy dependent, from 5 to 20
Protons of moderate to high energy	5
Alpha particles and fission fragments	20

Now we are in a better position to assess levels of radiation as they affect human beings, and whether they would be harmful.

Everyday Radiation Levels

We live our lives submerged in an ocean of nuclear radiation totally regardless of whether we live in an imagined nuclear free

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[3] The amount of energy deposited by the absorption of nuclear radiation at the level of one gray is defined as one joule of energy per kilogram of absorber. It is roughly the energy delivered if a torch bulb is flashed for a second.

zone. As the example of Kate showed, we cop it from all directions. In Australia the average dose to an adult is around two millisieverts, or two thousandths of a sievert. The world average is around three millisieverts. To keep the numbers manageable for the next few paragraphs we will use the unit of one millionth of a sievert, otherwise known as a microsievert with the abbreviation μSv. And for activity we use the bequerel (abbreviated to Bq) as already defined.

The human body is composed of chemical elements in a myriad of cell-forming combinations that go to build up our flesh, bone and organs. Having read the previous sections, it should come as no surprise that we ingest radioactive elements in water and food. Here are the amounts typical for a 70 kg adult having a total radioactive burden of around 20,000 Bq:

Radioactive elements in an adult human body

Element	Amount found in the body	Resulting level of radioactivity
Potassium	17 mg	4,400 Bq
Carbon-14	95 μg	15,000 Bq
Uranium	90 μg	1.1 Bq
Thorium	30 μg	0.11 Bq
Radium	31 pg	1.1 Bq
Polonium	0.2 pg	37 Bq
Tritium	0.06 pg	23 Bq

Note: One pg is one millionth of a μg. One μg is one millionth of a gram.

The potassium-40 in the body contributes approximately 100 microsieverts to the annual radiation dose, while the others collectively contribute approximately 250 microsieverts.

Radioactivity of Food and Drink

The intake of food constitutes a steady source of radioactivity, topping up the bodily burden if it is not promptly eliminated. Setting aside foods that have been contaminated with radioactive

fallout, the most radioactive food one is likely to consume are brazil nuts, which not only are rich in potassium but they also concentrate radium from the soil their parent tree grows on. Their activity can range from 0.3 Bq/g to 0.5 Bq/g. A typical brazil nut weighs four grams so each nut emits one or two particles of nuclear radiation every second. Other nuts and beans are also more radioactive than most foods.

Many fruits and vegetables are naturally quite radioactive. A typical banana weighing in at 190 grams has a radioactivity of 20 Bq. Monkeys love bananas, and nuts, so it's surprising there have been no claims that they glow in the dark! Raw lima beans are slightly more radioactive than bananas, while carrots and potatoes are slightly less so. Red meat is radioactive to the extent of 125 Bq per kilogram. While the number of radioactive decays per second in a sizeable steak with potatoes and carrots might run to three figures you shouldn't allow it to spoil your appetite.

It is interesting to see how various liquids stack up. Unless it is carefully purified, normal tap water comes in at around 1 Bq per litre; that is to say one nuclear disintegration per second in every litre. If the water is drawn from a monazite sandbed the presence of entrained radon gas boosts its radioactivity considerably.

There is also the radioactivity all living, breathing plants and animals derive from carbon-14 produced by cosmic rays in the atmosphere. So if water is made more drinkable to tipplers by presenting it in the form of beer the activity jumps to around 15 Bq per litre. Or if water is made more pleasing to the palate of a Scot by turning it into whisky the activity then reaches 45 Bq per litre. Babies prefer milk, which, even in the absence of radioactive fallout, is worse than whisky, tripping a radiation counter at the rate of 50 Bq per litre. Babies don't glow in the dark and the level of radioactivity in their milk does not seem to harm them, so don't be too alarmed to learn that the activity of salad oil can reach as high as 180 Bq per litre.

Taking all of the above figures into account the daily food and drink intake of an average adult imparts to that person an annual radiation dose of about 300 μSv. Roughly a microsievert per day. That is about one sixth of the total dose from all sources except medical exposures.

Some Life-style Hazards

The greatest natural radiation hazard by far to humans is to live in a poorly ventilated basement, especially in regions underlain by granite rocks or in houses built on monazite sands. A few years ago several houses built on sand at Byron Bay were condemned for habitation. The villain in each instance is the odourless, colourless radioactive gas radon given off by rocks and minerals rich in uranium and thorium. Measurements made inside some dwellings in the United States have recorded radon activities of one thousand Bq per cubic metre, equal to the American occupational radiation dose limit annually of 50 mSv, and almost that of many of the worst-affected Chernobyl evacuees! The average indoor radon activity in a well-ventilated dwelling is around 10 Bq per cubic metre, which equates to an annual radiation dose of about 500 μSv. But if the dwelling is not well ventilated that figure could easily be trebled.

One radiation hazard that few people know about is taking regular hot showers using bore water. Because it has been underground it contains a considerable amount of radon gas. This is released most rapidly when the water is heated and divided into droplets in a shower. This can easily add 700 μSv or more to a person's annual radiation dose.

Let's bring these figures into perspective. Persons exposed to radon gas at a concentration of one thousand Bq per cubic metre are one hundred times more likely to eventually die of radiation-induced lung cancer than would be the case if they lived in a dwelling where the concentration was only ten Bq per cubic metre. Even so, the chances are low compared to the risk of contracting lung cancer through cigarette smoking.

While discussing our habitation, the materials used to build our homes are very relevant. A completely wooden house without much concrete gives an adult occupant an annual radiation dose of about 500 μSv due to potassium and other radioactivities in the wood and wall cladding. If the house is of brick, stone or concrete one can easily add another 200 μSv or more.

The Hazards Where You Live

Radiation exposure varies considerably around Australia. The coastal sandstone areas are almost as low as you will find provided there are no deposits of monazite sands nearby that are significantly radioactive. A good indicator is the presence of sand mining activity now or in the past. The annual radiation dose from sandstone alone is about 400 μSv.

Moving to granite highland areas like New England adds about 300 μSv, bringing the annual dose up to 700 μSv. Not a lot really.

The extra altitude of highland areas also increases the exposure to cosmic rays. Cosmic rays come mainly from little known sources far beyond the solar system. Some carry more energy than the fastest sub-atomic particles produced by the most powerful accelerators in the world. The sun also produces some cosmic rays, but at the low end of their energy spectrum. When cosmic rays slam into the Earth's atmosphere they collide with air molecules and explode into a burst of lower energy sub-atomic particles, which then further collide until a cosmic ray shower results. Near sea-level the particles are mainly protons, neutrons and muons the effects of which we have already discussed.

At sea-level the annual radiation dose from cosmic rays is close to 260 μSv. For locations above sea-level an extra annual dose of 0.2 μSv must be added for every metre of height. Jet travel adds more. For every thousand kilometres travelled 2 μSv of extra cosmic radiation dose is accrued.

Astronauts in space cop the raw cosmic rays, giving them serious doses of radiation. Then when the sun is very disturbed the high additional bombardment of solar cosmic rays can reach potentially lethal levels up to one hundred times greater. This has not led to a shortage of volunteers wanting to travel in space.

In discussing radiation levels dependent on where one lives, the proximity to power stations needs to be taken into account. The pollution from coal-fired electric power generating stations is of serious concern because of the amount of toxic wastes liberated from the coal and either vented up the smoke stack or

Compute Your Own Radiation Dose (for an average adult) © C. Keay 2001

SOURCE OF EXPOSURE		*ANNUAL DOSE in microSieverts*
BECAUSE YOU ARE YOU		
Internal Potassium-40 in blood and tissue		100
Other internal isotopes (Carbon-14, Polonium, Uranium, etc.)		250
WHAT YOU EAT		
Natural radioactivity in your food and drink		300
Plus contribution of weapons-test fallout worldwide		15
HOW YOU SLEEP		
With spouse, defacto, partner, etc.,	ADD from 1 to 3*	....
(* depends how close, and for how long)		
HOW YOU LIVE		
Medical:	ADD number of chest X-rays times 60	....
	no. of gastric tract X-rays times 2,000 to 4,000	....
	number of scans times 1,200 to 24,000	....
	1,000 for plutonium heart pacemaker	....
Dental:	ADD number of dental X-rays times 40	....
TV or VDU viewing	ADD 1.5 times number of hours per day	....
Regular hot showers using bore water	ADD 700	....
Jet-setting	ADD 2 per 1000 km travelled	....
WHERE YOU LIVE		
Locality: Coastal sandstone areas		400
Granite highlands	ADD 300	....
Building: Wooden (assuming half time indoors)		500
If brick or concrete	ADD 200	....
If poorly ventilated	ADD 1,000 or more	....
Cosmic rays: At sea-level		260
For every metre of altitude	ADD 0.2	....
Coal-fired power generation**:	World-wide contribution	5
If living near power station	ADD 50	....
If living 10 km from station	ADD 20	....
If living 50 km from station	ADD 5	....
Nuclear power generation**:	World-wide contribution	2
If living near power station	ADD 20	....
If living 10 km from station	ADD 1	....
(** 1000 megawatt capacity assumed, and spending half time at home)		________
TOTAL DOSE (Minimum about 1,800 in Australia)		________

Compare with Australian average of roughly 2,000 microSieverts.

filtered out into the waste ash. Increased asthma incidence has been reported where residential suburbs exist near a station.

Because most Australian coals contain between one and two parts per million of uranium the burning of many tens of thousands of tonnes of coal per annum results in the release of hundreds of kilograms of uranium. Whether it goes up the chimney or out in the fly ash, the uranium is unburnt and retains its natural radioactivity.

This means that people living close to a coal-fired power station receive an extra 50 μSv or so of radiation every year. Ten kilometres away this reduces to twenty, while fifty kilometres away the radiation dose is down to an extra five microsieverts.

Now consider a nuclear power station which, for the same megawatt output, consumes about the same amount of uranium! This is because nuclear energy release is a million times greater than chemical combustion processes, offsetting the factor of a million times less uranium in coal. The fissioning of uranium destroys it but leaves behind a small, compared to coal, residue of radioactive waste trapped in the used fuel rods. A small proportion of the fission products are radioactive gases which are vented to the atmosphere. These wisps of gas are detectable at the station boundary and over the course of a year would contribute 20 μSv to anyone living there, the same as the extra dose they would get by living on a hill 100 metres high. Ten kilometres away the annual dose is only about one microsievert.

The difference is not all that important compared with the radiation doses one receives from the other sources we have discussed, but I would much rather live near a nuclear power station than a coal-fired one because of the absence of much more noxious pollutants.

Medical and Dental Radiation Doses

When your dentist decides to x-ray your teeth, the radiation dose you receive is about 40 μSv per x-ray; much of it scattered from your teeth to other parts of your head and body. You will notice that the dentist or x-ray operator remaining in the room wears a heavy lead-lined apron as a shield and you may be given one as well. But the patient usually has fewer than a dozen dental x-rays a year and does not need the shield as much as the staff who stand to receive scattered x-radiation many times a day on every working day of the year. Without the aprons their exposures could accumulate to exceed maximum permissible working levels of radiation. But, as we shall see, those levels are highly conservative in the interests of adequate protection.

Medical x-rays and other radiation treatments are far more intense than dental x-rays. In fact some cancer treatments apply levels of radiation that would be lethal without associated measures, but we'll come to those shortly.

Hospital radiology departments are very conscious of radiation safety issues and adhere to the ALARA principle, which keeps the radiation dose to a patient As Low As Reasonably Achievable. But here a risk/benefit assessment operates. The radiologist must weigh up the benefit of the radiation against whatever harm it may cause. This is particularly the case with cancer treatments. For more minor cases, such as x-raying a broken leg, the benefit of finding out if the fracture is simple or multiple far outweighs the additional radiation exposure which, in this case, may statistically shorten life expectancy by maybe a hour. So it would be silly to refuse an x-ray on those grounds.

A chest x-ray as part of a screening program will deliver about 60 μSv. Through the use of image intensifiers this exposure is a lot less than it used to be years ago. The value of the program in providing an early indication of a potentially fatal breast cancer far outweighs the very minor radiation dose, in fact, as we shall see later on, it may contribute to better health - cancer or no cancer!

The radiation doses received from a scan procedure can be quite high, ranging up to twelve times the normal annual amount from everyday living. Scans are prescribed only when they are necessary for diagnostic purposes. Although no limits are set for medical exposures to radiation, the International Council for Radiation Protection sensibly recommends that they should be as kept as low as feasible to achieve the required result.

Scan procedure	Dose in microsieverts
Liver scan	1,200 μSv
Lung scan	1,600 μSv
Bone scan	4,800 μSv
Kidney scan	5,600 μSv
Brain scan	8,100 μSv
Heart scan	19,000 μSv
Soft tumour scan	23,000 μSv
Thyroid scan	24,000 μSv

This brings us to the field of radiotherapy - the use of nuclear radiation to cure serious cancers that would otherwise be fatal. Radiation may cause as well as cure cancerous tumours. Modern oncological studies have shown that three changes (continuous growth stimulation, immortalisation and changes on the cell surface) must first have taken place in order to induce a tumour. This gives a very low probability of radiation-induced cancers, a probability so low that no excess cancers have been detected among Japanese exposed to bomb radiation, nor has any excess been found among the Chernobyl clean-up workers. A task group of the International Nuclear Societies Council has reported that "there is no scientific evidence for increased cancers or heredity effects in humans for doses up to at least 50 millisieverts (50,000 microsieverts). However there are cases of cancer linked to high long-term radiation exposure, especially among the early workers with nuclear radiation before the dangers were properly understood.

On the other hand, large doses of radiation are used to kill cancerous tumours, the challenge to radiologists being to keep the dose of radiation as low as possible to healthy parts of the body. Every year in the State of New South Wales alone about 25,000 people are diagnosed with a new cancer. And about half of them are advised to receive a course of radiation therapy.

In cancer treatment the highest total body irradiation (TBI) is delivered to patients suffering from acute monocyclic leukaemia.

Powerful gamma or x-rays of six million electron-volts[4] of energy are used, giving a dose of from 10 to 14 sieverts over a period of from one to four days. This would normally be fatal. However it is survivable when combined with bone-marrow salvage and subsequent replants, and with blood transfusions. It is no wonder the patient's hair falls out under such extreme body stress!

When the cancer is localised, unlike leukaemias which are a blood disease and therefore affect every part of the body, the radiation dose may be directed to a specific region of the body. It is then possible to deliver what is called radical therapy over a period of four to six weeks when a total of 50 to 70 sieverts is delivered. This is ten times the normally fatal dose and is delivered at the rate of two sieverts to the tumour volume every day over a five-day week. With modern techniques it is possible to restrict the dose to parts of the body outside the radiation beam to less than one thousandth of the tumour dose. So the radiation is fatal to the tumour and survivable to the remainder of the body. Chemotherapy is employed to reduce side effects.

For palliative therapy, to alleviate pain, single radiation doses of up to eight sieverts are delivered to a localised area. These may add up to as much as 30 sieverts over a two-week period. This is usually done in combination with chemotherapy.

Radiologists and oncologists working on cancer treatment around the world have accumulated an enormous amount of experience. As they gain knowledge they develop ways to reduce the dose rates for both radiation and chemotherapy to improve the comfort of their patients. Their skills save thousands of lives every year with remission rates that get lower all the time. Their safety standards ensure, through the use of radiation-measuring badges, that they are not exposed to the lethal radiation levels delivered to their patients. Radiologists are permitted a maximum occupational radiation exposure of 20 millisieverts per year and in normal circumstances their personal doses come in well under that figure.

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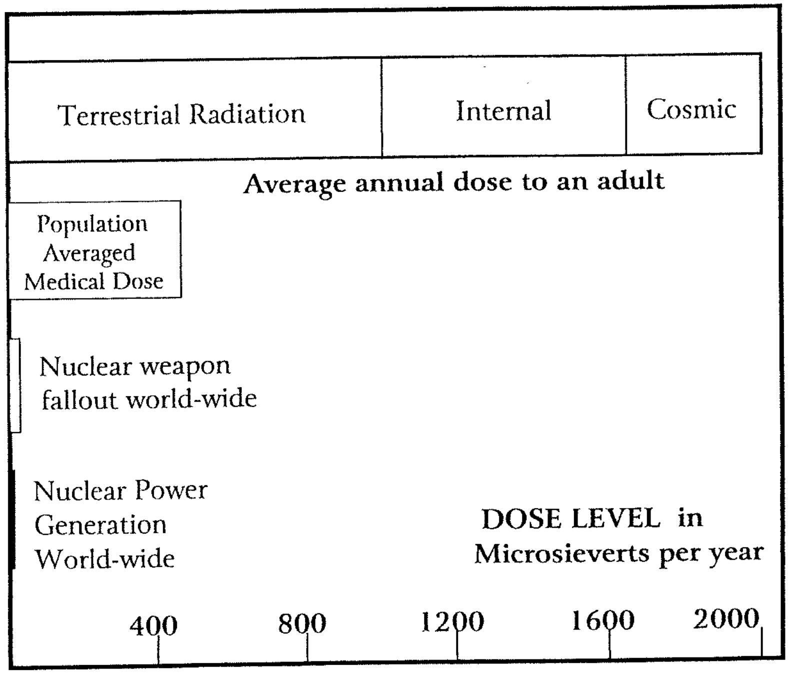
[4] This is the energy an electron gains when accelerated by a potential of one volt. The electron beam in a colour TV tube is accelerated through 26,000 volts giving each electron an energy of that many electron-volts.

We will now look at the range of radiation doses that are normally encountered by the public and see how they relate to the levels we've been discussing.

Whole-body Radiation Dose Rates

The centre pages of this booklet contain a table which allows the rough estimation of one's own personal annual radiation dose in microsieverts. It gives some idea of the level of radiation exposure of an Australian adult under a variety of circumstances. More importantly, the table leads to a better appreciation of the relative importance of the varied sources of radiation exposure.

The following diagram shows graphically our normal exposures compared with those from the two well-publicised scares of nuclear weapon fallout and nuclear power generation. They scarcely matter by comparison with the two main causes for an individual exposure in Australia.



The factors most likely to cause the Australian average dose to be substantially exceeded are exposure to a larger than normal radon dose and more than average diagnostic scans and radiotherapy.

The scale of the diagram is close to 50 millimetres per 1000 microsieverts (equal to one millisievert). This means that the occupational radiation dose limit of 20 millisieverts would be represented by a dose bar extending from the left (zero) side of the diagram to a point one metre away to the right[5]. A soft tumour or thyroid scan would be depicted on the diagram by a bar extending a little further than that.

The radiation dose at which signs of minor radiation sickness appear would be depicted by a bar extending from zero (left side of diagram) to a point at least ten metres to the right. The onset of serious radiation sickness occurs at a dose level that would be shown on the diagram fifty metres to the right, and a fatal dose would be depicted a further 200 metres to the right.

It is hardly possible to convey more vividly the relatively insignificant dangers of normal everyday nuclear radiation exposures than by the above illustration. We are dealing here with factors of over a million. Watching TV or a computer screen for four hours a day over the course of a year will give you a radiation dose of five or six microsieverts, one millionth of the lethal dose of five or six sieverts. It is nice to offer such a reassuring thought for TV addicts and computer junkies.

What are the Facts about Toxic Agents?

By reading this far I hope that you, the reader, are now much less fearful of nuclear radiation. So dare I go a step further and suggest that doses of radiation are somewhat akin to the many chemical elements essential to life. In small amounts they are needed to create a healthy organism while in excess they are toxic and behave like poisons. To understand why this should be we need to take a closer look at what is meant by toxicity, the property of being poisonous.

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[5] I am indebted to Sir Fred Hoyle for this graphic way of referring to large exposures.

But let us commence by looking at the reasons why some elements are vital and others not. Recent studies of surface reactions suggest that the first self-replicating structures were born on the flat planes of crystalline substances that allowed compatible chemical elements to assemble in a wide variety of forms. It only required one of the zillions of different combinations to acquire the knack of forming another copy of itself and the race to evolve was on.

This is not to be a discussion of evolution. Rather I want to make the point that the development of better, more complex units of life called upon whatever available chemical resources were needed to achieve each milepost in the upward climb from the primeval soup. We see the ultimate result in ourselves, or rather what we are made of.

Over the years it has been proved that one chemical element after another is essential for animal life. Back in the seventeenth century it was realised that iron is essential. This is not surprising because iron forms the basis of the haemoglobin which gives the red colour to our blood. Too little iron leads to anaemia, which can be a fatal condition. In the nineteenth century it was found that iodine is essential for preventing goitre in the thyroid gland, Since then a host of elements have been identified as essential in trace amounts, such as cobalt for vitamin B_{12} and selenium for viable heart muscle. Other essential elements include arsenic, cadmium, chromium, copper, fluorine, manganese, molybdenum, nickel, tin, zinc and several others.

The entire range of 92 naturally occurring chemical elements may be divided into those essential for life, like those mentioned above, and those that are not essential, like mercury, lead, thallium and uranium. The latter are quite understandably regarded as toxic elements because they represent unwanted intruders in the cells of living beings. Their presence interferes with the vital processes that go on in a cell, behaving like water in the petrol of your car. In other words, unnecessary elements inhibit proper operation of cells and for that reason are toxic to both the cell and the organism of which it is a component.

It is one of the basic tenets of toxicology that all substances - even those elements essential to life - are lethal in sufficient quantities. Don't be surprised that this rule applies to essential substances. Make no mistake; a gross excess of anything - air, milk or chocolate - will kill. And of course that includes nuclear radiation, but we'll return to that later.

The relationship between the intake, or dose, of a toxic substance and the harmful effects it produces is given by a dose-response graph. Figure 1 shows such a graph. I have depicted it with harm shown increasing downwards, which is the reverse of the usual toxicology convention. I think ill-health is a negative condition. So death is the shaded region at the bottom.

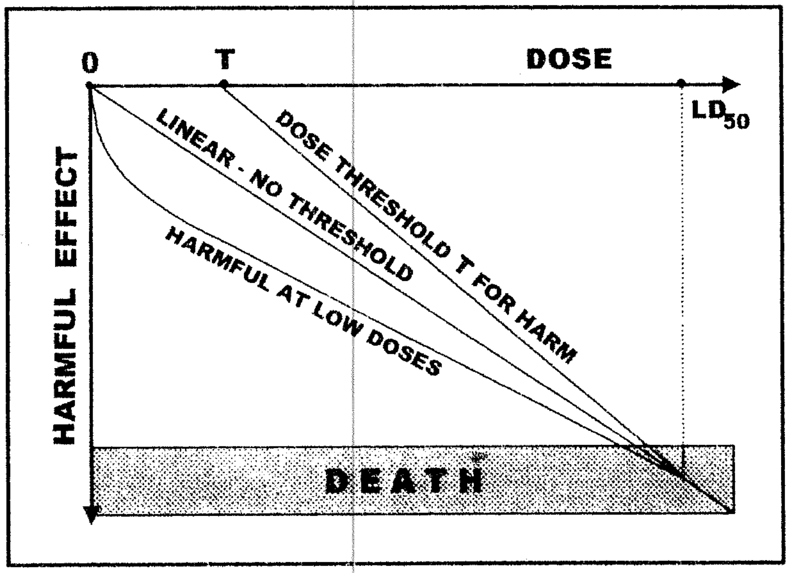

Figure 1: Dose-Response for Toxins

The horizontal axis of the diagram represents the level of dose of a given element or chemical substance. The lethal dose varies from person to person, which is why the terminal stage is shown as a shaded area rather than a sharp line. Frail people and infants succumb to a toxin more readily than adults with a strong constitution. So for that reason toxicologists define the toxic level at which half of a population dies as the LD_{50} level, which they call potency. It is shorthand for the Lethal Dose in fifty percent of cases.

For elements like lead, which does not seem to be of any use to a living organism, the response is taken to be linear. The more lead ingested the greater the harm done until death results. This is depicted by the straight line labelled "Linear - No Threshold" in Figure 1. At very low doses the toxic effect may be offset by the rate of elimination of the toxin. For this reason the body may seem to tolerate extremely low doses of lead, for example, before identifiable harm is evident but this does not mean that no harm is done. So to play it safe at low doses the LNT approach is taken.

As for the substances necessary for life such as, say, fluorine there is a threshold for harm. Above the threshold increasing doses of fluorine cause increased harm in a more or less linear manner. For simplicity we'll take it to be linear. This is shown in Figure 1 by the line from the threshold T to the point of death at LD_{50} in the shaded region.

It is claimed in some quarters that small doses of radiation are particularly harmful. This totally unproven state of affairs, if it were true, would be depicted by the lowermost curve in Figure 1.

The Bright Side of Nuclear Radiation

It will come as a surprise to many folk that nuclear radiation is not entirely bad. Certainly not as bad as it is frequently made out to be. Like our domestic friend, electricity, nuclear radiation is dangerous in large amounts. In the case of electricity small amounts are taken to be harmless, otherwise we would not allow our children to replace the 1.5-volt batteries in hand-held toys and computer games. But we keep ourselves, and our children, away from high voltages. Recently a boy died when he tried to retrieve a soccer ball from an electricity sub-station surrounded by a high wire-mesh fence sprinkled with "Danger High Voltage" notices. Somehow he got into the enclosure, walked too near an 11,000-volt wire and was killed instantly. Or he could have been very severely burned and hospitalised for months.

High levels of radiation also require care. That is why high-level nuclear wastes need to be isolated like high voltage electricity. On the other hand low levels of radiation are not only exist all around us but what's more its presence has actually been shown to be essential for good health.

Pardon me, what did I say?

Nuclear radiation healthy?

Yes, it has been demonstrated that low to moderate levels of nuclear radiation actually promote health. To understand why, exactly, we need to take a closer look at the essential requirements for the proper development and nutrition of animals like we humans.

Many of the elements we have identified as essential, such as arsenic and selenium, are well known as serious poisons. Yet here they were, in an earlier chapter, listed as vital to life. On the other hand it is a basic tenet of toxicology that all elements, without exception, are toxic in sufficiently large amounts. So we have the apparently strange situation that low concentrations of some elements are a necessity for life, while a large surplus can make them poisons. Can this also be true for nuclear radiation?

In the case of chemical elements, it is becoming clear that Mother Nature has extensively called upon their diversity to create the many enzymes, hormones, lipids, steroids and other large molecules essential to life. The necessary elements were readily available in the primal crust of our planet, waiting to be drawn upon by the first forms of life. At that time the level of nuclear radiation was greater than it is today, so might it be possible that radiation too was utilised in the evolution of life?

One of the lessons being gradually learned by the medical profession is that antibiotics should be prescribed with great care. Over the past few decades an increasing number of bacterial strains have developed resistance to most of them. The bacteria "learn" to recognise and combat the deadly powers of anti-biotics by altering their own internal chemistry to render the anti-biotics ineffective. The complex cells in plants and animals have quite a lot in common with bacteria. Recently, through advances in mapping DNA sequences, it has been discovered that we humans share about ninety percent of our DNA codes with those of lowly bacteria! So if bacteria can autonomously develop ways of dealing with the threats of anti-biotics, and as we mentioned earlier have learned to cope with deadly levels of nuclear radiation, is it not too far-fetched for our human cells to have done likewise?

The findings from hundreds of studies have shown that nuclear radiation in moderate amounts promotes good health! Such exposure tones up the body's immune system and stimulates efficient biological mechanisms for repairing both DNA and cell damage. This must be so, because there are approximately 150,000 single-strand DNA breaks and coding base lesions in every mammalian cell every day.

Way back in 1981 Professor T D Luckey wrote a book titled "Radiation Hormesis" in which he cited a massive weight of evidence showing beneficial effects from nuclear radiation. This is what is meant by the word hormesis. The benefits have been borne out by long-term studies of workers in nuclear industries and, of course, the Japanese atom-bomb survivors. In 1993 Professor S Kondo in Japan wrote a book "Health Effects of Low-level Radiation" in which he provided further evidence of support for the benefits to living organisms of moderate doses of ionising radiation.

In the United States a comparative study of radiation levels and cancer mortality rates in three Gulf Coast states and three Rocky Mountain states has been completed. The results show that the average natural background level of radiation is over three times higher in the Rocky Mountain states but the total cancer rate is 21 percent lower there than in the Gulf Coast states. Also the average radon level is four to five times higher in the Rocky Mountain states but the lung cancer rate is 31 percent lower than in the Gulf Coast states.

This hormesis effect, astonishing to those adhering to the LNT approach to radiation toxicity, is steadily gaining acceptance because of the increasing number of studies supporting it.

But what is even more astonishing is the dawning realisation that living creatures can actually suffer from radiation deficiency.

Say that again! A deficiency of a damaging agent leading to a harmful outcome? That would seem to turn logic upside down - a paradox, surely. Yet there is biological evidence for such an effect.

To understand this apparent paradox we need to digress a little and take a look at what are known as deficiency diseases.

What? A Deficiency of Nuclear Radiation?

Not until animal experiments were undertaken early last century was it discovered that lack of certain elements could lead to disease. This discovery resolved a major problem with sheep farming in many districts. In those areas lambing percentages were far too low. The sheep were failing to carry their lambs to term. Careful analysis revealed that the soils in the affected places were deficient in cobalt. When tiny amounts of cobalt were added to fertilisers and sheep licks, the problem vanished.

Chemically speaking, cobalt is an essential element in the make-up of the complex vitamin B_{12} molecule. Without it the vitamin cannot be created by micro-organisms such as moulds and bacteria and in turn its deficiency is fatal to a developing foetus. Or, for already developed organisms, a dietary lack leads to pernicious anaemia and death if not treated with the vitamin. On the other hand an oversupply leads to serious liver damage.

Other elements and compounds are similarly essential. Lack of iron leads to anaemia. Selenium is absolutely essential to build heart muscle, but it is a potent toxin in much more than trace amounts. Iodine is needed by thyroid glands to prevent goitre. Fluorine is vital for hardening teeth enamel. Shortage of water leads to death by dehydration. Lack of air causes suffocation. And so on.

Remember what we said earlier, an excess of any substance, even one vital to life, is toxic.

The pattern that emerges is a progressive one of deficiency, sufficiency and excess in order of increasing supply. Both deficiency and excess are life-threatening. This pattern is what toxicologists refer to as a biphasic response. We can depict it graphically by Figure 2, an amended version of Figure 1 where we now depict health as well as harm on the vertical axis.

The message given by Figure 2 is not hard to understand. For those substances essential to the health of living creatures there is a range between S, below which the substance is deficient, and T the threshold for harm beyond which the substance is in excess. The range S-T is the range for good health.

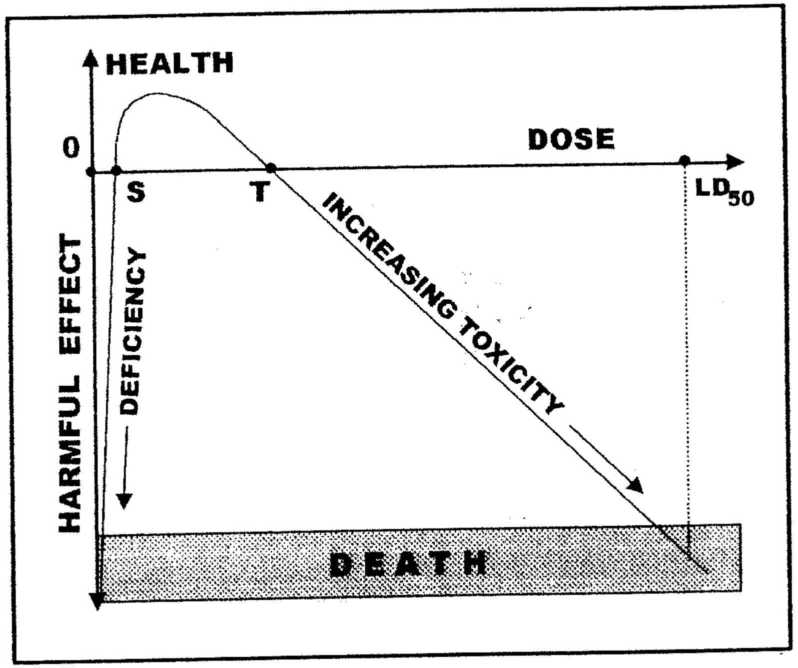

Figure 2: Dose-Response curve for substances essential for life.

It is quite amazing how universal the biphasic response of Figure 2 is in the world of nature.

Consider sunshine, for example. It is well known that a certain amount of sunlight is necessary for health through the photochemical production of vitamin D by the outer layers of the skin. Workers whose occupation denies them solar exposure need dietary vitamin-D to maintain good health. Without it they suffer deficiency diseases such as rickets.

So much for under exposure to sunlight. Over exposure leads to sunstroke that can be fatal. Again we see a biphasic situation.

Now we come to the point. We have seen that nuclear radiation in moderate amounts can promote health. With the full meaning of Figure 2 in mind we are entitled to ask if there is such a condition as a radiation deficiency.

Would you believe? It appears that there actually is such a condition.

Because everyone on this planet exists in the depths of an ocean of nuclear radiation we do not see a disease that might be referred to as "radiation deficiency syndrome". However some scientists, mainly French, have carried out experiments on various organisms under conditions where practically every source of radioactivity and ionising radiation have been excluded, both by stringent purity and by massive shielding of external radiation sources. Humans have not, to the best of my knowledge, been guinea pigs in such experiments but the various organisms tested under low-radiation conditions exhibit poor health and fertility compared to their control groups.

There we have it. Nuclear radiation follows the same biphasic dose-response behaviour as the other toxins we've been discussing. In the light of what we have learned about measuring radiation dosages it now remains to place some estimates on the curve shown in Figure 2 as it applies to the effects of nuclear radiation on human beings.

The Real Danger of Nuclear Radiation

Starting at the low-dose end of the curve we assume that a human totally deprived of exposure to nuclear radiation would become sick and die like the laboratory organisms the French experimented on. That means a low-dose LD_{50} point will be found close to the origin of the graph at O. Like the upper LD_{50} point it is where odds of dying are fifty fifty. If the amount of deficiency is lessened the curve must rise in a more or less linear fashion until the point S is reached, where there is no longer a deficiency of radiation. Because of a lack of human data in this region we may only guess where S lies on the dose axis. It would, at a guess, seem to be in the region of a few tens of microsieverts. I leave it to you, the reader, to estimate whether living close to the boundary fence of a nuclear power station would be sufficient to cure a radiation deficiency, if you had one!

Between S and T, the onset of harm, good health prevails. According to Professor Luckey, good health peaks at an annual radiation dose of around ten millisieverts. This accords well with the data we mentioned earlier on the comparison between Americans living near sea-level in the Gulf States and those dwelling in the Rocky Mountain states. It also upholds the century-old belief that a little nuclear radiation is good for you, as exemplified by devotees of wallowing in hot spas noted for their radioactivity levels.

Now we must decide where the threshold point T lies. Earlier we mentioned the high levels of background radiation in places like Kerala and Ramsar. Some inhabitants of Ramsar receive an annual gamma radiation dose of up to 132 millisieverts with no evident degradation of health compared to people of similar socio-economic status in areas with much lower levels of background radiation. The levels in Kerala are not as high, but again there are a number of studies showing no harmful effects.

Studies of women who during WW2 painted numbers on instrument dials with radium paint to make them luminous have not detected any ill-effects except for those receiving doses of over 200 mSv. This also is the level above which the Japanese atomic bomb survivors showed signs of radiation sickness and recovered. One of the most heavily irradiated women of all time must have been the discoverer of polonium and radium, Madam Marie Curie. She eventually died at age 67 of leukaemia, doubtless brought on by excessive exposure to nuclear radiation.

So for nuclear radiation the threshold for harm would seem to lie in the region of 200 mSv. At exposures of one sievert, serious radiation sickness occurs and medical intervention is called for. And for a normally healthy individual the LD_{50} level is reached at about five sieverts. Above that level heroic measures are needed, as is the case with the extreme cancer treatments mentioned earlier. The highest radiation dose received by one of the victims of the Japanese Tokiamura criticality accident was reported to be 17 sieverts. He failed to survive.

Concluding Remarks

Hopefully you, the reader, will now be reassured that you have little to fear from the levels of nuclear radiation you are likely to encounter during your lifetime. Even for a major nuclear reactor accident such as the one at Chernobyl it is clear that the doses received by most of those in surrounding areas were insufficient to justify their forced evacuation. They were less than the doses received by Ramsar citizens. At Chernobyl the authorities applied dose limits originally set very conservatively using the LNT model rather than the more up-to-date response relation depicted by Figure 2. Fear of radiation is worse than radiation itself in all but extreme cases.

The existence of radiation hormesis is gradually being more widely accepted. Professor Roger Clark, Chairman of the International Commission on Radiological Protection, argues that it is time for a change and current radiation exposure limits based on the LNT concept should be seen not as absolute limits, thereby frightening people, but as action levels indicating that more care is called for.

Furthermore, Emeritus Professor Zbigniew Jaworowski of the Central Laboratory for Radiation Protection in Warsaw points out that "every human life hypothetically saved in a western industrial society by implementation of the present radiation protection regulation is estimated to cost US$2.5 billion." Jaworoski considers that taking into account the costs of US$50-99 (sic) for saving a life in developing countries by immunisation against measles, diphtheria, etc., this state of affairs is absurd, immoral and scandalous.

Hopefully those who read through this booklet and think about its message will not be fooled by the prevalent scaremongering about the dangers of nuclear radiation. Sure there are dangers, but they exist at levels far beyond those encountered in all but the most extreme circumstances.

Lastly, it should be mentioned that the effects of ionising radiation differ from microwave, radio and power-line radiation. These demand a completely different treatment beyond the scope of this small book.