Chapter 8: Protected by Natural Evolution

Take no thought for your life, what ye shall eat, or what ye shall drink; nor yet for your body, what ye shall put on. Is not the life more than meat, and the body than raiment? ... Consider the lilies of the field, how they grow; they toil not, neither do they spin: And yet I say unto you, That even Solomon in all his glory was not arrayed like one of these.

St Matthew's Gospel, Chapter 6

Reaction of nature to radiation

Game changing

It can take a long time for the appropriate reaction to a sudden unexpected event to become clear. Immediate conclusions reached in a state of shock can be inept and injurious. So it was with the reaction to the terrorist attack on the Twin Towers in New York in 2001. It was immediately assumed by the US administration that this was a game-changing event, and that the rules and guidance for the conduct of society, provided by justice and diplomacy and built up over past centuries, no longer applied. More than a decade later – a decade that saw imprisonment without trial, unrestrained state-sponsored surveillance and wars that could not be won – it is widely agreed that the initial flash judgement was misguided.

The detonation of the two nuclear bombs on Japan in 1945 had a similarly profound and unbalancing effect. Suddenly the rules of life seemed to have changed and the spirit behind the bombs appeared all-powerful. So, when it came to matters of safety, whatever physics and physicists seemed to say was treated with priority. The power of nuclear energy was seen to be alarming and extra caution was readily added to match public concern, with which those scientists not knowledgeable in nuclear physics could only agree. Only clinical medicine continued, fearlessly and undeterred, to follow the legacy of Marie Curie in the use of moderate and high levels of radiation for real health benefits for many millions of people.

Natural and responsive biological protection

The effect of making health decisions based exclusively on energy needs, as described by physical rather than biological science, may be illustrated with a story.

> A physicist and a biologist enter for a marathon to be held in three month's time. The physicist argues that he will need to store up as much energy as he can and so stays in bed to ensure that his bodily reserves peak on the day. The biologist applies more common sense knowing that life is generally adaptive in its response to stress. Each day he runs for exercise, going a little further every time and building up to the marathon distance. When the day of the race comes, the biologist runs a good race but the physicist collapses well short of the half way mark and is taken off to hospital.

The message is so obvious, but does it apply to the stress caused by radiation? Unfortunately the authorities' view of its safety is to follow the physicist and minimise the dose by staying in bed, or rather the equivalent. A common sense view would look at the biology more than the physics – but the biology has been largely ignored for the past 70 years.

Natural biological radiation protection is as significant as that provided by the constraints of physical science, described in the previous chapter. The two are complementary and the combination is outstandingly effective. Only under exceptional circumstances is there any justification at all for adding a third level of protection, such as regulation. The biological response ensures that most current safety prescriptions should be redundant – such as those put in place by authorities with an eye on the public political reaction to the bombs of 1945 and the Cold War propaganda that followed. Unfortunately, few physicists have any appreciation of the role of biology, and many biologists are in awe of the physics expressed in a mathematical logic that they are not able to follow because their education never prepared them. Meanwhile, popular opinion, guided by politicians and the media who have little or no understanding of either discipline, remains confused and easily frightened. So for many decades nuclear power has been seen as mysterious and unsafe, and therefore to be avoided whenever possible. In reality its safety is outstanding and second to none.

Biology designed for survival

The business of life is survival, and life searches for the best design for the prevailing conditions by trial and error. In principle, life might have existed as a single vast organism, for instance as envisaged by the astronomer Fred Hoyle in his novel, *The Black Cloud* [1] – but that would make it very vulnerable. Biology found that survival is best assured when its chances are divided statistically into a large number of similar elements, so that if some happen to fail, there will be others that succeed. If some are unlucky, there will be lucky ones too. In life this design feature is realised on two distinct scales – the scale of individuals and the scale of cells. Society, or life as a whole, is made of modules – individuals – and each individual is made of cells that are also modular. A child playing with LEGO bricks quickly learns the versatility and potential for strength that such a modularity brings. Unlike the design of nature realised in physical science, biological realisations in nature are not simple, unique or universal. They come in many forms – the vast array of different animals, plants, fungi, fishes, insects, viruses and bacteria, each competing for viability in the given local environment.

The expression of life as multiple individuals allows each to survive on its own, and also to cooperate and work together in herds, packs or families. They may also compete or fight one another with the benefit of internally selecting the strongest and fittest within the group. This improves the chances for the herd as a whole by culling the oldest and weakest, and maximising resources for the survivors. However, mutual help and communication between individuals, especially within family groups, can also improve the survival prospects for the herd as a whole.

On a microscopic scale and within each individual, the design of life repeats the statistical strategy by building individuals from many cells. These cover different functions, but, as with individuals, a spread of risk is achieved by having large numbers of them that are more or less interchangeable. The provision of master copies of the DNA, the individual's unique genetic barcode, within every cell makes for resilience in the face of external attack. It also acts as a personal identification system that minimises incidents of *friendly fire* between cells. The affiliation of cells is policed by the immune system which attacks any seen as foreign. Communication between cells within an individual by chemical messaging is as highly developed as it is between individuals in a group by speech, written and electronic means.

On each scale the design is honed to maximise survival, and everything gets reproduced and replaced: cells are copied and die in the cell cycle; individuals reproduce, sexually or asexually, and die. If a cell is attacked and does not survive, there are replacements that do. If an individual dies, there are others to take its place, because life aims for the survival of the species, not the survival of the individual. The sanctity of life, the survival of the individual, is not part of the scheme, and nature endures losses of individual lives on a massive scale, which is salutary for us to remember as we face a challenging future. Until now there has always been another distinct civilisation to take over when one fails. But with globalisation the strategy of survival for human society through plural diversity appears to have reached its limit.

Active response to an attack

When life is attacked, either at the cellular or individual scale, it does not simply rely on its passive design but has active responses as well. At a social level, there are all the familiar defence mechanisms of individuals, separately or jointly, including concerted military action. At the cellular level the proteins and other working molecules of biochemical life when damaged can be replaced by reference to the DNA as master record. When the DNA itself is damaged it can usually be repaired without introducing an error. This is relatively straightforward in the case of a Single Strand Break (SSB) because the famous double stranded helical structure of DNA means that the other strand remains attached and error-free correction is normal. If both strands are severed, a Double Strand Break (DSB), correction is still possible and recent work has shown how this is done [[13]]. Most errors that might be introduced into the DNA during the DSB repair process would prevent it being copied in the cell cycle, so the mutation does not propagate. Furthermore, a cell with damaged DNA may be selectively killed, a process called *apoptosis*. The choice between repair and replacement as the best way to remove the damage is determined by making the optimum use of the resources available. Nevertheless, if the mutation does get copied successfully, the immune system continues to scan for any cell that shows signs of not belonging. This is a major problem in transplant surgery; such foreign cells are liable to be rejected unless the immune system has been suppressed.

What happens when biological protection fails

The protection system has two failure modes, described in Chapter 6:

First there is a short term functional breakdown of organs caused by having too few operational cells; typically there may be insufficient resources to maintain both the repair of damaged cells and the cell cycle that produces new ones by copying. Such widespread cell death first affects systems with rapid cell cycle activity, notably the central nervous system and the gut. This condition is Acute Radiation Syndrome (ARS) which may be fatal within a few weeks. Otherwise, recovery is usually complete once the cell cycle has been re-established.

Then there is longer-term failure through undiagnosed repair errors that can give rise to uncontrolled growth of cells, injurious to the health of the organism as a whole. Such growth, unchecked by the immune system, is what we know as cancer. If not treated, this can develop and spread elsewhere in the organism, hijacking resources and leading eventually to death.

Cancer induced by radiation is not generally distinguishable from cancer initiated by other oxidative agents. Such agents occur naturally in the absence of radiation when reactive oxidant species (ROS) leak from the mitochondria that provide energy to cells for muscular activity, nervous communication and the process of thinking.

We may imagine analogous failures in an army of men. The first such failure mode is when the army is defeated through a loss of men and resources in battle. The army is united, but the defeat is quick and decisive. The second mode is through an insidious loss of morale, desertion or mutiny with men turning on one another. As an illustration, these may be likened to death by ARS and by cancer, respectively.

Historically, it was found that an exposure to radiation above a certain threshold gave rise to a reddening and inflammation of the exposed tissue where excessive cell death caused a loss of function in a few days. This is like familiar sunburn, although the radiation and damage penetrate deeper.

This *early reaction* is still sometimes referred to as *tissue reaction* today. Then there is *late reaction*, an alternative name for radiation-induced disease like skin cancer.

Other names for the two reactions, *deterministic* and *stochastic*, suggest, deceptively, that there is more than one kind of causality at work; the data simply show outcomes with high and low probabilities, respectively. For example, among those who received high whole-body doses of internal Cs-137 in the Goiania accident, half of those with more than 100 million Bq died of ARS, including one person with 1,000 million Bq and a dose of 4,000 mGy. But another who did not die of ARS survived until 1994 before dying of alcoholic liver failure, not directly related to radiation, in spite of an accumulated dose of 7,000 mGy. In biology the effect of a dose varies from patient to patient, and the label *deterministic* appears inappropriate.

Stabilisation and adaptation

Examples of stability and its characteristics

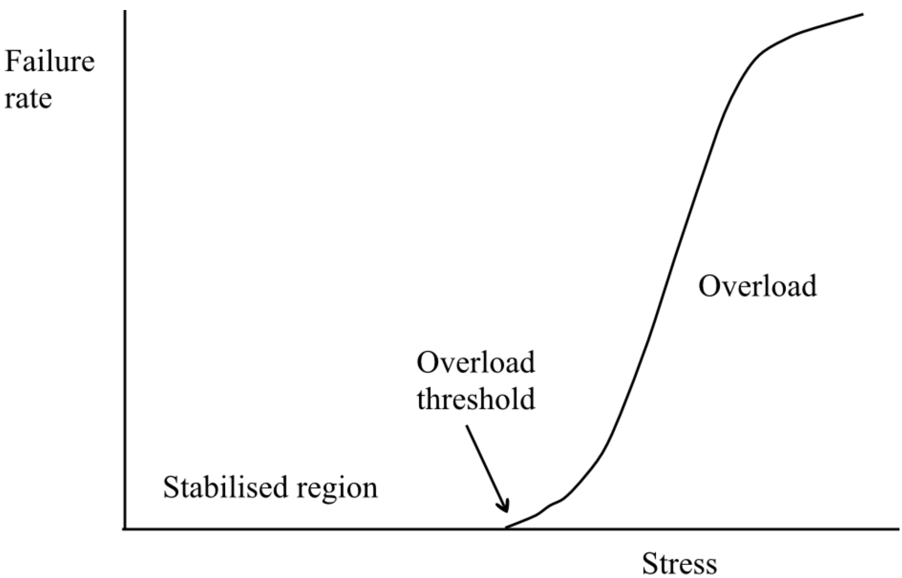

Illustration 30: A sketch graph showing a typical stabilised response (or failure rate) to a stress,as found in electronics, management and engineering, and characteristic overload threshold.

Illustration 30 shows an example of a curve that might describe the stabilised response to a stress. It could apply in many different contexts, like the management of a company, for example. Any small stress should have no noticeable effect on the company, provided everybody concerned knows what to do and takes action accordingly. However, there is a threshold beyond which there are not enough staff, or not enough money, for example, to cope. Or, perhaps, there are not enough phone lines, or warehouse capacity. There is no need to be precise about the meaning of failure – in each context it is usually clear. Anyway, this is where the curve rises to the right of the threshold, and for a stress or loading that exceeds the threshold, the failure rate rises relatively sharply.

An electronic amplifier stabilised by feedback behaves in a similar way; there is only so much current available to provide the correcting signal, so that above a certain threshold the feedback is no longer effective. We could look at many more examples, but all have similar features, and there is no reason to suppose that the response of living tissue to the stress of different radiation doses is any different. If there is, why should that be? There is nothing different about radiation, it is just another stress. Contributions to the response come from the initial effect and then the correction and repair effects, that together reduce or eliminate on-going damage.

In each example there is a time element to the story. The stress that matters accumulates in a short time window needed for repair or feedback to act. For the biological impact of radiation, as in the management or electronic examples, what happens outside this recovery period is less important. As always, empirical evidence should be the arbiter of whether this picture is qualitatively correct or not. We need to look at further details but it is significant that the mortality curve for Chernobyl workers (Illustration 26 on page 136) has the same generic shape as Illustration 30 and is not a straight line.

Adaptation, when the response learns

But the generic feedback or repair description shown by a stress-response curve like Illustration 30 is seldom a complete description of what happens. As a result of a stress failure or a near-miss, the shape of the curve may adapt or change. In this way the curve itself may depend on the history of recent stresses. For the example of a company, recent experience may persuade the management to hire more staff, increase financial provision, install more phone lines, or acquire more warehousing, so that next time there is an unusual stress there will be less chance of a failure. In terms of Illustration 30, that means the curve would be shifted to the right and the threshold raised. Such dynamic adaptation increases the likelihood that the company survives. That is what good management does.

Indeed survival is central to the function of biology too, and it would be surprising if such adaptation played no part in its strategy. Adaptation is what is happening in any fitness regime. Exercise, taken each day below the threshold of real harm, encourages the body to improve cellular repair resources and blood flow. Provided exercise is not excessive and damage is not done, the improvement means that the threshold at which damage occurs is actually increased each day. Then the exercise taken each day can be extended without harm – there is a limit, but it is very much higher than the limited exercise that can safely be taken by someone who lives a sedentary lifestyle. As explained in Chapter 5 oxidative stress plays a crucial part in physical and mental activity, and the adaptive benefit of exercise and cognitive activity is effective in overcoming oxidative attack.

We should expect that radiation too would stimulate the cellular repair and replacement mechanisms, so that following a radiation exposure, cells would increase their inventory of antioxidants, DNA repair enzymes and other defences against oxidative damage. Indeed there is evidence that they do, and they add to resources for immunity, too. On this basis we expect that the damage threshold would increase for subsequent radiation exposures. Do real data suggest such adaptation to radiation actually occurs? We shall see that they do [2, 3, 4].

Chemical nature of initial radiation damage

Exposure to radiation and muscular activity seem very different, but that is not true of the damage they inflict. Some damage to DNA caused by radiation is a direct collision of the radiation with the DNA molecule itself, but since the DNA forms a small fraction of total body weight, and half of that is water, most of the broken molecules left by radiation are fragments of water, such as H, OH, O and H_2O_2, in electrically charged and uncharged states. These hot radicals, the ROS mentioned in Chapter 5, are also made by a cell's mitochondria, its power source. In fact it is estimated that in a single cell, 10^9 ROS per day are produced by normal metabolic activity – that is just over 11,000 per second [5]. Is that reasonable? In the box on the next page we calculate how well the biology is designed.

All ROS are highly destructive, and every cell has to keep a supply of anti-oxidants whose business is to mop up and quench the ROS before they use their high activity to break and ionise further, otherwise undamaged, DNA. In recent years it has been popular to take antioxidants to enhance the suppression of early pre-cancer conditions. However, this is found to be ineffective, probably because it is the concentration of oxidants that triggers inter-cellular chemical messages. By taking extra antioxidants such messages about oxidative attack are suppressed and other cellular defence mechanisms are stood down.

We can do a rough calculation to check that these numbers are reasonable:

If the mass of a cell is about 10^{-9} g, that is 10^{-12} kg, then this leakage rate is 1.1×10^{16} ROS per kg per second.
If one ROS carries an energy of about 10 eV, that is 1.6×10^{-18} J,
so all these ROS comprise a power loss of 0.0018 watt per kg.

A resting human produces about 2 watts/kg. So for every 2 watts generated, the energy lost by leakage of ROS is 0.002 watts, roughly.

So biology has evolved a power source with an inefficiency of 1 part per 1,000. That seems reasonable. Much worse would waste energy. Much better would suggest a waste of resource and over-design.

The message to take away is that the ROS from a radiation dose and from normal metabolic activity are chemically rather similar for many purposes, including carcinogenesis, the tendency to initiate cancer. What is important for control of ROS is their uniformity in space and time – short acute bursts in time and high concentrations in space are not easily quenched.

War games of evolution

However, it is not only the response to a threat that may change and adapt, but the threats themselves. Consider first the political world of individuals and nations. (We will come back to the microscopic world of cellular life later.) In that case responses to military threats are frequently explored and evolved by engaging in *war games*, to find ways to out-wit the other side. An actual engagement might go either way, depending who is the stronger or cleverer. But if one side sticks to a never-changing strategy, then eventually the other side should find a way to win, whatever their relative strengths.

And so it is in the microscopic world too. In the battle between cells and viruses there are no certain outright winners – both sides are constantly changing strategy by mutation and immunological adaptation. The battle goes on. Sometimes the virus wins and there is an epidemic. Sometimes the immune system with its antibodies wins, often with active help from health programmes too.

But in the battle between physical ionising radiation and life, the situation is quite different. The effect of the radiation is set and fixed by physical science – it never changes. But living organisms and their cells are free to evolve and find a defence against radiation that is more or less complete. This is true in spite of the overwhelming *fire power* on the radiation side and the extraordinary frailty of life on the other. Biology has had over 3,000 million years to come up with its defence strategy against the seemingly all-powerful ionising radiation.

This is the point that mankind has failed to realise. In formulating our attitude to radiation, we have been too readily impressed by the imbalance of fire power without noticing the overwhelming effect of the strategic design of life.

Energy, mitochondria and keeping fit

Keeping fit encourages the body to maintain adequate resources ready to repair its working cells. Regular exercise is a simple way in which to raise the norm of what the cells of an organism expect and are prepared for. At the microscopic level the damage to be repaired is due to the oxidative processes that we have been discussing. Energy is provided to cells by the mitochondria, which burn nutrients taken from the blood stream using oxygen carried by the red blood cells, and make the energy available to the rest of the cell by means of molecules of adenosine tri-phosphate (ATP). This process or metabolism produces about one watt of energy per kg of body weight, enough to keep the body warm and provide the basic physical and mental energy it needs, and where extra energy is required it provides more. In so doing oxidative agents (ROS) may leak from the mitochondria and inflict damage on the DNA in the cell nucleus that is indistinguishable from the damage caused by the ROS released in the radiolysis of water – that is the break-up of H_2O by radiation.

However the energy per second absorbed from any ionising radiation is remarkably small compared to one watt per kg, the power of metabolism when resting. A patient receiving a course of radiotherapy gets a high radiation dose each day: the energy deposited in healthy tissue is 1,000 mGy per day, that is one joule per day per kg. That means that in one second the metabolic process delivers as much energy as the patient receives in a whole day in radiotherapy treatment. The ratio, the number of seconds in a day, is a factor of 86,400, so it is no wonder that ionising radiation does not make the patient feel hot – it is extremely weak. Natural background radiation at an average 1 mGy per year is even weaker, less than the metabolic rate by a factor of one billion. It is the leakage of ROS from the mitochondria that is responsible for most of the natural oxidation of DNA. Adaptation, as a response to moderate physical or mental exercise, stimulates and strengthens protection against ROS and their effects. Radiation is no different because the ROS and their effects are very similar, especially at low LET. This is probably why *low-dose radiotherapy*, usually as whole-body or half-body, can be effective at stimulating the body's resistance to cancer. It may be why treatment in health spas that offer radioactive waters brings welcome relief, even in an era when fear of radiation dominates the lives of many people. Somehow people have allowed themselves to imagine that radiation health from natural and artificial sources are quite unrelated. For instance, the radiation in the *onsen* in Japan, and the Baden in Germany, is the same as the radiation that comes from the radioactivity released at Fukushima Daiichi. In fact both are harmless at the levels encountered, but cultural perceptions have prevented people seeing the connection.

Evidence for adaptation to radiation

The effectiveness of regular stimulation by moderate doses of radiation applies to the immune system as well as to the inventory of antioxidants and DNA repair enzymes. As early as 1915 and 1920 the results of simple but clear experiments on mice were reported by Murphy and published in the Proceedings of the National Academy of Science [[6], [7]]. The experiments were carried out on two groups of mice. Those in the first were given a single small exposure to X-rays and a week later were injected with transplantable cancer. Those in the second were treated in the same way but without the exposure to X-rays. The experiment was repeated three times. In each case the cancer infection rate for the group given the X-rays was a factor three smaller than for those given no X-rays, as shown in Table 9.

Reference [[5]]	Exp 1	Exp 2	Exp 3	Average
Infection rate in mice after X-rays	25.0%	29.0%	28.6%	27.5%
Infection rate in mice without X-rays	77.8%	87.5%	60.0%	75.1%

Table 9: Effect of X-rays on infected mice observed by Murphy (1915).

The experimenters found a similar stimulation by five minutes of exposure to dry heat at 55-60^{o}C in place of the X-rays. Evidently the increased lymphocyte count responsible for the improved immunity could be stimulated in different ways. The beneficial effect was not immediate and did not persist; they found that one week was optimal. Further, if the X-ray dose was increased even more, there was a negative effect on the lymphocyte count.

Hormesis – the by-product of adaptation

A recent general review traces the history of the beneficial effects of low doses of radiation back to the original discovery of X-rays [[8]]. As an illustration of this positive view we sketch a possible dose-benefit curve, Illustration 31, where the damage threshold is at point *B* and there is benefit in region *A*. To emphasise the benefit instead of the damage, this diagram is shown *upside down* compared to Illustration 30. There is a popular saying *You can have too much of a good thing.* So it is with the health effect of most agents – the right amount may be healthy, even essential, but too much is harmful, whether it is a drink of water or a dose of aspirin.

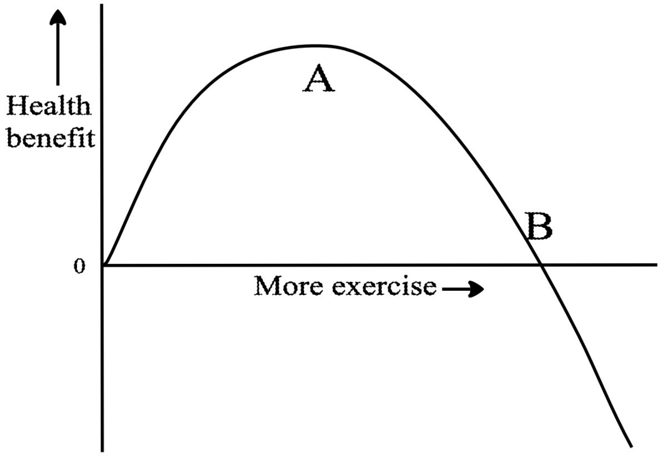

Illustration 31: A sketch graph of a health-exercise curve indicating some benefit for modest exercise but damage for an excess.

The principle also applies to physical exercise; some is much better than none, but an excess causes injury. This idea was described five centuries ago by Paracelsus, the physician and botanist (1493-1541), who wrote, *Omnia sunt venena, nihil est sine veneno. Solo dosis facit venenum,* which translates *Everything is poisonous, nothing is without poison, but it's only the dose that makes it poisonous.*

With exercise or regular stimulation the point *B* moves to the right – each day the damage threshold increases a little. That is, it adapts. So studying curves misses the point – response is a live parameter, not easily tamed by mathematics or simple diagrams. The benefit of adaptation may only last for a certain time and may need to be stimulated again. As an example, the efficacy of regular exercise for general health is well known [9], although fitness does not last very long. So it is back to the gym.

But what about the body's response to radiation? That is not likely to be a simple matter of studying straight lines or even curves, either – radiation response seems likely to be a matter for flexible pragmatism rather than cautionary dogma. Because the initial effect on cells of exercise and radiation includes the chemical action that increases production of ROS, these two elicit the same protective and adaptive responses. Thus a history of past exercise and past radiation are both effective at stimulating adaptation. Doses of ionising radiation at low rates suppress cancer incidence to below what would have occurred from background oxidation in the absence of radiation, just as exercise does.

In summary, because of adaptation to past history, a response curve like Illustration 30 tells only part of the story. For a dose below damage threshold, beneficial adaptation does not just reduce the incidence of any cancer that might have been caused by radiation, but it reduces the incidence of cancers from other causes too. This effect is called *hormesis,* although it is of secondary importance as far as safety is concerned. The primary question concerns the dose rate at the threshold of damage, point *B*, the *No Adverse Effect Level* (NOAEL), as Jerry Cuttler has called it. In summary, the point *B moves* as the organism adapts.

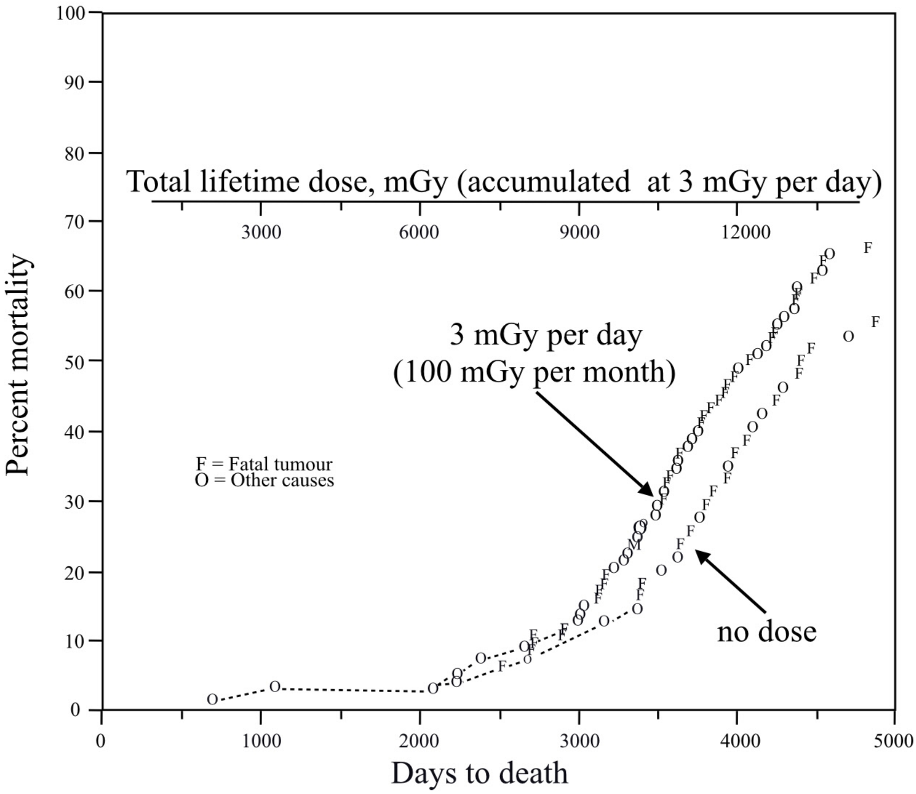

Illustration 32: Data showing the mortality and lifespan of dogs: (1) lifelong chronic whole-body 3 mGy daily doses of radiation; (2) similar dogs given no dose. Data from Fritz et al [12].

Effect of chronic radiation doses on dogs

We are interested to find the damage threshold for a lifetime dose received as a steady chronic dose rate. To date the most thorough experiments to answer this question have used dogs. For a single acute radiation dose the mortality of Chernobyl workers, shown in Chapter 6, was similar to that for a large numbers of rats. But rodents are not suitable for whole-of-life studies of chronic doses because they have much shorter lives than humans. But dogs live longer than rodents and a fair fraction of a human lifetime.

Lifespan and mortality data for dogs, given a chronic 3 mGy daily gamma radiation dose throughout life, are shown in Illustration 32 [[10]]. This also shows similar data for dogs who received no dose. Each plotted symbol represents the death of a dog (some are omitted to improve clarity where they coincide);

- the horizontal position of the symbol on the plot gives the age in days at death (and, on the upper scale, for the irradiated dogs, the corresponding accumulated lifetime dose at death);
- the vertical position gives the mortality of that group of dogs at that time;
- the choice of symbol shows whether the dog died of a fatal tumour (F) or another disease (O).

The data show that the mortality of the 92 dogs who received 3 mGy per day is not significantly different from the un-irradiated dogs until they have received a lifetime dose of somewhere between 6,000 and 9,000 mGy. So for dogs, this is an estimate of the threshold we want, and, interestingly, the symbols do not suggest that fatal cancers predominate. Such data do not exist for humans, but the numbers are indicative for this high chronic dose rate. We will need more such indications before we can suggest convincing safety thresholds for dose rate and for whole-of-life dose in humans. This we do in Chapter 9.

There is another but more sensitive way to look for changes that may give rise to cancer, perhaps many years later. Instead of examining data on mortality or morbidity we can look instead at the actual genetic changes induced by the radiation. There is an important study of this kind on genetically identical mice [[11], [12]]. The mice were irradiated chronically for 5 weeks at a rate of 3 mGy per day, and compared with mice a) that were not treated at all, and b) that had received the same radiation but as a single acute dose (100 mGy). The authors found no genetic effect at all for the treatment of the chronically treated mice. The acutely treated mice showed genetic effects linked to DSB only, showing that the SSB had been repaired successfully. Evidently both the SSB and the DSB were correctly repaired for the mice receiving the chronic dose, confirming that for mice a chronic dose of 90 mGy per month for 5 weeks is harmless. This genetic observation is more sensitive than a test for cancer as it is looking before the immune system deteriorates later in life.

Furthermore, recent research on mice has successfully explained and shown how DSBs are repaired [13]. This is a field in which understanding is progressing rapidly. As far as safety regulations are concerned, the important point is that for a chronic dose delivered at 90 mGy per month, there is no detectable genetic damage after five weeks – and if there is no genetic damage there can be no link to subsequent cancer. It is true that this conclusion is for mice, not humans. But we can say that the risk of cancer for mice is reduced by at least a factor of 50, if the dose is given chronically, instead of acutely. ICRP guidance acknowledges no more than a factor 2 relaxation of risk for a dose delivered chronically. In the LNT model this factor is called the Dose and Dose Rate Effectiveness Factor (DDREF) [14].

Low-level radiation protection by regulation

From the dawn of cellular life, biology has had to cope with attack by oxygen and by radiation. Step by step it has evolved methods of protection that are extraordinarily effective, as the accident at Fukushima and other similar evidence have shown. None of these methods calls on the sensory system or the brain of a living organism to do anything at all – for most of the evolutionary span the organisms that needed protection had no such sensory system anyway.

But now something has gone seriously wrong. What has happened? In the middle of the twentieth century the international community suddenly engaged with the problem of protecting life from radiation. Initially, that is in 1934, safety levels were chosen based on limited data and modest understanding of radiobiology. Nevertheless they were quite close to those that science would justify today. In the meantime, in the names of conservatism and precaution it was decided to use the LNT and ALARA philosophy, ignoring completely the understanding of modern radiobiology, in particular the evolved protective provision that has been in place since life began.

Illustration 5 on page 7 is a comment on the relative efficacy of the regulatory safety system and the natural evolved one. The latter has been honed to do the job of providing actual and immediate protection; the former offers only bureaucratic regulation, but no active protection at all. It is time to stop denying nature and trusting solely in regulation.

Medical treatment with ionising radiation

Life out of warranty

Evolution has delivered life designed to survive so effectively that we may wonder why there is any need for humans to study their own survival any further. It is true that often the best medical treatment is to not intervene and let natural protection apply its remedy. But this ignores the fact that evolution has worked to ensure the survival of species, not individuals. If mankind wants individuals to survive, medical intervention will sometimes be necessary. Evolution has little interest in the life of individuals beyond the reproductive and parenting age. After that individual life is *out of warranty*, as it were. Only through education, the useful ongoing transfer of knowledge from older to younger individuals, is there any evolutionary advantage in the extension of life into old age. So medical treatment adds to what nature can do.

Countries by income	Mortality, age <5yr, % [15]			Mortality, age 15-60yr, % [16]			Life expectancy at 60, years [17]		
	1990	2011	change	1990	2011	change	1990	2012	change
Australia	0.9	0.5	-0.4	9.6	6.3	-3.3	21	25	+4
Japan	0.6	0.3	-0.3	8.1	6.5	-1.6	23	26	+3
Russia	2.7	1.1	-1.6	21.8	24.1	+2.3	18	17	-1
USA	1.2	0.7	-0.5	13.2	10.5	-2.7	21	23	+2
Germany	0.9	0.4	-0.5	11.8	7.4	-4.4	20	24	+4
UK	1.0	0.5	-0.5	10.4	7.4	-3.0	20	24	+4
China	5.4	1.5	-3.9	15.0	9.7	-5.3	18	19	+1
India	12.9	5.9	-7.0	27.4	20.5	-6.9	15	17	+2

Table 10: Some changes in mortality and life expectancy in recent years.

Mortality and life expectancy have improved dramatically in recent decades for rich and poor alike, as shown by the numbers in Table 10. Control of disease, advances in clinical medicine, improved standards of living and better availability of food and clean water are responsible.

Diagnostic imaging including CT scans

For most of its evolutionary development, life had a very basic nervous system, if any. As a result the powerful brain that man has today remains poorly informed about those processes that are active in his own body and evolved long ago to be able to work unsupervised. Undoubtedly, given the power of the brain, life could have evolved a broadband diagnostic network that allowed each individual a much higher degree of self diagnosis. On the other hand, perhaps, giving such power to the *worried well* to fret over their potential ailments does not help their survival by selection. When a patient presents himself to his physician, he has little to say because his brain often has only vague ideas about his complaint. The physician needs more diagnostic information than the patient can give. Apart from what he can learn from a superficial examination and the patient's own account, he needs scientific aids to probe the body using the penetration of sound waves, radiowaves or ionising radiation [[18]]. These have been developed to image both the anatomy and how it is working – a functional image. The physician can select a method from the simple and readily available, to the finest and most sensitive, from a low technology X-ray photography, through ultrasound and MRI scans, to CT and radionuclide scans. All but the simplest are in 3-dimensions, and today these can be combined to produce composite images. They are described in accessible terms in *Radiation and Reason* [see Selected References on page 279, SR3]. These advanced techniques are becoming more and more widely available in spite of the high cost and expertise required. The reason is that physicians find them effective and so money is made available to pay for them. It is a good example of what public confidence in science can achieve when the benefits are properly appreciated.

On the public side, patients are reassured to see the pictures, even though some worry whether the methods themselves are dangerous in some way – although they are not, and we shall see why. The radiation involved in MRI is in the radio range and non-ionising. This has not caused the same concern about safety as methods using ionising radiation – CT scans and isotope scans. In fact, the power used in an MRI scan is far higher than used in a scan based on ionising radiation. As discussed in Chapter 5, the former is measured in watts per kg – it can only heat tissue and its safety limit is set by comparing with the regular metabolic heating rate, a few watts per kg. The power of an ionisation scan is measured in microwatts per kg, a million times smaller. As explained in Chapter 5, its safety is not related to heating, but to its effect on a minute number of individual molecules.

The number of MRI and CT units has grown very rapidly in recent years. The extent of current provision can be judged from the data shown in Table 11.

The US authorities have reported that the mean annual radiation dose from CT scans has risen to about 3 mGy per member of the US population, comparable with the mean natural background and three times the suggested limit for artificial sources of 1 mGy per year. There are two points to note. Firstly, there can be no difference between the effect of doses from natural sources and from medical or other artificial sources. Secondly, there is no evidence that doses hundreds of times larger than these figures have any negative health effects whatever. Many concerns would be laid to rest by comparisons with information for much higher doses or by simple statistical scrutiny. (Mistaken claims in the fields of biology and public safety often arise from a naive use of statistics. For instance, they treat as established any result with 95% confidence level, without accounting that 1 in 20 such conclusions is false. Such methods cause misunderstandings and publicity disasters that do not occur in fields with more discipline in their use of statistics.)

	MRI		CT	
	units	examinations per million per year	units	examinations per million per year
OECD	12	47	23	132
Australia		23	39	94
Germany	10	17	17	49
Ireland		16	15	69
Japan	43		97	
UK	6	39	7	73
USA	26	91	34	228

Table 11: Scanner units and examinations per year per million population for 2009 or nearest year. [[19]].

Isotope imaging

The radiation of a CT scan is transitory. It passes through the body in a flash. What is left are the broken molecules, as already described, but the radiation itself has gone. The case of isotope imaging is different. The radioactive isotope is injected into the patient's body and radiation is emitted as the isotope decays. In this way the radiation is spread out by the delay of the decay process. There are two technologies, Single Photon Emission Computed Tomography (SPECT) and Positron Emission Tomography (PET). The half life of commonly used isotopes are: two hours for fluorine-18 in a PET scan, or six hours for technetium-99 in a SPECT scan. The way these methods work is described in *Radiation and Reason* [SR3]. The story of the Goiania accident, told in Chapter 6 of this book, is a graphic demonstration that delay does not worsen the effect of a radiation dose; in fact, by spreading out the initial damage, the repair and replacement mechanisms are enabled to reduce long-term damage far more effectively.

The PET method of imaging gives better images at lower doses than SPECT, but is more expensive. One problem is that, because it decays so quickly, fluorine-18 has to be brought within a couple of hours or so from the accelerator where it is made. On the other hand, technetium-99 comes from the decay of molybdenum-99 that is produced in nuclear fission, with a useful half life of a week, which eases the logistics of supply. Readers worried about nuclear waste should note that molybdenum-99 is just one of a number of valuable components of fission waste. Although PET gives better images, its higher cost means that its use is spreading more slowly and 80% of isotope imaging uses SPECT [[20]]. There are some 30 million examinations per year, including 6-7 million in Europe, 15 million in North America and 6-8 million in Asia/Pacific.

Cancer as a class of diseases has proved particularly difficult to diagnose and to treat. As other diseases have been controlled or their incidence reduced, cancer has become a more prominent cause of death. Ionising radiation, far from being a significant cause of cancer, is a major tool in its diagnosis, and most effective in its cure. Just as diagnosis is often more effective when methods are used in combination, for instance PET plus MRI, so cancer therapy often combines radiation therapy with surgery, or more often with chemotherapy. Improved success with therapy has come with the use of real-time imaging to target the tumour and then monitor the progress of its demise.

Radiotherapy – the use of radiation to cure cancers

Human society is regrettably coy about talking of things thought to be unpleasant. The hope is that someone else will deal with them, unseen by sensitive society. For example, sewage must be reprocessed and recirculated in a densely populated environment. It is a luxury to be able to ignore it, but in a world facing climate change there may be more unpleasant matters that we will have to attend to. An important early task is to identify all those matters we prefer to ignore. The list is likely to include death and cancer, and many people would add nuclear radiation too. In each case we are stronger and better prepared if we study them. For instance, being hesitant about cancer is responsible for many tumours that are diagnosed too late.

Radiotherapy is used in the treatment of cancer care not only with the aim of achieving complete remission, but also in palliative care to reduce pain and slow the advance of a cancer that may already have spread or metastasised. A diagnosis of cancer is a shock to the patient, but in fact the prognosis for many cancers today is usually good, and a majority of those receiving therapy go home to further productive years of life. At the end of their treatment they shake the hands of their clinician and nurses, warmly and with thanks. This is in spite of the fact that during the 4-6 week treatment they will have received a radiation dose to large parts of their healthy body that may be more than 1,000 times that from a CT scan or from the radiation experienced at Fukushima, incorrectly thought by many to be dangerous.

The radiation used in normal high-dose radiotherapy (RT or HDRT) comes either from a radioactive source or from a beam of electrons from an accelerator. The latter is essentially an X-ray gun, as used in a dentist's surgery but at higher power. Ideally the radiation shines onto the tumour and kills its cells. The difficulty is that the gamma radiation cannot be focussed – at best it travels in straight lines, at worst it is scattered and wanders about, some getting absorbed by the healthy tissue in front of the tumour (unless the tumour is on the surface) and some behind. It is this poor delivery of the radiation dose that gives rise to the *friendly fire* or *collateral damage* inflicted on nearby healthy tissue during the treatment of the tumour itself.

There are various ways in which the delivery can be optimised:

- By the use of gamma rays with energy well above 1 MeV to reduce scattering and absorption for deep penetration;
- By using a number of different beam angles to deliver doses that overlap at the tumour but spread out around to reduce the dose to healthy tissue;
- By carefully mapping the delivered dose in 3-dimensions linked to automatic collimators that shape the beam profile, a computerised process called *treatment planning*;
- By *brachytherapy,* the use of low-energy gamma or beta radioactive sources of short range, temporarily implanted in or near the tumour, instead of an external radiation beam. Iodine radioisotopes are used to treat thyroid cancer, one of the most successful kinds of cancer treatment – even though at Chernobyl exposure to such isotopes may have caused the cancer in the first place. The efficiency with which any iodine in the body becomes concentrated in the thyroid, and nowhere else, is responsible for both effects. The iodine has only to be injected into the bloodstream and does not need to be surgically implanted. Brachytherapy is also used to treat non-malignant thyroid disorders. Iridium-192 implants are used especially in the head and breast. They are produced in wire form and are introduced through a catheter into the target area. After administering the correct dose, the implant wire is removed to shielded storage. Brachytherapy is designed to give less overall radiation to the body in cases when radiation can be localised to the target tumour, and it is used in particular in the treatment of prostate cancer.
- Unlike gamma rays, energetic beams of charged ions can be focussed and targeted to stop at the depth of the tumour and deliver most of their energy there. Such *ion beam therapy* is not yet available in every clinic, but is the best for the treatment of deep cancers. In such

therapy, the dose can be delivered to the tumour more efficiently. Then the peripheral dose can be reduced while the tumour dose is increased, thereby improving the prognosis for successful treatment.

In the early days of radiotherapy, before WWI, the dose had to be given over a period because of the limited power of X-ray machines – and patients did well. As the equipment improved, it became possible to deliver the whole dose in one or two sessions, but it was found that patients did not survive. Today the dose is given in daily *fractions* spread over a period of 4-6 weeks [21]. Each day the tumour cells get slightly too much radiation and die progressively. Each day the healthy cells get about half as much radiation and just manage to recover by the mechanisms of replacement, repair and adaptation – in simple common sense terms, they get used to the radiation, and this helps them to survive the extended chronic dose rate of 1,000 mGy *per day,* far in excess of 0.08 mGy per month (1 mGy per year), the ALARA limit recommended for public exposure in the environment by the ICRP [14].

Unless ion beam therapy is used, the dose that can be given to the tumour is limited to about 2,000 mGy per day, by the effect on healthy tissue within 5-10 cms. In a century of experience oncologists have learned that any tissue that receives much more than 1,000 mGy per day is likely to fail as a result of cell death; they have also learned that if the peripheral dose is reduced much below 1,000 mGy per day, the chance that the tumour receives a sufficient dose for successful treatment falls significantly. As described by the Royal College of Radiologists best practice is rooted in such compromise and empirical guidance rather than in regulation [21].

In spite of scare stories in the press, the medical use of radiation continues to expand. The World Health Organisation (WHO) reports that the number of X-ray examinations worldwide is more than 3.600 billion annually [22]. Currently 37 million nuclear medicine procedures are carried out and 7.5 million radiotherapy treatments are given. These numbers were posted in 2014 but the use of radiation in medicine continues to increase as the benefit to patients gains further recognition and more equipment becomes available. A directory of radiotherapy centres (DIRAC) has been available since 1955 and is now maintained by IAEA. Some data are summarised by geographical zone in Table 12.

Sub continent	centres	treatment planning stations	therapy units		
			accel-erator	external radioactive source	internal (brachy-therapy)
North America	2,787	326	4,083	158	885
Western Europe	1,039	1,587	2,552	107	427
Eastern Asia	1,934	2,113	2,048	596	222
South Asia	366	287	225	390	185
Central America	148	134	126	103	53
Africa	145	166	179	88	58
South America	494	330	560	207	203
Middle East	188	225	295	102	39
South East Asia	139	111	176	90	46
East Europe & North Asia	406	567	487	506	277
Total	7,646	5,846	21,462	2,347	2,395

Table 12: Geographical distribution of radiotherapy centres and units with radiation from electron accelerators and from radioactive sources, external and internal [23].

Apparently resources are unevenly distributed. Less developed countries have few electron accelerator therapy units as these are expensive and require more highly trained staff. But units are available that use intense gammas from external radioactive sources, usually cobalt-60 or caesium-137 – the accident at Goiania described in Chapter 6 involved such a source. Ion beam therapy requires a more powerful accelerator, but is already available in some countries and in future it will doubtless become the preferred treatment for all deep cancers.

Radiation dose rates in excess of 40,000 mGy per month have been in use for over a century and accepted by the public to cure cancer in the tradition of

Marie Curie [21]. This treatment would be more accurately described as High Dose Radiotherapy (HDRT). It is aimed at the offending tumour with the intention of killing the cancerous cells, while sparing the surrounding healthy tissue as far as possible.

There is a further way in which ionising radiation has been used to combat cancer, and that is called *Low Dose Radiotherapy* (LDRT). In this case low doses are given over a period of time to the whole body, or sometimes half the body. The dose, perhaps 50 mGy per month, is chosen to stimulate the adaptive reactions described in this chapter. The effect is to harness the body's natural defences against cancer, particularly the immune system. Success in the use of LDRT has been reported in Japan and elsewhere [24, 25, 26]. Members of the public have some general familiarity with such radiation therapy at a low level through the popularity and benefits of spas, worldwide. However, LDRT has yet to be as widely accepted as it may be in the future.

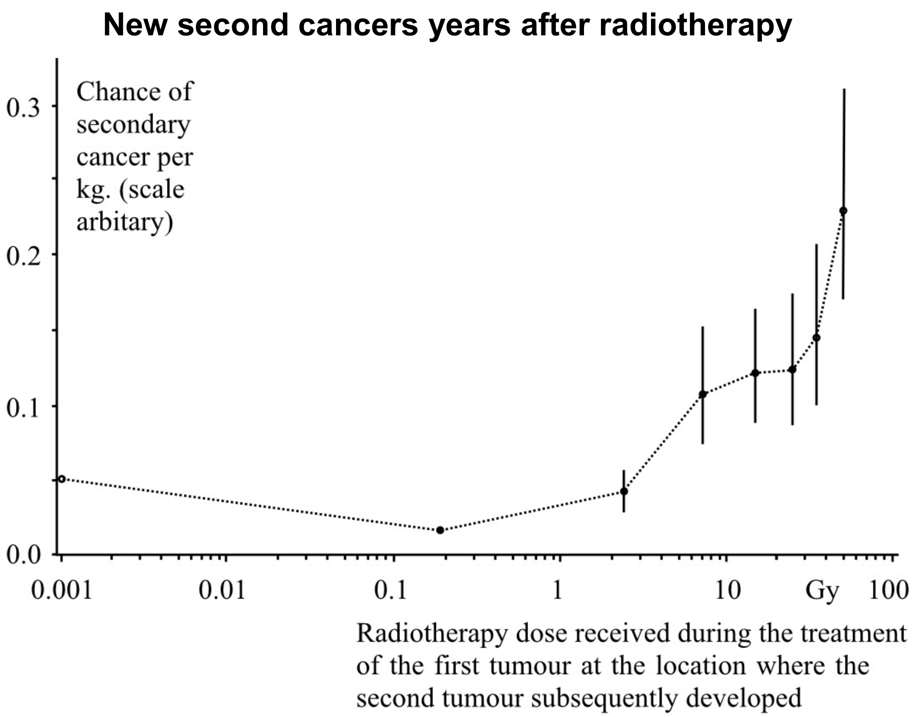

Illustration 33: Plot of data from Tubiana et al showing how incidence of a second new cancer depends on total dose absorbed (if any) in treatment of the first cancer.

In the previous section it was stated that when planning a course of HDRT radiologists give a tumour as much radiation as the healthy tissue around it can withstand. That means that radiotherapy patients sometimes suffer from peripheral skin burns, and also that the radiation that kills the tumour cells may accidentally cause a new primary cancer in the previously healthy tissue. The chance is said to be about 5%, and the cancer can usually be spotted and treated early. It is important that authoritative data from an international group confirm this description.

This has been provided in a recent paper by Tubiana and his clinical team in UK and France [[27]]. Five thousand survivors of childhood cancer who had received radiotherapy treatment were studied, and their subsequent health followed for an average of 29 years. The number who developed a new second primary cancer was 369, or 7.4%. The study asked a very interesting question about these second cancers:

> *What was the total absorbed radiation dose from the first treatment at the site where the second cancer later developed?*

They were able to infer the answer from a reconstruction of the original treatment plan. They then plotted the number of second cancers per kg against this dose – the result is shown in Illustration 33. Along the bottom on a log scale is the total dose in Gy (the daily dose added up for the whole treatment) at the site where the second cancer turned up. On the left is the cancer incidence for places far removed from the radiotherapy beams. From this plot it is possible to draw the following conclusions:

- there is no evidence of any new primary cancer caused by a radiation dose less than about 5 Gy, that is 5,000 mGy;
- for doses in the range 5 to 40 Gy the risk of a second cancer increases progressively at higher dose – this is evidence for a late response to a very high protracted dose;
- there is evidence of a beneficial suppression of cancer incidence for radiation doses around 0.5 Gy, that is 500 mGy.

Cancer induced by CT scans

Another study, also of children, has claimed that there are health risks for CT scan doses that are 100 times lower than the threshold shown by the radiotherapy work of Tubiana et al. Its authors, Pearce et al [[28]], conclude:

> *Use of CT scans in children to deliver cumulative doses of about 50 mGy might almost triple the risk of leukaemia.*

Many technical objections that cast severe doubt on this claim have been published [[29]], but, unfortunately, when the label *children* is attached to a study, the media are ready to accept any story, in spite of technical objections. The use of the word *might* in the Pearce claim is characteristic of publications seemingly designed to influence by suspicion rather than to convey any firm scientific conclusion.

There is a fashion to cast doubt on the efficacy of radiation medicine and to question the goodwill of the medical fraternity. This seems to be driven by a wish to enhance fears of radiation, in line with the media reaction to the Fukushima accident. A casualty is a general and unsubstantiated erosion of trust that is itself dangerous.

But within clinical medicine the dangers are elsewhere, as observed recently by Bill Sacks, a retired radiologist:

> The craze that emerged 10 [or more] years ago for whole-body screening with CT of asymptomatic patients resulted in a lot of harm to patients and a little benefit. The harm, however, was not from radiation, but rather from incidental findings which were exceedingly common, with follow-up including such things as thoracotomies for lung findings that needed biopsy but turned out to be benign, with all the pain and suffering that such surgery occasioned, plus out-of-pocket expenses. The number of false positives when you go hunting without reason is always large. The small benefit was thought at that time to consist of the much smaller number of patients in whom incidental unsuspected cancers were found at early stages that were treatable. ... the whole-body screening CTs did more harm than good, except for the owners of the imaging centers, who usually were also the ones to do the follow-up imaging for "incidentalomas."

So asymptomatic patients should be worrying about subsequent procedures, not radiation.

Symptomatic patients should not worry about radiation either. For them a radiation scan may resolve doubts about a diagnosis. In such situations there are several risks, some small, some large. In a recent paper Zanzonico and Stabin [[30]] reported a study of the net benefit of diagnostic radiation scans for several medical treatments. They showed that PET scans save the lives of more than 2,000 suspected lung cancer patients a year in USA, at the expense of a theoretical loss of 60 lives by CT-induced cancer as calculated pessimistically using the false LNT mortality (5% per person per Gy [[14]]). Similarly, they found that over 30,000 lives of coronary artery disease patients are saved by CT scans for a dose to which the LNT attaches less than 3,000 deaths by CT-induced cancer – although there is no clear evidence for any of these LNT risks. Thus the net benefit of a scan is quite clear whenever there is the slightest symptomatic concern.

It is remarkable that the public and press worry about trivial risks from radiation scans when the benefits are so evident [[31]]. The safety of radiation should be a minor consideration in any decision to have frequent asymptomatic scans.

Opposition to CT scans on grounds of safety seldom mentions radiotherapy with its higher doses. Perhaps that is just ignorance; perhaps it is because details of the treatment of those who are more seriously sick, are seen as personal and less suitable for attention-grabbing publicity. Yet people should know that for a radiotherapy dose, a thousand times higher than CT, the benefit of radiation treatment is overwhelming.

Here are some numbers. Over a month of a radiotherapy treatment the tumour gets more than 40,000mGy and the peripheral healthy tissue as much as 20,000mGy – that is five times the fatal dose experienced by some Chernobyl workers. Evidently, the success of radiotherapy with its fractionated treatment is witness to the biological repair mechanisms. And everyone knows a friend or relative who has experienced this, if they have not done so themselves. So, put simply, radiotherapy treatment of deep cancers would not be effective if LNT were applicable, and every member of the public has the evidence close at hand.

Biological safety of radiation

French National Academy Report

Current radiation safety regulations are based on LNT and ALARA, in part because, in professional memory, they always have been. For most of those with responsibility in the field, it is simply their job to follow them [32] – they may differ somewhat from nation to nation, but by small factors compared with what the scientific data indicate. There has not been any great pressure to update them to match the science, because they are seen to be safe – in respect of litigation, rather than actual danger. As long as safety levels are set with an eye on a court of law, the answers are likely to be highly distorted. But, with job and budget security in mind, few are interested in upsetting the apple cart. Truth can wait – it must be someone else's problem.

However, there are two groups of professionals who have reasons not to be easily impressed by this *laissez faire* position: the environmentalists and the medical profession, at least those familiar with the science. The environmentalists have serious questions to ask about a new worldwide expanded use of nuclear power to replace carbon – there is no other solution that is up to the job of providing liberal energy on the scale required. Some environmentalists who were previously opposed to nuclear power on political grounds have now understood the technological benefits and safeguards – we met some of them in Chapter 2. Some radiographers, oncologists and radiobiologists know the science and are alarmed that their patients have been affected by a popular wave of radiophobia that discourages them from accepting radiation treatment that would be beneficial to their health. The views of the international committees that firmly resist change are heavily influenced by American concerns – there, threats of litigation seem to be more important than science and the environment. But an initiative has come from the French, a unanimous Joint Report of the Académie des Sciences (Paris) and the Académie Nationale de Médecine, published in 2005 entitled *Dose-effect relationships and estimation of the carcinogenic effects of low doses of ionizing radiation* [33]. The Report is a technical review of biological evidence that repeatedly contradicts LNT and supports the existence of response thresholds. A conclusion directly relevant to the application of nuclear power is expressed in typically dry terms:

> *Decision makers confronted with problems of radioactive waste or risk of contamination, should re-examine the methodology used for the evaluation of risks associated with very low doses and with doses delivered at a very low dose rate.*

Unfortunately, neither the public nor such decision makers read these reports.

The treatment of pregnant women and children

Many a popular article about the safety of radiation includes a reference to the sensitivity of children. The assumption is made that they are more sensitive than adults, and pregnant mothers and foetuses more sensitive still. Few medical accounts challenge this, but little evidence is offered either. It is usually seen as obvious in any popular discussion. But is it true?

Without getting into details, there is reason to expect that children and foetuses should be different from adults. Their cells divide more frequently because they are growing and developing, rather than simply being maintained as in an adult. However, immune protection slows with age, and it is immune failure, not increased mutations, that increases the likelihood of cancer.

The mutation model of cancer cannot explain the following three observed features of cancers:

- When the immune system is suppressed, as in organ-transplant patients or HIV patients, cancer rates more than double. Hence there is little credibility in the prediction of a small percentage increase in cancer from LDR based on this model.
- When people exercise vigorously and regularly – even 5 minutes of vigorous exercise results in DNA damage [34, 35] – their cancer rates go down considerably for many types of cancers.
- Everyone has mutations in their bodies that are potentially cancerous but no more than half are diagnosed with cancer in their lifetime [36].

New research shows how the immune system controls cells transformed by low levels of radiation [37].

Less than 1% of all cancers are found in young children aged 0-14 years. Predominantly cancer is a disease of the old, not the young, and headline accounts of individual cases of child cancer, with the concern that they naturally raise, should not be seen to override this general observation. This has been checked in particular cases, for instance in careful work based on large populations, to confirm that there is no evidence for an excess of radiation-induced leukaemia cases among children living near nuclear power plants [38]. In any event the size of possible doses is much smaller than variations in the natural background radiation.

The results were recently published of an experiment designed to test the effect of radiation on pregnancy and early development of mice [39, 40]. These were divided into two groups, two weeks before mating. Throughout the experiment, which lasted for up to 20 weeks from birth, the groups were given to drink either natural water or water containing 20,000 Bq of caesium-137 per litre. This activity in water is 2,000 times the regulation limit for human consumption imposed in Japan since April 2013. A human drinking a litre of such water per day, every day, would reach a steady whole-body activity of 2.9 MBq [41], which is 30 times less than the smallest whole-body activity that caused any loss of life at Goiania. The mice experiment observed no significant differences in the pregnancies, blood counts and other markers indicative of bone marrow function between the two groups. The number of mice is not made clear, but these results are not inconsistent with the two successful human pregnancies at Goiania and they do not suggest that a chronic dose of caesium at this level is above any threshold that affects foetuses or children (or adults).

Thyroid cancer in children is a special case because any iodine, whether regular or radioactive, that enters the body gets concentrated in the thyroid gland if the food supply was previously deficient – as was the case at Chernobyl, but not at Fukushima. The short lifetime of radioactive iodine means that the radiation dose is acute and confined to a small volume. These are the conditions in which biological protection is most easily overloaded. The same is not true for any of the longer-living caesium, strontium or other environmentally significant radioisotopes that get widely spread through the human body.

Whether regulations should treat children and pregnant women as a category distinct from adults is a question separate from whether they are affected differently by radiation. Should they be permitted radiation scans and therapy under the same criteria as adults? That parents and husbands should take special care of them – and exercise that care when giving permission for treatment – is not the issue. Natural affection and bonding ensure that they would do that in any event, whatever any safety regulation might say. But should special care be taken of children and pregnant women at a legal level, as well as a family level, when in fact there is no scientific or medical evidence for a general increase in sensitivity to radiation? It seems unwise to double count by stacking caution on top of itself, rather than to provide family education and advice – as is given for sunshine and UV. There appears to be no logical case for treating pregnant mothers and children any differently from adults as far as regulation of exposure to radiation is concerned. Unfortunately nobody seems ready to say this in public – another omission that is a result of radiophobia. This is a case of confusing personal and family care, where sentiment should have free rein, with societal and legal responsibility, which should be rooted in objective evidence.

Social and mental health

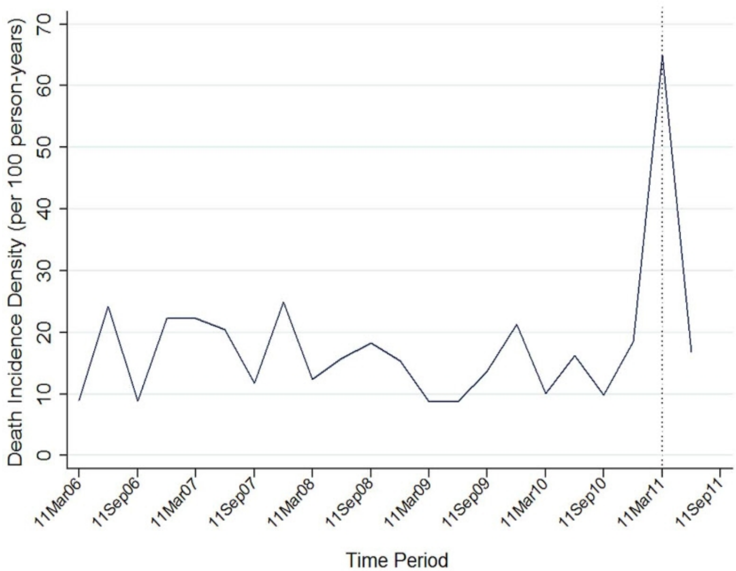

Illustration 34: Data showing the mortality of residents in care homes for the elderly that were evacuated in Japan [44].

If the physiological effects of radiation accidents have been exaggerated by a wide margin, that cannot be said of social and mental health. Feelings of ignorance in the event of an accident cause personal distress that can turn into panic, especially if large numbers of people find themselves in the same situation. If no one is ready to explain what is happening, some feeling of mutual support is given by blaming some individuals or authorities, right or wrong. This is a relief mechanism which gives the impression *we are doing something*. Without it distress can result in mental or social illnesses of various kinds.

The elderly and less articulate are least able to *take it out* on someone else, and so are worst affected. Social and mental stress may be expressed in many diverse ways and it is not easy to find firm quantitative estimates, but social workers are in little doubt about the symptoms that they encounter. At Chernobyl the result was alcoholism, family break-up and states of hopelessness [[42]]. At Goiania the number affected was smaller, but the stress was expressed in cases of alcoholism and high rates of depression compared with the national average [[43]].

At Fukushima there were early deaths among the elderly, bed wetting among children, and a general witch hunt of those in authority who were thought to be responsible. As mentioned above, this acted as a stress-relief mechanism, but built up collectively, with encouragement from the media, into ugly demonstrations and pressure groups which are not easily reassured by factual explanations they do not wish to take on board. Elderly residents in care homes are a particularly vulnerable group. At Fukushima, those who were evacuated at short notice suffered disruption to their normal level of care in addition to feelings of fear. Both contributed to the high mortality recorded for residents at the time of the accident [[44]]. This is shown clearly in Illustration 34 as an increase in mortality from an average of 10-20% to 65% in the period of March 2011.

Notes on Chapter 8

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2) UNSCEAR Annexe B: *Adaptive responses to radiation in cells and organisms* pages 185-272 http://www.unscear.org/unscear/en/publications/1994.html

3) *Low-Dose Cancer Risk Modeling Must Recognize Up-regulation of Protection* L.E. Feinendegen, M. Pollycove, R.D. Neumann; Dose Response 8: 227 2010, http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2889507/

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6) *The effect of Roentgen Rays on the rate of growth of spontaneous tumors in mice* James B Murphy and John J Morton, Rockefeller Inst (1915) http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2125377/pdf/800.pdf

7) *The Effect of Physics Agents on the Resistance of Mice* James B Murphy, Rockefeller Inst, PNAS (1920) http://www.pnas.org/content/6/1/35.full.pdf+html

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8) *Radiation Hormesis - Research Compilation* http://library.whnlive.com/RadiationHormesis/

9) *Health Benefits of Physical Activity - the Evidence* Warburton et al (2006) http://www.canadianmedicaljournal.ca/content/174/6/801.full

10) *The influence of dose, dose rate and radiation quality on the effect of protracted whole body irradiation of beagles*. Fritz TE. Brit J Radiol suppl 26: 103-111 (2002)

11) *Integrated Molecular Analysis Indicates Undetectable Change in DNA Damage in Mice after Continuous Irradiation at ~ 400-fold Natural Background Radiation*, Olipitz et al http://ehp.niehs.nih.gov/1104294/ http://newsoffice.mit.edu/2012/prolonged-radiation-exposure-0515

12) http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3440074/

13) *Evidence for formation of DNA repair centers and dose-response nonlinearity in human cells* Neumaier et al PNAS http://www.pnas.org/content/early/2011/12/16/1117849108.full.pdf+html http://newscenter.lbl.gov/news-releases/2011/12/20/low-dose-radiation/ http://www.ncbi.nlm.nih.gov/pubmed/22184222

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17) http://apps.who.int/iris/bitstream/10665/112738/1/9789240692671_eng.pdf?ua=1

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