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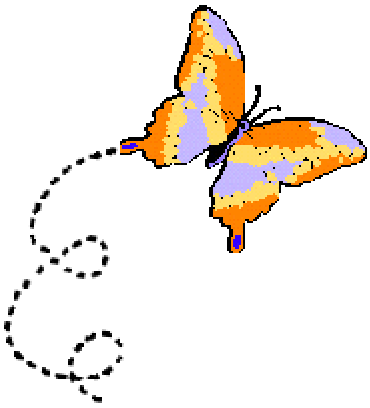

Spirit of Life Unitarian Fellowship
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To Esprit Readers:

Over the years poems, essays, sermons and travelogues have graced the pages of Esprit, but never a scientific review article. Today, however, we publish a letter from David Blair which sets out his thoughts on an important aspect of nuclear energy.

David is a PhD in physics. Now retired, he was formerly a senior lecturer at the University of Technology, Sydney, and then a senior research scientist at the Defence Science and Technology Organisation, where his research was in signal processing for sonar (underwater ultrasound imaging).

He is a member of the Sydney Unitarian Chalice Circle and the Humanist Society of NSW.

Unitarians have a deep respect for science and a long history of welcoming controversy, so in that spirit I am proud, as editor, to bring you David's thoughts regarding this contested area. It has great relevance to how we view nuclear power and therefore how we cope with global warming.

Jan Tendys, Editor

A Letter Regarding Nuclear Energy[1]

From: David Blair, davidblair@tpg.com.au
To: Jan Tendys
Date: 21 October 2013

Preamble

This letter follows from the several references to web sites that you've sent to me on the subject of nuclear energy. In most cases the references are presenting evidence that the LNT (linear, no threshold) hypothesis vastly overestimates the risk that results from nuclear radiation when the radiation dose is ***low***. In the last few months this has prompted me to look further into the low-dose issue with a view to forming a definite opinion on the matter.

I've carried out a literature survey (which grew to quite a size) and here is my report. So that new readers can follow what I'm saying, I'll start almost from square one. And some of the references that we exchanged earlier will be discussed again.

Introduction

Nuclear energy, as a means of producing electrical power, relies on the fission (splitting-up) of the nuclei of suitable heavy elements (uranium, but also others, including thorium) in a nuclear reactor. Such reactors have been around since the 1950s. They have long been a subject of controversy—a topic to which I'll return.

Since the 1970s, proponents have pointed to the perceived additional desirability of this source of power, in the light of two developments. The first, dating from 1973 (the "energy crisis", prompted by the "oil crisis"), is the realization that fossil fuels are a finite resource, but more particularly the perception that the end of the era of cheap oil was looming on the horizon. The second is the threat posed by anthropogenic global warming ("climate change"), which may require that the use of coal, as well as of oil, needs to be phased out before too long, because the emitted CO_2 is a greenhouse gas.

But among the public there has long been much fear of using nuclear fuel as an energy source. As we shall see, of the negative claims that have been made about nuclear and have gained traction among the public, many are outrageously different from the truth. In consequence, the fear in the community about nuclear is a huge overreaction. In addition, nuclear regulators (at least in Western countries), possibly with the best of intentions, have brought in quite strict safety regulations. So strict that, as each year passes, the evidence mounts that, in respect to ***low*** levels of radiation, the risk posed to humans has been wildly exaggerated. If so, the practical result is that much of the money spent on nuclear so far has been unnecessary, and the reactors of the future could be built and run much more cheaply.

Among the scientists who work in the area of *safety regulations*, a key point in the dispute over risks is whether or not to accept the ***linear, no-threshold hypothesis***—the ***LNT***

hypothesis for short. I'll discuss this hypothesis briefly here, and in more detail further down. The hypothesis concerns the extra risk that a person has of getting cancer (and the corresponding risk of dying of cancer) when a given dose of radiation is received from the nuclear industry. The hypothesis concerns the graph that is obtained when you plot, against the dose of nuclear radiation received (call this x), the extra probability (y) of getting cancer. Let's call the added probability the "risk". The *LNT hypothesis* is that the plotted points lie on a *straight line* that, when extended, passes through the origin; the line represents a relationship of the form $y = mx$, where the "slope" m is a constant. More correctly, the plotted points *would* so lie if the measured values of x and y were *accurate*. In practice, the errors in y, in particular, are fairly high. The errors can be represented on the graph by vertical "error bars". One then determines the "line of best fit". What is usually found is that, over a certain range of x values (in the region of doses that are "high" but not "very high"), the line of best fit is *consistent* with the error bars. The value of m then tells us something about reality, unless the error bars are enormous.

What has been in dispute is whether this line is applicable at ***low*** doses x. The simplest way in which it could fail is if there is a *threshold* value of x, such that (due to the body's defences) any dose below the threshold poses *no* risk (and y is equal to m times the *excess* of x over the threshold value). It has been very hard to gather adequate data on these low doses, as will be discussed below. Basically, the problem is that many people get cancer anyway, and we're trying to measure the small ***extra*** probability of getting cancer from a small dose x. It's a classic case described by saying "the signal is lost in the noise".

Keay's booklets, which introduced me to the science behind the LNT controversy

Around March 2013, when perusing one of my bookshelves, I was reminded that I have two brief books on the subject of risk from nuclear radiation. Both are by Colin Keay. The titles are:

1. *Nuclear Energy Fallacies: Forty Reasons To Stop and Think* (2001), and
2. *Nuclear Radiation Exposed: A Guide to Better Understanding* (2001).

{Keay Fallacies} and {Keay Understanding} will be used here as the abbreviated titles. It turns out that Keay has produced four such books (including the above two), and all are available for free on the Internet, in their second edition (2004–2005); go to

http://www.scribd.com/nuclearissues

Keay is a retired Australian academic with expertise in nuclear and reactor physics, who has "encountered under laboratory and research conditions both radioactive substances and high-voltage electricity". He has 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" (Preface of each of the two books). He has no connection with the nuclear industry.

Keay concludes that, at low doses, the LNT (linear, no threshold) hypothesis is strongly out of kilter with the facts. In more detail, he concludes that there is a threshold dose (and it's above the background radiation level), such that any ionising radiation amounting to less than the threshold produces no increase in the probability of getting cancer. (*Ionising radiation* includes nuclear radiation, but includes also very similar radiation such as X-rays and cosmic rays.)

[By way of explanation, we are being bombarded all the time by ionising radiation. This component is called *background* radiation, and it includes *natural* radiation. Two components of the latter are: radioactive materials in the earth, and cosmic rays that reach us from outer space. More on this topic is given below.]

I began this search for information with the two books by Keay, plus references supplied by you. However, a deeper search was necessary due to the controversial nature of the safety issue. It was especially necessary, given that it is now 12 years since Keay's booklets were published, so that one must expect that new information has come to light. I found several articles coming to essentially the same conclusions as Keay, written by authors who appear to be genuine experts (some being leaders in their field). There has been quite a lot of new experimental work pointing in that same direction. Nevertheless we are reminded that there have been quite a number of studies that appear to support the LNT hypothesis or at least to show that there is statistically significant harm at low doses. I shall return to the question of what attitude should be taken towards these studies.

To gain a technical understanding, I strongly recommend {Keay Understanding} above. In addition, {Keay Fallacies} is well worth a look, to see the extent to which we have been hoodwinked by exaggerated and sometimes utterly outrageous claims.

Preliminary, including types of cancer

The damage to the body done by nuclear radiation is of two principal types: *radiation sickness* and *cancer.* "Radiation sickness" (also called "acute radiation syndrome") is a short-term, acute response that comes from a high dose. When it kills, it does so in a relatively short time—one or two months, but coming down to two days at very high doses. It is quite distinct from cancer. Much of our knowledge of the cancer effect comes from studies of the survivors of the two atomic bomb attacks (Hiroshima and Nagasaki, 1945). Many of the subjects in the study had had radiation sickness and recovered.

By definition, "*deterministic effects* always happen when a particular threshold dose is exceeded, increase in severity for higher doses, and are absent for lower doses"—{Rational Wiki} (not grammatical, but you get the message). I gather that deterministic effects are the same as "radiation sickness". Effects other than deterministic ones involve probabilities and are called *stochastic* effects. Cancer is the main stochastic effect. (It's now suggested that there are also some effects that occur much less often, for example a slight increase in the probability of a heart attack). If a radiation-exposed person later gets cancer, it is impossible to say whether that *individual* got the cancer *as a result of* the radiation.

Cancers (also called malignant tumours) can be either "solid" or "liquid". *Solid* cancers grow in a mass of cells in a particular organ or tissue. Around 90% of all cancers are of this kind. *Liquid* cancers (of which leukemia is the most common example) develop in the blood (and lymph) and can travel to any part of the body. They constitute 8% of all cancers. References are:

http://www.stemcellnetwork.ca/index.php?page=cancers-solid-tumor

{Stem Cell}; and

http://www.ncbi.nlm.nih.gov/books/NBK9963/ {Causes NCBI}.

To get more definite results, many of the studies on the cause-and-effect relationship between radiation and cancer are restricted to solid cancers.

In the USA, the fraction of the population that eventually dies of cancer is 13%. The world average is 10%. (Presumably the difference arises because, in less developed countries, a lot fewer people reach the advanced age at which cancer is most likely to occur.)

The significance of various doses of radiation

I now turn to the quantity or "dose" of radiation received—by a person, an animal or an organ. A complication (fortunately we don't have to go into the details) is that the "dose" of radiation received (by a person, an animal, or an organ) can be expressed in a number of different ways, using different units. We'll be concerned with a unit called the sievert (Sv), which is concerned not just with the energy in the radiation, but with how effective that particular type of radiation is in damaging living tissue. A further complication is that the effectiveness varies from organ to organ. However, in cases where the radiation is applied more or less uniformly over the whole body, it's possible to quote a figure, in sieverts, that expresses the "*whole-body dose*". In this "letter" I'll be talking, almost always, about whole-body doses.

Each dose received is measured in sieverts. A person may receive many doses over time, and the *cumulative dose* is simply obtained by adding these "sievert" doses together. The LNT hypothesis actually makes a further *assumption*, namely, that the risk (or the damage) done by a given cumulative dose is *the same as if that whole dose had been received at once*. This assumption is at best an approximation, and we know that it often fails badly: in general the damage from a cumulative dose is *less than* the assumption states.

First, I'll state the significance of some **single doses**.

0.1 Sv: A *low* dose means a dose less than (around) 0.1 Sv; a dose above that is considered *high*. Most sober sources are prepared to doubt that LNT holds at doses below this level—e.g. {Rational Wiki}. Some regulators express concern even regarding doses that are tiny compared to this (e.g. 1 mSv, which is 1 millisievert, equal to 0.001 sievert)—concern mostly when an event causes a very large population to receive such a dose.

0.15 Sv: If the recent conclusion of Cuttler (near the end of this "letter") is accepted, for an adult, "a single whole-body dose of 0.15 Sv is safe".

0.25 Sv: Below this level, no *deterministic* effect on health is observed. This level is the threshold for getting a lowered blood cell count—a relatively minor symptom.

1 Sv: For a person exposed to this dose, the probability of eventually dying from cancer *due to the exposure* is likely to lie between 7.5% and 11%—based on putting together many studies. The probability varies with the person's age and the time since exposure, as well as with gender; the two figures stated refer to some average. (A figure of 5%—or 5.5%—is often quoted, but apparently its meaning is a bit different.) These matters are discussed further down.

Also at 1 Sv: Mild radiation sickness

3 Sv: 50% chance of death from (untreated) radiation sickness

I note that, as the dose rises from 0.15 Sv up to 2 Sv, the expected harm (due to the combined risk from radiation sickness and cancer) ***rises steeply***. When it comes to preventing doses (above or) in *this* interval , strong vigilance must be maintained.

Second, let's consider a **continuous dose**, applied as a *dose rate* of so many sieverts per year.

1 mSv/yr: The nuclear industry is required to plan so that that no member of the *general public* gets a dose rate (from the industry) exceeding this. Note that this level is one-twentieth of what a nuclear worker can get (see 20 mSv/yr below). (Both these figures are internationally recognized limits.)

2.4 mSv/yr: This is the world average value of *natural radiation* received continuously. There are populated areas where the dose rate is much higher, as is discussed below.

3 mSv/yr: The average medical dose received by a person in the USA.

20 mSv/yr: For nuclear workers, this is the maximum continuous dose rate permitted. In an emergency situation, a worker may receive 20 mSv in a single dose, but then he must be kept away from nuclear radiation for a year. [In what is probably a recent amendment, for a *life-saving emergency* response, a single dose of 250 mSv (= 0.25 Sv) is permitted.]

0.7 Sv/yr: If the recent conclusion of Cuttler is accepted, for an adult, a continuous dose at this rate is safe.

1 Sv/yr: Recommended by Cuttler (discussion and reference further down) to replace the "20 mSv/yr" as the level for evacuation of nuclear workers. (However, this does not mean that this rather high dose rate would be permitted to continue for a whole year.)

References for the above figures:

http://rationalwiki.org/wiki/FAQ_on_radioactivity_and_nuclear_technology

{Rational Wiki}; also {Jawor Ethics} below.

The LNT hypothesis, and why it is hard to test

What is the LNT hypothesis, in detail? And how did this hypothesis get going? A key step was taken when, following the 1945 dropping of the atomic bombs, studies were done on the survivors. They had received different doses of radiation, depending mainly on their distance from the explosion. These studies continue to this day, because cancers can still develop in the aging survivors as a result of that distant-past event. The principal reference for what follows is

http://en.wikipedia.org/wiki/Radiation-induced_cancer

{Radiation-induced}.

A graph in that reference (p. 4) shows, plotted against the dose received, a measure of the cancer risk faced by a person who received that dose. One way of measuring risk is to look at the set of people that received that dose, and to state what percentage (or fraction) of them contracted a (solid) cancer over a fixed period. But many people would have got cancer even if there had been no nuclear radiation; and the corresponding percentage could be, and was, estimated by studying a control group many kilometers from the nuclear explosion. What is of interest is the number of *extra* cancers due to the nuclear radiation. In other words, we want to estimate the *difference* between the above two percentages. This is what is plotted on the vertical scale. It measures *the increase in the probability of getting cancer* (in some specified fixed period of time, or in the period through to the person's death) for a person who received that particular dose.

The graph, which considers dose levels from 2.0 Sv down to zero, is consistent with the increased probability being *proportional* to the dose. This is the *LNT hypothesis*, that has been used as the basis of designing reactors (and medical procedures) for safety. But note the word "consistent". As always in science, each measurement comes with an experimental error (often called the *uncertainty* in the measured value). The size of the error in a data point is often represented by a vertical bar drawn through the point. The error bars shown in *that* graph make it clear that the errors are very considerable. (A measure of error often used is the *90% confidence interval*, meaning that there is a probability of 90% that the true value, of which the stated value is an estimate, lies between the two ends of the interval.)

Most problematic are the errors at low doses, say less than 0.15 Sv. While the error bars at those doses look small in absolute terms, what is important for safety policy is the *relative* error in the extra probability. [Here and elsewhere, the "relative error" in a quantity means the ratio

(absolute error in the quantity) / (the quantity itself)

(then multiplied by 100 if to be expressed as a percentage).] And this relative error, at small doses, becomes greater than 100%—making the measurement almost useless. [Remember that safety authorities have been interested in doses all the way down to 1 mSv —or even 0.1 mSv (which is 0.0001 Sv)—doses which, on the present graph, are crowded into a tiny space next to the origin.]

What makes the relative error so large at low doses is that the extra risk is calculated by subtracting one percentage risk from another one that is almost equal to it—this inevitably magnifies the relative error. This is also commonly expressed by saying that *the signal is lost in the noise*. The "signal" is the difference (A –B, say) that you're trying to estimate, while the "noise" is the variability (or error) in each of A and B.

How the body responds to nuclear radiation. Can this radiation be beneficial?

The simplest kind of *threshold* would mean that, when the dose of ionising (e.g. nuclear) radiation is below the threshold, the radiation poses *zero* risk to the person concerned. Keay actually *goes further* than to hold that there is this kind of threshold. Evidence, he says, suggests that the response of the human body to radiation as you consider a series of increasing doses of the radiation, follows a curve that's basically the same as for increasing doses of *chemicals* that the body *needs* (e.g. various trace elements, even arsenic; and each of the vitamins). Thus (1) a certain amount of the chemical brings benefits; while (2) too much results in poisoning. But also, from (1) it follows that, relatively speaking, making the dose *too* small produces *harm*. Figure 2 in {Keay Understanding} shows all this in the form of a graph of harm versus dose. (The curve in the graph is J-shaped. Not surprisingly, at large doses the curve is rising fairly steeply. As the dose is *lowered* the curve traces out the bottom of the "J" and then rises again.) Importantly, *there is a range of doses* (near the bottom of the J) *for which the harm is negative, meaning that the dose is beneficial*.

The explanation that Keay gives for these surprising conclusions (surprising when applied to nuclear) is that the body has an *immune response* to radiation, as follows. Most of the radiation damage leading to cancer is damage to tiny part of a DNA molecule in a cell. (Much of the damage occurs in more than one step. First, damage is done to some molecule other than DNA, producing either a very reactive molecule or a free radical. This in turn damages another molecule, which can be DNA.) A DNA molecule consists of two strands laid out so that each spirals around the other. Along each strand is a long sequence of "bases"; and each base on one strand is paired with another base on the other strand. Overwhelmingly, the DNA damage that occurs in a single "hit" is damage to just one base in one of the strands—called a "single-strand break". Huge numbers of these breaks occur in the body all the time, due partly to ionising radiation but due also to other agents (discussed in the next section).

When a single-strand break occurs, *the body repairs it*; this is possible because the other member of the pair determines what base its partner should be. But occasionally, there is a *double-strand* break—a base and its partner are both damaged. In that case the healthy response is that the whole cell dies. This is an *immune response*. Cancer can get going when (due to a failure in the immune response) such cells do not die—and they continue to reproduce. If the rate of reproduction exceeds the rate of cells dying, the number of damaged cells increases with time; this is what constitutes cancer.

Now here's where radiation (in "natural" doses but also in artificial doses) can be beneficial: Keay and others say that the radiation *stimulates* the immune response—training it to work better. (I see here a strong analogy with ordinary immunisations.)

I used the word "surprising" when introducing the body's immune response. But upon reflection, I see that most of the surprise comes to us because we have, imprinted on our mind through the media, a particular feeling about nuclear radiation—that it is very different from chemical carcinogens in an almost magical way, that makes it vastly stronger in damaging us.

Causes of cancer

References are:

http://en.wikipedia.org/wiki/Carcinogen {Wiki Carcinogen};
http://en.wikipedia.org/wiki/DNA_repair {DNA Repair};
http://en.wikipedia.org/wiki/Background_radiation {Wiki Background};

as well as {Keay Understanding}.

Cancer always involves damage to DNA. The damage leads to what is called cancer if the cells containing the damaged DNA multiply without limit. The items that cause cancer are called ***carcinogens***—whether they be chemical substances, beams of ions or electrons, or electromagnetic waves. Carcinogens are classified as follows.

1. **Internal** ("endogenous"). These are the result of normal ***metabolic processes*** in the body (digestion, production of new cells, use of muscles, etc.). The DNA is attacked via molecules, radicals or ions that are strongly reactive (e.g. reactive oxygen species —related to the OH^- ion). Note that these processes are chemical and do not involve nuclear energy.

2. **External** ("exogenous").

    a. ***Various chemical substances***. Examples are inhaled asbestos, some dioxins, tobacco smoke, and substances whose molecules contain benzene ring(s). (These sources again are non-nuclear.) Carcinogenic substances can be *natural* (e.g. produced by plants) or *artificial* (produced by industry). For a non-smoker in the modern world, I presume that the artificial carcinogenic chemicals predominate over the natural ones as a cause of cancer. (The smoker takes a very significant risk, which puts him in a class of his own. In the USA, one-third of all cancer deaths are from smoking.)

    b. ***Some viruses*** (natural).

        c. ***Ionising radiation: Natural***.

            i. Radioactive isotopes in the ground and in building stones—plus radon gas produced as a daughter product and released into air. In the case of radon, the atoms are inhaled and thus can lodge in the body.

ii. Cosmic rays. These are particles, such as protons, from outer space. Living on a mountain or taking an airline flight increases one's dose from this source.

iii. Ingestion of radioactive isotopes via (ordinary) food and water.

iv. Ultraviolet light from the sun.

d. ***Ionising radiation: Artificial.***

i. Atmospheric testing of nuclear bombs.

ii. Nuclear energy industry.

iii. Other uses of nuclear (and related, e.g. X-rays), as follows: use of radioactive isotopes for medical scans and for treating cancer; the same but used to scan inanimate objects; use of X-rays for similar purposes.

The term "***natural***" refers to the internal causes (item 1) as well as the causes that are explicitly labelled above as "natural". In the context of ionising radiation, the term "***background radiation***" refers to all natural doses of radiation, together with much of the radiation that comes from artificial sources (item 2d). Consider item (d ii) (reactors). Under normal operations, including minor accidents, a reactor emits minute amounts of radioactive materials into the atmosphere that contribute slightly to the radiation levels present around the world, in places near and far from the source. The resulting levels of radiation are fairly stable, so for convenience they too are included in the "background". However, the radiation received by nuclear workers due to their work is *not* taken to be background, because it needs comprehensive monitoring and regulation. (I presume that, when a *major* nuclear accident occurs, the resulting considerable rise in levels experienced by the general public, nearby and downwind, are regarded as non-background.) For similar reasons to the above, most of the doses under item (d iii) (medical scans, etc.) are regarded as routine and part of the background. Item (d i) also comes under "background".

Putting nuclear radiation into perspective

Consideration of the natural carcinogens in the table above helps to put into perspective the fear that many people have concerning reactors. Let's begin with a quote from {Keay Understanding}. "Scaremongers love to claim that a single 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 … Hence the use of the weasel-word 'may' … " (The "billions of particles" are due to the four natural sources in item 2c.)

As above, there are even radioactive agents contained in our ordinary food. Bananas, for instance, contain a higher level of these atoms than the average. But we don't, on these grounds, have a fear of eating!

Due to the food and water, there are radioactive atoms throughout our body. The greatest radioactivity in our bodies comes from potassium-40 and carbon-14.

Again {Keay Understanding}, "the DNA in **each** cell … in a human body undergoes more than 100,000 spontaneous alterations per day from metabolic and other bodily functions". [These come under item 1 and *do not involve ionizing radiation*.] "A daily radiation dose of four times the annual average exposure adds only 20 additional events per day per cell." [Yes, you read right—this brings the total to just 100,020.]

How do we survive the 100,000 alterations, multiplied by the number of cells? Answer: the body copes through its highly effective repair mechanisms described earlier. Aah, you might think, doesn't nuclear make a *different kind* of damage? No! It's all a matter of causing chemical changes of the same kinds.

Let's pause and review. Suppose that we assess the risks from ionizing radiation, *based on* the "emerging consensus" (that there is a practical threshold). Except in very unusual situations, there is no risk from the following: items c (i, ii and iii) and (d i). [Correction: Item (c i) can pose a problem in very poorly ventilated basements, due to radon gas.] Habitual exposure of the skin to the sun (item c iv) for long periods is to be avoided (while exposure for small or medium periods is healthy, and even necessary for the production of vitamin D). In item (d iii), the item relevant to most people is medical scans. For this, the average dose rate (3 mSv/year in USA) is very safe according to the emerging consensus, being less by a factor of over 200 than a level found by Cuttler (below) to be safe.

Even under LNT, the risks remain fairly small (though not entirely negligible). According to LNT, the world average background radiation increases one's chances of dying from cancer by (very roughly) one-tenth of what it would otherwise be. Hence, if one accepts this figure, together with the quite separate "10%" given just above the heading "The significance of various doses … ", the background increases the chances of dying from cancer from 9% to 10%—see {Radiation-induced}.

Evidence that LNT does not apply at low doses: first bite

This section describes evidence that, at low doses, the LNT hypothesis is wrong, and severely overestimates the cancer risk.

References to the first item of evidence are: {Keay Understanding}, {Wiki Background}, and two further documents for which the detailed references are given below. The latter are {Jawor Chernobyl} and {UNSCEAR 2000}.

To understand the first item, recall that everywhere on earth each inhabitant receives background radiation, to the tune of 3.0 mSv/year—on average. Of this, the major contribution comes from *natural* sources (2.4 mSv/year). But the background radiation varies a lot from place to place. Of the 19 countries listed in {Wiki Background}, the UK has the lowest average dose with about 1.6 mSv/yr, while Finland has the highest with about 7.3 . Among cities, Ramsar, in Iran, comes out particularly high. But these figures don't give the whole picture. {Jawor Chernobyl} quotes the UNSCEAR report of 2000 as saying that the "typical range" for natural radiation reaches up to 10 mSv/yr. And that, moreover, the dose in some geographical regions is "many tens and hundreds times the average natural global dose" (the latter being 2.4 mSv/yr).

The cancer rate, as well, varies from place to place (due e.g. to communities being exposed to different carcinogenic chemicals from industry, and to many third-world communities having a lower life expectancy quite apart from cancer). But ***no correlation*** has been found between background radiation level and the incidence of cancers. (Actually that's not quite true. In particular, it has been reported—anecdotally at this stage—that, within Ramsar, the 1000 people contained in the area with the very highest radiation level enjoys markedly *better* health.) This lack of positive correlation is a strong piece of evidence against the LNT hypothesis, and suggests that there is a threshold.

Second, consider the deaths from the major nuclear accidents, particularly **Chernobyl**. Keay, in {Keay Fallacies}, speaks of "the Chernobyl mythology"—repeated assertions that vastly overrate the deaths from this 1986 nuclear accident. The Australian Conservation Foundation claimed in 1999 that "250,000 people have so far died as a result of the Chernobyl tragedy". In 2001 its president gave a revised figure of 30,000. The truth is far different. It's known that there were 31 deaths among the heroes who served "in the early hours of the disaster". (Three of these deaths were from mechanical accidents. The remaining 28 presumably succumbed to radiation sickness, not cancer.) As Keay tells us, a report by UNSCEAR (***United Nations Scientific Committee on the Effects of Atomic Radiation***) in 2000 {UNSCEAR 2000} found that "apart from 1800 cases of thyroid cancer in children exposed at the time of the accident, there is no evidence of increased overall cancer incidence or mortality 14 years later". Thyroid cancer is a special case: it can be caused by low levels of radiation, but it is readily curable. Of the 1800 cases, UNSCEAR found that about 10 died. There are pessimists who say that there'll be a huge number of extra cancers over time, but it's hard to maintain that after 14 [now 27] years of observations have gone by.

"So the Chernobyl death toll stands at about 40 caused by radiation; three due to mechanical accidents … ". Tellingly, Keay's sentence continues: "an unknowable number [of deaths] caused by the stresses of relocation of those forcibly (and in hindsight mostly unnecessary) evacuated from the fallout zones; and the estimated 50,000 needless abortions". Yes, 50,000 abortions due to needless fear.

How does the Chernobyl data bear on the LNT model? The literature ({Jawor Chernobyl}, reporting the view of UNSCEAR) tells us that the number of cancer deaths is considerably less than what the LNT model (with the extrapolated value of m) predicts; and that the predicted number (if present) would be detected, because it exceeds the "noise". {Jawor Chernobyl} gives some further information and comment on the relationship to LNT.

It is possible for a sober-minded scientist to maintain that, while LNT exaggerates the cancer risk, there may still be *some* cancer deaths due to Chernobyl, among the more highly exposed in the general population. The figure most usually quoted now is "potentially as many as 4000 premature deaths" (this quote from {Pandora Lumsden}, ref. further below). Note that this means that the figure could be anywhere from 4000 down to zero. Also, the 4000, if they exist, would be "lost in the noise" of other cancer deaths. Lumsden continues: " … but these figures pale into insignificance next to the figures on coal".

References re Chernobyl, besides {Keay Fallacies}, are:

(article by Zbigniew Jaworowski, "The Truth About Chernobyl Is Told"), at:
http://www.21stcenturysciencetech.com/articles/chernobyl.html

{Jawor Chernobyl}; and (to a lesser extent)

Z. Jaworowski, "Radiation Risk and Ethics", *Physics Today*, Vol. 52, Sep.1999, pp. 24–29 {Jawor Ethics}. Usually obtainable on the web, but Physics Today is changing its web layout, causing problems. You can try

http://media.cns-snc.ca/uploads/branch_data/branches/Toronto/radiation/JaworowskiPhysicsToday1999.pdf

Otherwise use

http://www.physicstoday.org/resource/1/phtoad/v52/i9/p24_s1?bypassSSO=1

to get to the title and mini-abstract, and then try following the links. Good luck!

Jaworowski is a former chairman of UNSCEAR and (as of 2001) is a professor at the Central Laboratory for Radiation Protection in Warsaw. The United Nations report, a work of 1220 pages, can be viewed directly, thus:

> *Sources and Effects of Ionising Radiation,* subtitled *UNSCEAR 2000 Report to the General Assembly* (Sep. 2000), available at
> http://www.unscear.org/docs/reports/gareport.pdf {UNSCEAR 2000}

There's a similar story in regard to the **Fukushima** nuclear disaster (March 2011). Here I have been fortunate to find the following reference:

http://ansnuclearcafe.org/2012/07/11/lnt-examined-at-chicago-ans-meeting/

{ANS Chicago}. The article, by George Stanford, is a summary of the principal points made by a number of speakers at the ANS (American Nuclear Society) Meeting in June 2012. Stanford stresses that the speakers "seemed unanimous that basing policy and regulations on LNT has no empirical justification, and moreover has turned out to be a very costly blunder".

At the meeting, Kazuaki Matsui observed that "the earthquake and tsunami … left 25,000 dead, injured or missing. In contrast, there was 'probably minimal or no health effect' from radiation from the damaged reactors at Fukushima. However, the ensuing evacuation disrupted more than 150,000 lives and has led to 13 suicides, along with 50 deaths of elderly evacuees [another source claims 573]. The prevalent widespread radiophobia has led to grotesque overreactions".

More from this meeting will be reported below.

For balance, I add here that there are a number of studies, published in the early and not-so-early decades since 1950, that **appear to support LNT** at low doses. I shall return to this point.

Safety: Comparison with Other Industries

We have seen that, as far as is known, the *major* nuclear accidents have led to only 40 to 50 deaths due to the radiation. But while these events get the publicity, there other deaths in the nuclear industry, the number of which, relatively speaking, is much greater. Some are from radiation-induced cancer and some from radiation sickness (in addition to "ordinary" accidents, e.g. mechanical). It appears that these arise from many "minor" accidents, leading to exposures of 0.15 Sv or above. (Exposures up to this level are safe, according to Cuttler, below, and expected to be safe by many others. But note that there are sober articles that claim also many deaths from considerably lower exposure levels.) I expect that the majority of these exposures arise when the procedures that are laid down have not been followed.

Now let's put these casualties into perspective. For a reality check, let's compare the safety record of nuclear with that of other industries. References on this are {Keay Fallacies} and {Rational Wiki}. {Rational Wiki} quotes data showing that the accident rate (recordable accidents per 200,000 working hours) is 0.9 for nuclear power, compared to 5.6 for manufacturing. "Surprisingly, nuclear power plants fare better than financial institutions", with the latter scoring 1.4.

For energy sources, another measure, perhaps the most significant one, is the number of deaths per unit of energy produced, expressed in *deaths per PWh* (Petawatt-hours; P = Peta = 10^{15}). *Nuclear is safest*, with a death rate of 40, with hydro (100) and wind (150) coming next. *Worst is coal*, with the world average coming out at 60,000 (for electricity only) or

100,000 (for all uses). The factor, going from coal to nuclear, is astonishing. From {Keay Fallacies}, the coal station emits "much more noxious pollutants" [mainly chemical in form] than the nuclear reactor. And, due to uranium found in coal deposits, even regarding deaths from radioactivity alone, coal comes out somewhat worse than nuclear energy (when the residues (wastes) from both are taken into account).

As described in

http://blogs.scientificamerican.com/the-curious-wavefunction/2013/04/02/nuclear-power-may-have-saved-1-8-million-lives-otherwise-lost-to-fossil-fuels-may-save-up-to-7-million-more/

or the following link (which seems to no longer work)

http://ansnuclearcafe.org/2013/08/09/matinee-hansen-on-on-nuclear-power/

{ANS Hansen}, James Hansen, former head of the NASA Goddard Institute, co-authored a study that conservatively estimated (in 2013) that nuclear power has saved 1.8 million lives since 1971 that otherwise would have been lost due to the use of fossil fuels.

Practical Implications of Assuming LNT

Besides Keay (especially in {Keay Understanding}), others discuss this question, including Jaworowski in {Jawor Ethics}. He notes that, when it comes to protecting people from radiation, the established worldwide practice "costs hundreds of billions of dollars a year to implement". Costs would be slashed if limits on doses were raised to bring them into line with reality—with the much lower, or even zero, risks that low doses actually pose. The number of deaths hypothetically saved by the present extra stringency is so tiny (Jaworowski continues), that he estimates that the money spent to save *each* such life is about $2.5 billion. "Such costs are absurd and immoral—especially when compared to the relatively low costs of saving lives by immunization against [diphtheria, etc.], which in developing countries entails costs of $50 to $99 per human life saved".

Articles such as the two above note that in other areas of life a *principle* of *cost-versus-benefit* applies. Thus, we know that cars produce fatal accidents, but we don't respond by banning cars. Similarly we have not banned the burning of coal for electricity, even though the number of resulting deaths per unit of energy produced is *orders of magnitude above* the figure for nuclear (Greenhouse is a separate issue.). {Jawor Ethics} concludes that "there is an emerging awareness that radiation protection should be based on the principle of a practical threshold—one below which … *detectable* radiogenic [health effects] [are] not expected". (Perhaps he should say "are strongly unexpected".)

The risk per sievert; absolute and relative risk

As discussed earlier, the quantity to be found, i.e. the risk per sievert, is the coefficient m in the equation $y = mx$ (or sometimes $y = mx + b$). Here x is the dose received, in sieverts, and y is the probability that, *as a result of that dose*, the person will (during the next 20 years, or other period, or through to the end of the person's life) cross some pre-specified threshold *of damage*. The latter may be "contracting cancer", or it may be "dying from cancer" (or it may single out e.g. lung cancer or leukemia). The probability can also be thought of as a fraction. Of all the people selected by some criterion (e.g. "aged 40 when they received the dose x"), y is the fraction whose damage (as a result of the dose) lies above the threshold.

The A-bomb data, and later data, usually show that the linear relationship $y = mx$ gives a reasonable fit for doses over the interval 0.25 to 2 sieverts. As discussed above, one can determine a "line of best fit", a "best estimate" of m, and a "90% confidence interval" for m.

The risk per unit dose (i.e. the slope m above), is expressed as a probability per sievert (or a fraction or percentage, per sievert). It is an ***absolute risk***.

An alternative way of expressing the risk is to specify the ***relative risk***. The latter is the *ratio* C/D, where

C = absolute risk of exceeding the threshold of damage due to the nonbackground radiation,
D = absolute risk of exceeding the threshold of damage due to all other causes

(times 100 to get a percentage). This ratio compares *the added risk due to "nuclear"* to *the risk that was already present from "ordinary" causes.*

The size(s) of the cancer risk(s)

What is an approximate figure for the absolute risk? And the relative risk? In this main text I'll give brief answers to these questions. But the topic is *very complicated*, and simple answers can be misleading. Some more detail, rounding out the picture, is presented in the Appendix (which also gives references).

The article {UNSCEAR Lux} (ref. in Appendix) gives figures that seem to typify the conclusions of the major studies. There the lifetime risk of exposure-induced deaths from solid cancers is estimated to be 11% per sievert. This is an *absolute* risk. (Strictly speaking, what is estimated in that article is the risk *at 1 Sv.* But, because that dose is well inside the interval where LNT gives a reasonable fit, the result should give a good approximation to the risk per sievert.) But (as the article points out) there is appreciable uncertainty in this figure, because it was calculated assuming a particular *model*. An alternative model leads to an estimate that is about 70% of that value (i.e. about 7.7%). The article allows that the true figure could be appreciably below 7.7% or appreciably above 11%.

These figures illustrate *the difficulty in getting precise estimates of risk* in the area of nuclear radiation. To help in dealing with this difficulty, "pooled studies" and "meta-studies" have been carried out. In these, the data or results from several studies are combined (this requires care and a critical eye) to increase the precision. In fact, the article {UNSCEAR Lux} is such a meta-study, combining studies from five different countries.

A widely spread set of answers is also found in regard to *relative* risk. For exposure-induced deaths from all cancers except leukemia, the article {15-Country} found a relative risk of 0.97 /Sv. The 90% confidence interval found was (0.28, 1.77) /Sv. (Here each figure is expressed as a fraction; thus the first figure could be expressed also as 97% /Sv.) Note that the confidence interval is disappointingly wide. And it occurred despite the fact that as many as 407,000 people (nuclear industry workers) were monitored for the study. {NIH Gilbert} (ref. in Appendix) mentions that result, and notes that the corresponding figure (i.e. corresponding except for fine detail) found for A-bomb survivors is 0.32 /Sv—different by a factor of three. (Yet, as Gilbert points out, the "0.32" figure is still "statistically compatible" with the "0.97" figure taken together with its confidence interval.)

Note that there is a rough compatibility between the absolute risk figures and the relative risk figures. Suppose we take the former as A = 0.10 (i.e. 10%) and the latter as R = 1.0 (i.e. 100%) (rounded from 0.97). Let's accept the estimate (given early in this letter) that, world-wide, the fraction of people whose death is due to cancer is C = 0.10. Then, from the absolute risk figure of A = 0.10, we would expect the relative figure to be R = A/C = 1.0 —which agrees.

A highly influential body, the ***International Commission for Radiological Protection*** (ICRP), has, for a long time, recommended that those concerned with safety assume that the (or an) absolute risk is about 5% /Sv (often taken to be 5.5% /Sv). This figure is quite low compared with the other figures for absolute risk quoted above (7.7% to 11%). This "discrepancy" is discussed further in the Appendix.

Some evidence appears to support LNT at low doses

For balance, I add here that there are a number of studies, published in the early and not-so-early decades since 1950, that *support* (or appear to support) *LNT at low doses*. The review article {NIH Gilbert} describes quite a number of such studies. This evidence cannot be simply ignored. The case against LNT needs to include making a reasonable fist of explaining how errors are likely to have crept in—errors that invalidate the relevant conclusion—a point to which I shall return.

Gilbert gives evidence both for and against LNT at low doses. (Evidence *for* the LNT—or at least for a statistically significant positive-harm effect below 0.15 Sv—is described there on pages 7, 8, 10 and 13.) In her summing-up (p. 17), she leaves the issue undecided (Wikipedia articles also leave the issue undecided); she in fact says that that the issue is quite a long way from being resolved. "Studies of [workers exposed at] lower doses and dose-rates provide a more direct assessment … Results thus far have generally supported the use of linear estimates obtained from higher dose data with little indication that such estimates need to be reduced for … low doses. However, imprecise estimates and potential for confounding limit what can be learnt from low dose studies." She adds that, rather than rely on pure epidemiological studies, studies of mechanisms via which the cancer is ultimately produced—for example, studies of persons exposed to radioactive isotopes such as iodine-131—would help to settle the question.

"Imprecise estimates" and "potential for confounding" (in the above quote) provide two ways in which confirmations of LNT may be queried. Confounding was in fact the basis of one challenge, mentioned in {UNSCEAR Lux}, as follows. A study of A-bomb survivors confirmed LNT. The challenge suggested that, on the occasions when a doctor assessed the cause of a survivor's later death, in the case of persons who were relatively close to the hypocentre of the bombing, there may have been be a predilection (in borderline cases) to say "yes, cancer", due simply to a strong mental association between A-bomb and cancer.

Nuclear offers great future benefits, even if LNT does hold at low doses

What I have not mentioned so far is a very important point, as follows. Over the last two and more decades, considerable research and development work has been done on proposed "Generation IV" reactors of various kinds. The majority of these (the breeder reactors and some "once-through" reactors) are immensely more fuel-efficient than present-day reactors, extracting up to 99% of the available nuclear energy in the fuel, as opposed to the present 1%. At the same time the radioactive wastes are reduced to negligible proportions. These reactors would also take safety to a new level: the measures incorporated to shut the reactor down when a problem occurs would be *passive*. That is, they would automatically come into play even if all electrical power to the system was cut off and there was no human intervention.

The above matters are discussed, for example, by Alasdair Lumsden in a review of the 2013 documentary film *Pandora's Promise*. This review is the 3rd of 12 on the site

http://www.imdb.com/title/tt1992193/reviews?ref_=tt_urv

{Pandora Lumsden}. Lumsden gives what I regard as a sober but very positive assessment of what nuclear offers for the future, especially for a world threatened by greenhouse emissions. He is quite open in acknowledging that "Existing Nuclear has many problems … ", but he continues with " … but these are solvable"; and he proceeds to outline the way ahead.

The film *Pandora's Promise* (several websites deal with it)—directed by Robert Stone—is itself of interest. (I've seen it.) It makes a powerful case for embracing nuclear energy in a big way, and could have much traction with the general public. [Hopefully, in a few months' (or a few weeks') time, the film will be shown more widely in Australia, and the DVD copy of the film will become more easily available.]

Evidence that LNT does not apply at low doses: second bite

There is more recent evidence for this conclusion.

A paper by Bernard Cohen, obtainable at

http://www.phyast.pitt.edu/~blc/LNT-06%20fig.rtf

{Cohen LNT} (probably pub. 2006), summarises itself well. "A strong sentiment has developed in the community of radiation health scientists to regard the risk estimates in the low-dose region based on LNT as being grossly exaggerated or completely negligible." "The purpose of this paper is to review the basis for LNT and to present some of the mostly recent information that has caused this strong shift in sentiment". I regard the paper as thorough and sober. It's a technical paper, but one point of particular interest is that it displays some "J curves", similar to those proposed by Keay, but in this case determined experimentally, from studies of mice.

Earlier I introduced the article {ANS Chicago}, which describes a meeting held following Fukushima, in which researchers presented the results of their respective investigations into the effects of low-dose radiation. Virtually all the results pointed in the one direction: that LNT is false, and that it vastly overstates the risks. Some of the researchers (see especially the presentations by Jerry Cuttler and Kiyohiko Sakamoto) probed the issues more fully, and concluded that there *is a threshold*. And that furthermore, for a range of doses below the threshold, the radiation is *beneficial*: it stimulates the immune system and thus gives added protection against a subsequent dose of radiation.

In particular, based on human data, Cuttler concludes that:

- A single whole body dose of 0.15 Sv is safe
- Continuous exposure of 0.70 Sv/year is safe
- Both of these exposure rates are also beneficial

[Conversion value used for present purposes: 1 Gy = 1 Sv (*sic*)]. Cuttler recommends raising the radiation level for evacuation (from a nuclear plant) from a rate of 20 mSv/year to 1.0 Sv/year—an increase of *a factor of 50.*

Sakamoto "discussed his work both with cancerous mice and with around 200 human cancer patients, reporting impressive rates of cure". From this work he reached the conclusions attributed to him above (a few lines up), and concluded also that the radiation level near Fukushima is *not* a cancer risk.

Finally, it is pertinent to refer to a speech delivered on behalf of UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) in December 2012:

http://www.mofa.go.jp/policy/energy/fukushima_2012/pdfs/statements_m68.pdf

{UNSCEAR Dec 2012}. A major finding was:

> "Because of the great uncertainties in risk estimates at very low doses, UNSCEAR does not recommend multiplying very low doses by large numbers of individuals to

> estimate numbers of radiation-induced health effects within a population exposed to incremental doses at levels equivalent to or lower than natural background levels."

This statement is very significant because, being a body that has to speak "for everyone", UNSCEAR tends to be cautious in making revised claims.

Concluding Discussion

With the urgent need to stave off the worst effects of climate change, it's important to move quickly in switching our sources of energy away from fossil fuels—mainly to solar, wind and nuclear. While Australia may be able to do this without nuclear energy, countries in Europe and much of Asia have very little land per person: for them, solar and wind energy are much less plentiful. In their situation, it seems eminently prudent to include nuclear in the mix of sources, through to near the end of the century and probably longer. Adequate research, such that Generation IV reactors of various kinds can come online in 2040 to 2060, should be supported by governments. Of these, the breeder reactors (and some others) have the advantage of being immensely more fuel-efficient than present-day reactors—at the same time reducing the radioactive wastes to negligible proportions.

Furthermore, if the capital and running costs of nuclear reactors can be slashed without prejudicing safety, clearly that is the smart thing to do. Equally important is the need to educate the public on the facts about safety, because unless the public revises its hugely irrational level of fear, nuclear energy will not play its rightful role.

Endnote

[1] Added by DB, 20.11.13: As a *next step*, I am considering how material in the letter would best be presented to the "green" community—by me or by another writer. Clearly an article for one of their magazines would need to be relatively short and less technical. Additionally, I've come to the view that, for that audience, the issue of the LNT hypothesis (which scientists have still not settled) should be reduced to a less-than-major component. Otherwise the issue is likely to become a *distraction* from the main message that needs to be hammered home. That message is threefold. Most importantly, that modern nuclear technology is *safe*, indeed very safe. Secondly, it is relatively cheap; and thirdly, it is known to be do-able on the large scale needed when replacing fossil fuels. I would then say: (i) that continued research surrounding the LNT hypothesis *may* lead to a considerable drop in costs; and (ii) that would be a bonus—it may come about, but we're not counting on it.

Appendix:

More on: The risk per sievert; absolute and relative risk; estimates thereof; difficulties in making estimates; complications; models

Note: This appendix presents some of the detail concerning the cancer risks from nuclear, at low doses and at moderately high doses. It also gives some idea of the many complications that exist in this subject area. The wording is terse and most readers will not want to go into this level of detail!

[*Preliminary comment:* I have a complaint about a number of papers that I've consulted. These include (i) figures given for some risk, but without fully stating what risk is being measured; (ii) speaking of a "relative risk" when what is being talked about is really an "absolute risk"; and (iii) giving a figure but with incorrectly stated units, the main example being the writing of Sv when what is meant is Sv/year. The article by Conca, circulated earlier, unfortunately has two serious errors. The worst-offending articles have not been cited in the present letter.]

Relevant references on this group of topics are as follows.

"UNSCEAR Lifetime Cancer Risk Estimates", by CR Muirhead and DL Preston, in *Low Dose Ionising Radiation and Cancer Risk: Proceedings of a scientific seminar … Luxembourg … 2000*. Available at:

http://ec.europa.eu/energy/nuclear/radiation_protection/doc/publication/125.pdf

{UNSCEAR Lux}. *Note:* Among other things, this paper presents estimates of risk derived by analysing data using *two models*. The original analysis is presented in an Annex to the slightly earlier report, {UNSCEAR 2000}. A little unfortunately, the website given above for {UNSCEAR 2000} does not include the Annexes.

"2007 Recommendations of the ICRP (Users Edition)", ICRP Publication 103. At: http://www.icrp.org/docs/ICRP_Publication_103-Annals_of_the_ICRP_37(2-4)-Free_extract.pdf {ICRP Pub 103}.

"Ionizing Radiation … Epidemiology", by ES Gilbert. At: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2859619

{NIH Gilbert} (NIH = National Institute of Health).

"Evolution of ICRP Recommendations … ". At: www.oecd-nea.org/rp/reports/2011/nea6920-ICRP-recommendations.pdf

{NEA ICRP} (NEA = Nuclear Energy Agency).

"The 15-Country Collaborative Study … ". At: http://www.rrjournal.org/doi/abs/10.1667/RR0553.1 {15-Country}.

Measures of risk are discussed in {UNSCEAR Lux} and {ICRP Pub 103} and especially in {NIH Gilbert}. Models that take account of the value of such variables as attained age are discussed in {NIH Gilbert} and especially in {UNSCEAR Lux}. The widely accepted model that takes account of both (i) the type of radiation and (ii) the specific organs irradiated, is described in {ICRP Pub 103}. The design of studies is discussed in {UNSCEAR Lux} and especially in {NIH Gilbert}. The review paper {NIH Gilbert} is of value in a number of ways. It describes a large number of studies, with emphasis on "the most informative" ones—and gives the bottom-line results in some cases. And it also discusses the various measures of risk used, the difficulty in obtaining precision, and issues that arise in designing a study.

By the way, Google Scholar is an engine that enables you to get access to much of the technical scientific literature. It can be accessed via http://scholar.google.com.au . I have made some use of it in the present literature search.

As stated in the main text, the cause-effect relationship between radiation exposure and the later appearance of cancer is quite complicated. The probability of getting cancer due to a given dose depends on both the *age at exposure* and the "*attained age*" (i.e. the age at which the cancer "hits"), as well as on gender. Nearly all the probabilities discussed prior to this paragraph are *averages* over some population. Also, instead of a uniform whole-body dose, the radiation may have been concentrated on one, or a few, organs. Complicating things further, a person may be exposed to a number of doses at different times. (These last two points are very important when designing a course of radiation treatment designed to cure a cancer patient.) The above matters are discussed in {UNSCEAR Lux} (which goes on to quote figures for the risks from radiation, as discussed in the main text). (The "attained age" is more correctly defined as the age A being considered when one asks: "What is the probability that the person will cross the threshold of damage while his age is A?".) As a final point, for solid cancer, there is a “latent period” of about ten years following the exposure to radiation; only in the years after the latent period do the cancers appear.

Quite apart from nuclear radiation, a person has a far higher probability of getting cancer when they’re old (or elderly). In other words, this risk rises steeply with attained age. Now, when it comes to the risk due to nuclear radiation received (with age at exposure held fixed), the absolute risk again rises steeply with attained age, but not as steeply as in the former case. Thus, if a figure, quoted as the absolute risk due to nuclear, is interpreted as applying equally at all attained ages, the resulting “picture” is highly misleading.

For this reason, it is often more meaningful to specify the ***relative risk***. Then it’s not so bad to think of *that* risk as being constant with respect to attained age—because it captures the fact that the absolute risk will increase as the person ages. (A constant relative risk implies that the absolute risk will follow the same steep rise, proportionately, as in the non-radiation case.) In fact, from the previous paragraph, the true relative risk *decreases* with advancing age. However, the relative risk has the advantage that it does not vary nearly so much with attained age as the absolute risk does.

The upshot is that, when an overall average figure for risk is being quoted, the figure for *relative* risk is the more useful when predicting how the risk to an individual will change as his life unfolds. On the other hand, the *absolute* risk is the more useful when predicting the total harm that will come to a whole population when, say, a serious nuclear accident occurs.

In order to help prevent cancers and also to find better ways of treating cancer patients, it’s appropriate that much research goes into measuring, where practicable, many of the above more complicated dependences. But for gaining a simple, overall understanding, often it is appropriate to go back to simple measures, in particular the *average* risks (absolute and relative) as discussed above. Moreover, commonly there is not enough statistical evidence (i.e. there is insufficient data) for anything beyond simple measures to be obtained.

{UNSCEAR Lux} reports on the analysis of cancer data collected from Japan (A-bomb survivors) and four other countries (nuclear workers, etc.). The five data sets were analysed separately (to produce results that would later be combined). In the analysis, it was judged that each of the sets of data was insufficient to extract the full dependence of risk on the *pair* [age at exposure, attained age]. Instead, UNSCEAR used two *“relative risk” models*; these were applied separately to obtain two answers for (i.e. two estimates of) each risk. Model 1 (as I’ll call it) is the “age-at-exposure model”, which is based on assuming that the relative risk is independent of attained age. Model 2 is the “attained-age model”, based on assuming that the relative risk is independent of age at exposure. In previous years UNSCEAR had often used Model 0 (zero), which assumes that the *absolute* risk is independent of attained age; but {UNSCEAR Lux} makes no use of that model, saying that it gives a quite poor fit to the data compared to each of the relative-risk models. The main overall result obtained in {UNSCEAR Lux} is given above in the main text (answers “11%” and roughly “7.7%”). Beware that these results are expressed as *absolute* risks, despite the fact that it is *relative* risk that plays a key role in the analysis.

As mentioned in the main text, the highly influential ICRP has, for a long time, recommended that those concerned with safety assume that the absolute risk (or rather, *some* absolute risk, which ICRP needs to specify somewhere) is about 5% /Sv (often taken to be 5.5% /Sv). This figure is to be applied, not only to single doses but to cumulative doses as well. References include {Radiation-induced} and {Rational Wiki}. At first sight, this statistic appears to be measuring the same thing as the measures of absolute risk given, for example, in {UNSCEAR Lux} (essentially, dying from cancer as a result of radiation exposure). To me, it has long been a puzzle that this figure is so low compared to the figures touted by others, particularly the “11%” in {UNSCEAR Lux} (and the relative risk of 0.97/Sv in {15-Country}, which would seem to translate into about a 9.7%/Sv absolute risk).

While I still don’t have a definite answer, here is my best take on why the “5%” figure is so different. We know that, at the juncture where the other measures simply count the deaths (from cancer), the ICRP assigns a different “score” for each death. This score, called the “detriment”, takes into account the number of years of life lost. Also, a further detriment (much smaller) is added in for each case of a *non-fatal* cancer. These properties of the “detriment”, but little more, are given in {NEA ICRP}. My guess is that, while the other sources give a score of “one” for each of the relevant deaths, the ICRP gives a score that averages out to less than one—possibly around 0.5. (There is a particular ICRP report that may give the answer to this question, but I balked at the $32 charge that I would have to pay.)