

Radiation and Reason

Wade Allison

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Enquiries should be sent to
w.allison@physics.ox.ac.uk

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For Alfie, Alice, Joss, Minnie
and those who come after,
may they understand one day.

Preface

The human race has a dilemma; it is threaten by economic uncertainty on one hand and by climate change on the other. Either of these could lead to widespread unrest and political instability, if the right choices are not made now. In particular, prosperity without carbon emission implies a comprehensive switch in our sources of energy. With luck, the activity generated by the process of switching will also contribute to prosperity in the short and medium term. There are many solutions – wind, tidal, solar, improved efficiency – but the most powerful and reliable source is nuclear. However, it is widely supposed that this presents a major problem of safety. Is this long-held concern about radiation and nuclear technology fully justified? Straight forward questions should have simple answers, and the simplest answer is No. Explaining and exploring the question and this answer in accessible terms is the subject of this book.

Over the years I have taught and studied many areas of physics, including nuclear physics and medical physics, although I have never had a close link with either the nuclear industry or any lobby. While it always seemed clear to me that radiation safety was somewhat alarmist and unbalanced, in earlier decades the apparent freedom to opt for fossil fuel as the primary source of energy meant that there was no special reason to confront public perceptions of the issue. But now the situation has changed, and it is time to address the whole question.

But how, and with what voice? A discussion in popular terms that would appeal to the native common sense of the reader is too easily dismissed by the science. But scientific answers are impenetrable to many readers, and so fall on deaf ears. A way forward is to vary the tone, sometimes scientific but still accessible, and sometimes with illustrations and examples that appeal to general experience. Nevertheless, I shall probably tax each reader's tolerance in places, one way or the other, and for that I apologise. Finding passages that seem either trivial or impenetrable, the reader should skip forward to rejoin further on. The passages that discuss recent scientific results are

supported with references labelled in square brackets in the text and listed in full at the back – but the text is self-contained and does not suppose that you look up these references. Should you wish to do so, most may be found on the Web at the address given. Also at the back, there is a short list of books and papers, headed Further Reading, for those who are interested.

The story starts with the physical science, much of which has been established for decades – the atmosphere, the atomic nucleus and radiation. And then it moves on to the effect of radiation in biology, most of which was not so well known thirty years ago. Often, popular science is written to amaze and inspire – and that is important. But here the target is more prosaic and practical, namely a clear understanding of the scientific background to some of the threats and decisions that are likely to determine our survival. The central question is this: how significant are the health risks due to radiation and nuclear technology? In Chapters 6 and 7 the current evidence is shown with some relevant ideas in modern biology. Not all questions can be answered completely yet, but they can be answered quite well enough. The conclusions are rather surprising, and do not match well with currently enforced radiation safety levels. This challenge by modern radio-biology to radiation safety regulation is well aired in scientific papers, but has not been explained to the community at large, who have a significant interest in the matter. The costs of nuclear technology are very high, largely because of the exceptional safety provision that is made. Scaling back such provision by a large factor would have a major beneficial effect on the financial viability of an extensive nuclear power programme.

These scientific findings do not depend on climate change, although that is what makes the question important at this time. But why, in the past, did most of the human race come to hold extreme views about the dangers of radiation and nuclear technology? The last part of the book describes what nuclear technology now offers, a large-scale supply of carbon-free electric power, with further options for the supply of food and fresh water.

E M Forster wrote

I suggest that the only books that influence us are those for which we are ready, and which have gone a little farther down our particular path than we have yet gone ourselves.

I hope that for some readers the message of this book is timely.

I have benefited from conversations with many colleagues during the writing of this book. It has been a privilege to have had the opportunity for quiet reflection and study, undisturbed by the pursuit of grant funding that distorts so much academic study today. This work would have not reached fruition without the contributions of many people. Former students and members of their families, members of my own family too, have spent long hours, reading and providing feedback on my efforts to produce an accessible account. In particular, I should like to thank Martin Lyons, Mark Germain, James Hollow, Geoff Hollow, Paul Neate, Rachel Allen and John Mulvey for their help and useful comments. Chris Gibson and Jack Simmons have provided me with invaluable comment and information. Throughout, I have relied heavily on the encouragement of Elizabeth Jackson and my wife, Kate – their advice and persistence were essential. I thank Kate and all members of my family for their love and tolerance over the past three years, during which time I have been rather absorbed.

Much has been omitted that could have been said, no doubt mistakes have been made too, and credit not given where it was due. Such mistakes and lapses are mine, and I apologise for them.

Wade Allison
Oxford
May 2009

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Chapter 1 Perceptions

Science is the great antidote to the poison of enthusiasm and superstition.

Adam Smith, economist (1723-1790)

A mistake

Radiation is seen as a cause for exceptional concern and alarm, though few people have any personal experience of its dangers. Is this view justified, and how did it come to be held?

Prior to the Second World War there was a degree of relaxed public acceptance of radiation, principally because few knew anything to suggest otherwise. That changed with the arrival of the Nuclear Age.

The destruction of the Japanese cities of Hiroshima and Nagasaki with nuclear bombs in 1945 was a military and political success that avoided a land invasion of Japan, which would have been immensely costly in lives for both sides. As a technical scientific enterprise, it was a triumph – no project, depending on fundamentally new physical developments on such a scale, had ever been attempted before.

As an exercise in the public understanding of science, it was a disaster whose consequences still continue. The message that came through was very clear – what happened was both extraordinarily dangerous, and incomprehensible to all but a few. The extreme apprehension generated in the population was self-sustaining. Sources of fear inhibit free enquiry, and few in the population ever questioned the extent of the danger. In the decades of the Cold War that followed, this fear was a useful weapon in international politics, and its basis was not doubted, even by those in a position to do so. And then there was Chernobyl – a further failure of public understanding. In the public mind the fear of nuclear war had infected views on civil nuclear power. Most people simply wanted to distance themselves from anything nuclear.

More questions should have been asked, although some of the answers could not have been given in earlier decades. There are three

concentric concerns, related like the layers of an onion, as it were. The first and innermost is to understand the effect of radiation on human life. This is a scientific question, not dependent on the other two. The second task is to educate public opinion and formulate safety regimes in the light of the solution to the scientific question. The final problem is to discourage nation states and terrorists from exploiting radiation as a source of fear, by threatening and posturing. This depends critically on the second task, establishing robust public opinion and a regulation regime that can face up to international arm twisting.

In the last 50 years these problems have been confused. During the Cold War era, international politics exploited public fear and ignorance of radiation, while only recently has the scientific evidence and understanding become established to answer the prior scientific question. In the absence of a clear picture of the biology and of adequate human-based evidence, radiation safety guidelines and legislation became established on a reactive basis. Public concerns were handled by imposing draconian regulation on radiation and nuclear technology, in the expectation that this would provide the necessary reassurance. But this was not successful and people were not reassured.

But now in the new century there have been two changes. Firstly, the scientific answers that were lacking previously are now largely available. Secondly, new nuclear power plants are urgently needed so that the use of fossil fuel can be reduced – this does not change the safety of radiation but it does affect the importance of setting matters right as soon as possible. So the purpose of this book is to explain the science in fairly accessible terms, together with the some of the evidence, and to offer a rough but justified estimate of the level of new safety regulation. Consequences for public policy and international diplomacy may then follow,

Personal risk and knowledge

Making decisions to reduce the risk of accidents involves everybody in society, what they believe to be the level of risk, as well as what is actually the level of risk. People may be alarmed, when they do not need to be – they may be fearless, when they should be more cautious.

What level of risk is tolerable in exceptional circumstances? We should not say zero – a risk-free society is utopian and unachievable. Although personal fear may feel absolute and unquantifiable, it should be controlled – any risks involved should be compared with those of alternative courses of action. Even the duration of life on Earth will have its term, hopefully not caused by early escalating climate change. But for us as individuals, the end is closer and more certain, for finally we all die – life expectancy may be 70 to 80 years, depending on standard of living, health and diet. So what is the average effect on a life of an accident that carries a 1% risk of death? For an average age of 40, that means a life expectancy reduced by an average of 0.4 years, or 5 months. If the lifelong risk is 0.1%, the reduction in life expectancy is just 2 weeks. This is at the same level as many risks and choices that people incur as they go about their daily lives. Many people would, willingly, give up two weeks of life for the benefit of their children or grandchildren if that would really benefit the large scale prospect for the planet. Well, wouldn't they? So, thinking straight, a lifetime risk of death at the level of one in a thousand is sensible – if undertaken for a really good reason, of course. As we shall see, the evidence shows that only under quite exceptional conditions is any nuclear risk at such a high level.

In general, those who make decisions need to be sure that they themselves understand the relevant situation. If their information is picked up from others on the basis of a collective idea that everybody knows, there is a chance that wrong decisions will be made. The greater, the number of people relying on the opinion of others, the longer it takes for them to realise that something is wrong. So, the bigger a blind spot in understanding, the greater the chance that basic questions go unasked and unanswered. At a practical level, a hard question may be beyond the immediate field of an individual – and so be passed to an expert for a specialised opinion, perhaps without reference to other problems. In this way the true picture may become distorted in the form of a collection of separate narrowly defined opinions.

An example was the flow of intelligence and decision-making in the conduct of the First World War. A consequence was the extreme loss

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of life, for example, on the Somme in July 1916. Decisions on the course of action were taken by commanders, who did not know or appreciate the actual situation in the field. And those on the battlefield were not permitted to use their own intelligence to modify the plan. It was assumed that the heaviest possible artillery bombardment would destroy the barbed wire and overcome the machine gun posts – but it did not. The commanders did not find out, and the men on the ground were required to obey instructions. The result was an avoidable massacre.

A more recent example was the effect on the stability of the world financial system of various trading and insurance practices employed in the first few years of the 21st century. Financial regulators and senior managers of corporations, who, in the years leading up to 2008, encouraged their dealers to negotiate and exchange contracts of risk for money, were not able to grasp the instability of the structures that they were building. These were described as complex and sophisticated – words that are themselves a danger signal. Used to impress, they invite acceptance without question. When the financial structures collapsed, nobody was able to determine the ownership and the worth of their holdings. The absence of anyone with the ability to see the consequences of what was happening was as serious as on the Somme in 1916. The financial dislocation, which played a dramatic part in the collapse of 2008, was foreseen years earlier by Wilmott [W7], who wrote as follows.

The once 'gentlemanly' business of finance has become a game for 'players'. These players are increasingly technically sophisticated, typically having PhDs in a numerate discipline. ...Unfortunately, as the mathematics of finance reaches higher levels so the level of common sense seems to drop. ... It is clear that a major rethink is desperately required if the world is to avoid a mathematician-led market meltdown.

When decisions are scientific, the availability of adequate first hand understanding can be a major hurdle, because such understanding is sparse in the population. This is especially true for decisions involving nuclear radiation. To the general population and those who make decisions for society, the words and ideas that describe the science do

not have familiar meanings. Apprehension of anything nuclear, or concerned with radiation, is deeply engrained in popular culture, and few scientists have pursued the broader inter-disciplinary field.

For reasonable decision-making, it is essential that the truth underlying the fears of nuclear material and radiation are properly exposed and that the science is more widely understood. This is more urgent now because new dangers affect the survival of the environment as a whole, not just the lives of individuals.

Individual and collective opinions

Should decisions on major dangers be made individually or collectively? Many creatures concentrate on collective survival at the expense of the individual – the herd or the swarm come first. But man is different – he places special value on the importance of individual rights, as well as the collective agreement that are essential to society and its survival. This dynamic relationship between individuals and society is what being human is about. But what happens if a collective understanding takes a wrong turn, leading to a consensus that threatens survival? Then the problem needs to be re-examined, which is most difficult if it is largely scientific.

What people understand of the world depends on their previous experience, including education and upbringing. Even what they think that they see is shaped and filtered by their background. Through the character of the Professor in his children's book, *The Lion, the Witch and the Wardrobe*, C S Lewis advises that we should listen to evidence from others, assess their reliability and sanity, and then await further developments. In modern physics, too, there are serious questions concerning reality in its different manifestations [D4].

But our concern here is not with such academic questions but with practical matters. If differing views are reconciled, plans of action can then be agreed and decisions taken that lead to success and increased confidence. So, decisions need an acceptable collective picture of reality, and this only becomes established through repeated observations at different times and by different people, and is confirmed when expectations based on it turn out right. This is most

18 Individual and collective opinions

credible when scientific observations are found to confirm precise mathematical predictions, although we cannot account for the unreasonable relevance of such mathematics in the world. There is no logic that requires that, when I wake tomorrow morning, the world as I know it will still be there. A chicken, accustomed to being fed by the farmer each morning, is unprepared for his day of slaughter, although that was the ultimate purpose of each morning feed.¹ So we become accustomed to the continuity and predictability of our experience. But could it be otherwise? We need always to be alert to the possibility that our collective understanding is quite wrong. It is the task of the following chapters to try to unpick the dangers of radiation and nuclear technology and to explain how we were previously mistaken.

Philosophers and physicists may mull over evidence for the existence of parallel streams of reality. Others may follow the ideas of Descartes by looking at which properties of the Universe are necessary, simply to allow us to be here now asking questions. This is called the Anthropic Principle and turns out to have significant effects, if you accept its premise. But our task is different, though related in a practical and local sense. We are re-opening our attitude to radiation and nuclear technology in order to help answer the larger question: what kind of World and choice of life style will permit the possibility that mankind will be here in the future to ask questions? This Local Anthropic Prospective is also very restrictive. If no solution is found, human life on Earth as we know it will die out.

Confidence and decisions

Consider an example. In earlier centuries exploration and the transport of people and goods depended on the confidence and safety of navigation. Observations and sightings had to be agreed, a ship's course calculated and steered – the arrival of the ship at its destination was the demonstration that these decisions were not just matters of opinion. The calculation of the position of the ship relied on measurements and the known apparent orbits of the Sun, Moon and stars, the magnetic field of the earth, the tides and other quantities. With every improvement in navigation came an up-lift in world

¹ Remarkd by Bertrand Russell.

communication; better accuracy gave improved confidence, leading to more ambitious voyages and better trading. Conversely, whenever confidence in the natural world fails, human activity gets choked off and prosperity declines.

If there is disagreement, the observations and preconceptions have to be talked through to reach a consensus. But it is an important concession to the variety of human experience that individuals have the right of choice. Except when it is unavoidable, we do not exercise choice on behalf of others – and then only with a degree of caution that we would not exercise for ourselves. And so it is in matters of safety, especially where apprehension is high.

The dangers of radiation and nuclear technology have been a matter of vocal public concern for half a century, mainly among the middle aged and elderly who remain confused and apprehensive. The younger generation never experienced the Cold War and are more relaxed. In the past many scientists kept away from the long running debate of nuclear politics. Meanwhile, radiation safety remains subject to exceptionally stringent conditions, although few people appreciate the related expense, and no one seems to feel safer as a result. In the 21st century the agenda has changed and decisions are needed for the future of the environment where the choice of primary energy source is between nuclear power with the dangers of its waste and the combustion of fossil fuel with its waste.

Science and safety

The astronomer who first predicted an eclipse and announced it to the political masters of his day discovered the influence that scientific knowledge can bring. His ability was held in awe by all around him. Today physics and astronomy have given the human race control over much of the natural world. In earlier times and in the absence of scientific interpretation, darkness, fog, thunder, lightning and other variations in nature tended to generate superstition and thoughts of divine intervention, even punishment. Such feelings suppress confidence and discourage initiative and enterprise.

The scientific enlightenment from the 17th to mid 20th centuries showed man how to overcome fear of the unknown by empirical study. Through universal education, training and communication this encouraged prosperity, better standards of living and health. However, misapprehension of the natural world is still the background of life for many.

Scientists too suffer misapprehensions, but these are overcome by continual re-measurement, re-thinking and re-calculation, like the helmsman steering the wrong course who, by making further observations, discovers and corrects his error. If this is not done, confidence may fail and unguided imagination and panic fill its place. Then careful observation and calm thought are at risk, and the opportunity to correct errors is reduced.

This is particularly true for those dangers that cannot be sensed. The prospect of a threat, unseen but lethal, makes people worry, even panic. Trivially, in the dark, when sources of danger cannot be seen, people can be frightened until the light is turned on. This case is instructive – to give people confidence they need to see for themselves using a basic instrument, like a flashlight or torch. Just telling them that they should not be frightened is not effective. Equally, consulting people for their opinion about safety, when they do not know or understand, may simply accelerate an implosion of confidence – decisions taken in everybody's best interest cannot emerge in this way. Regulation and legal restraint do not give people confidence either. Only real education of a sizeable fraction of the community can reassure, and this should be based on an objective understanding of the issues.

For the confidence of those on board, the ship should be on the right course, and be known to be on the right course. The two aspects of safety – actual and apparent – are different, though equally important. Once actual safety has been established, apparent safety becomes a matter for education, communication and information. If an appearance of safety is given priority over actual safety, real danger can follow, as reassured passengers on board the Titanic learned to their cost.

Chapter 11 Summary of Conclusions

Risks to health associated with ionising radiation have been overestimated by a wide margin. This conclusion has been reached by comparing: clinical experience with radiotherapy; current knowledge of radio-biology based on laboratory studies; the analysis of long-term health records of large populations of people exposed to radiation, either as a single (acute) dose or as a continuing (chronic) one. In particular, human radiation exposures that can be justified now as safe are at the following level: 100 milli-sievert in a single dose; 100 milli-sievert, total in any month; 5,000 milli-sievert, total whole-of-life exposure. These figures are conservative, and may be debatable within factors of two, but not ten.

The reasons why existing radiation safety standards are set at extraordinarily cautious levels are: the association in the public mind of radiation with the dangers of nuclear weapons; the advice of authorities, set up with a narrow remit to minimise public exposure to radiation; a lack of available firm scientific evidence and understanding in earlier decades. During the Cold War era there were good political reasons not to minimise the health legacy of a nuclear war, but this association is now engrained in the general consciousness. In their physical destructive power nuclear weapons are especially dangerous. But, when the initial blast with its flash of ionising radiation and heat has gone, the residual radioactivity and fallout have a much smaller impact on human health than was supposed in the past. The underlying idea that a radiation dose, however small, leaves an indelible mark on health is not supported.

New dangers are now evident. These are more global and threatening than any local nuclear incident, and arise from changes in the Earth's atmosphere, triggered by the continuing use of fossil fuels. Although many initiatives are possible in response, the only large-scale solution is a major switch to nuclear power, for electricity generation and the supply of fresh water and food. For this to happen rapidly, cheaply and safely, the public perception of ionising radiation needs to be turned around, and substantial changes in regulations and working practices, based on safety levels, determined afresh. For the future,

improved biological understanding may be able to justify relaxing values still further, and legislation and working practices should be drawn, allowing for this possibility. Such a relaxation of safety levels by factors of about a thousand means that current concerns, such as waste, decommissioning, radiation health, terrorism, and costs, are to be seen in a better light.

This is a most positive situation. But are we able and ready to reconsider our views, and then act fast enough to lessen the impending change in climate?

Further Reading and References

For a readable description of Chernobyl today, try the book *Wormwood Forest, a natural history of Chernobyl* by Mary Mycio, described on her website at <http://www.chernobyl.in.ua/> and published by Joseph Henry Press, Washington (2005)

For an accessible but more student-oriented account of the science, read *Radiation and Health* by T. Henriksen and H. D. Maillie, Taylor & Francis (2003).

For more on the science of nuclear and medical physics read *Fundamental Physics for Probing and Imaging* by Wade Allison Oxford University Press (2006).

For more about the science of energy production look at *Energy Science* by J. Andrews and N. Jelley. Oxford University Press (2007).

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